Biogeoengineering Solutions to Climate Change

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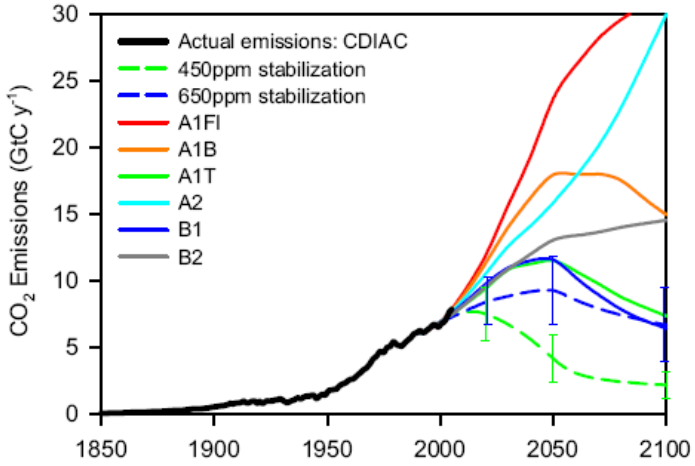
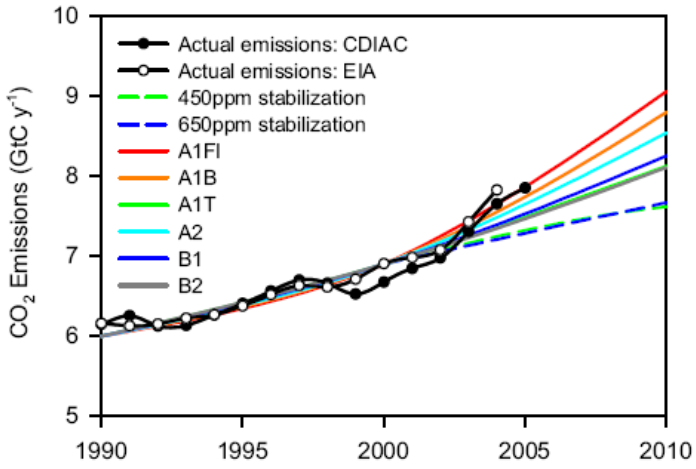
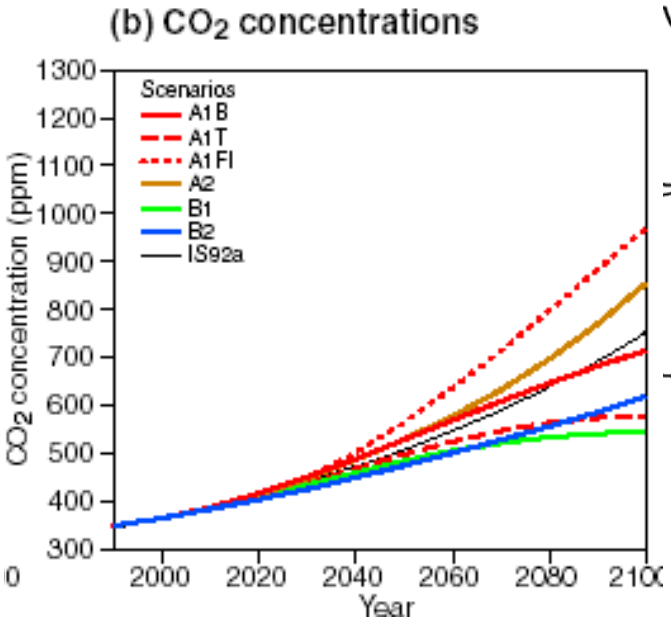
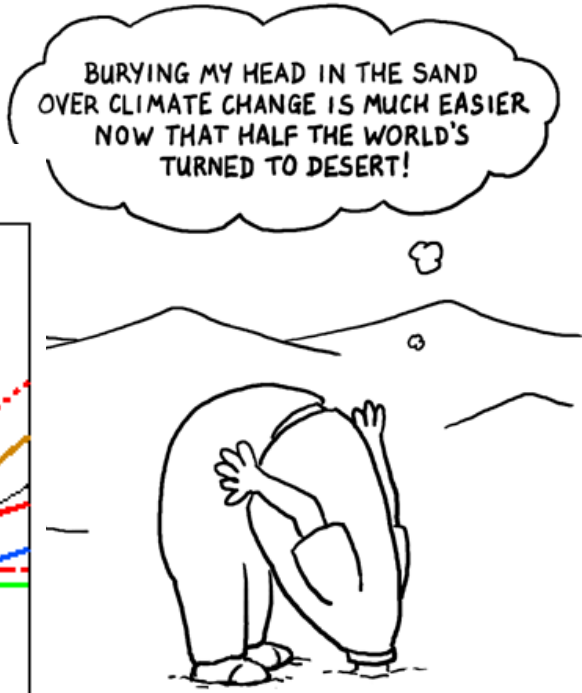
Emission trends

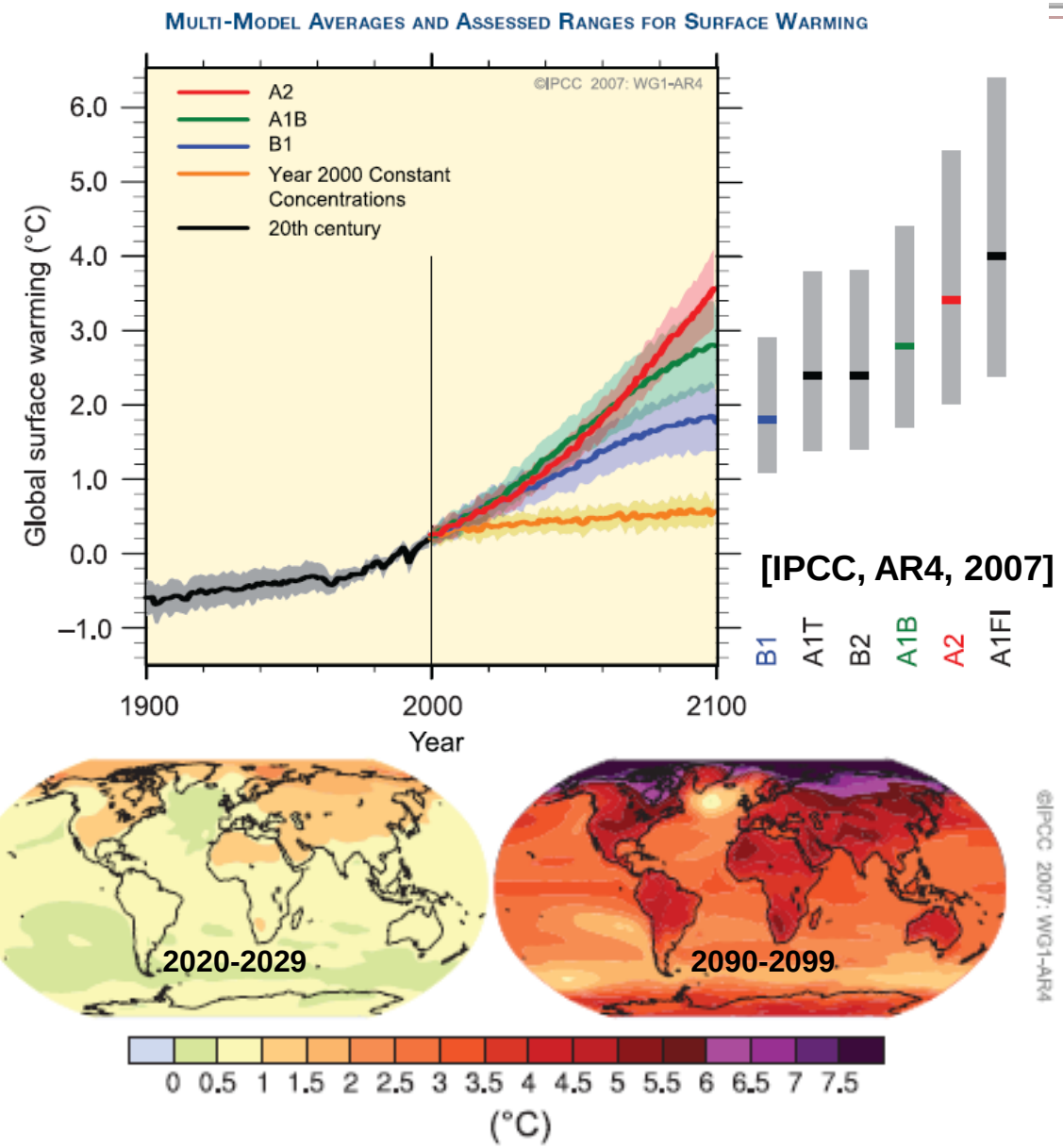






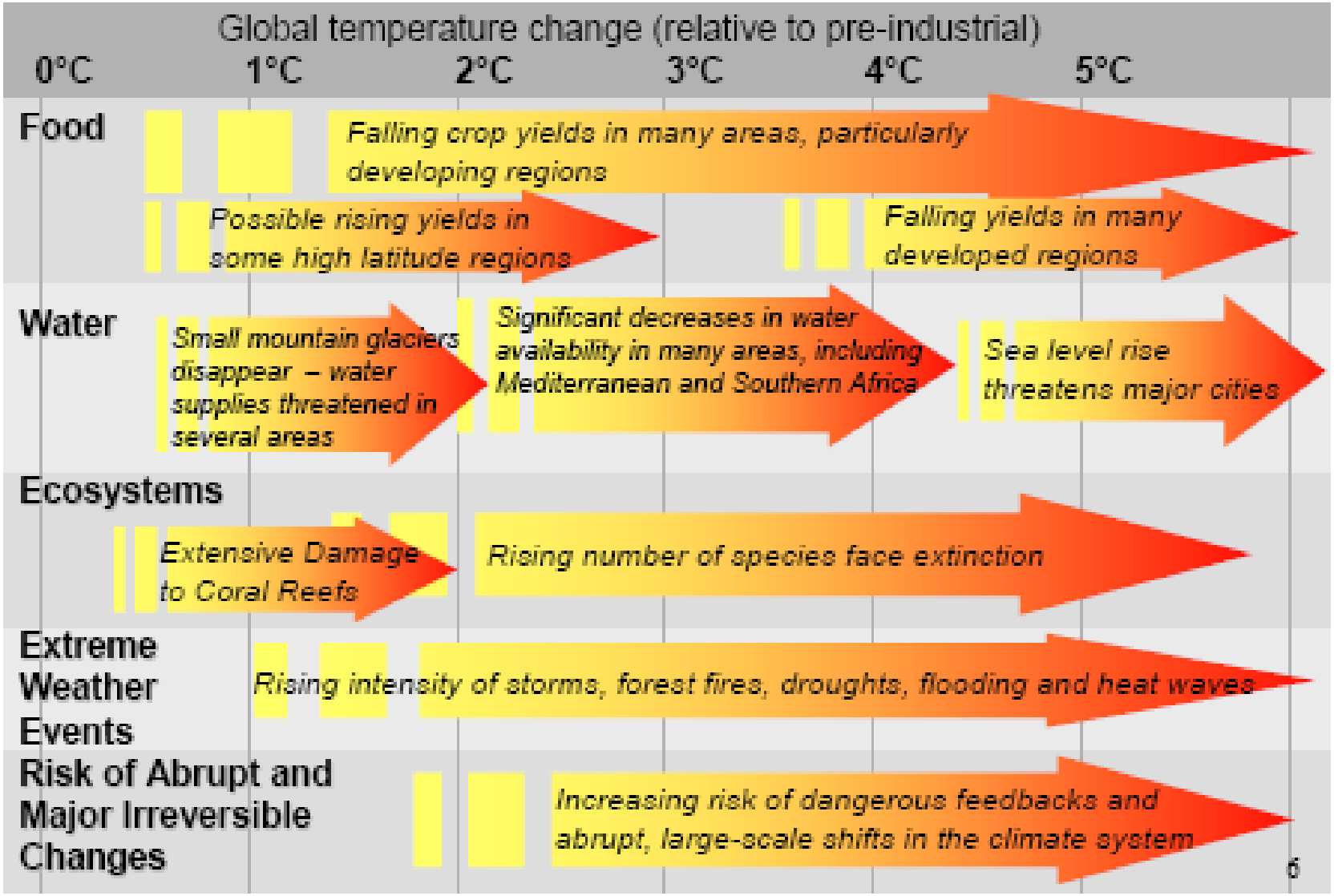


Climate Response



Scenario A2:

Projected Impacts

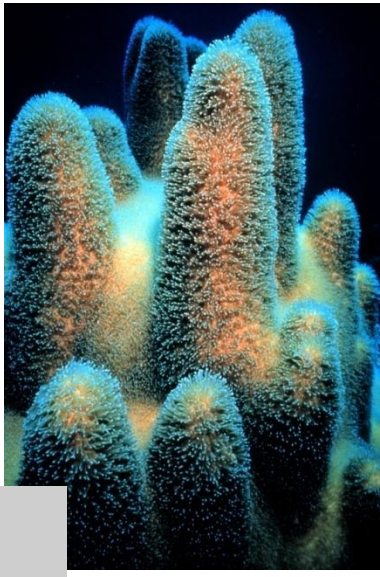


Ocean Acidification

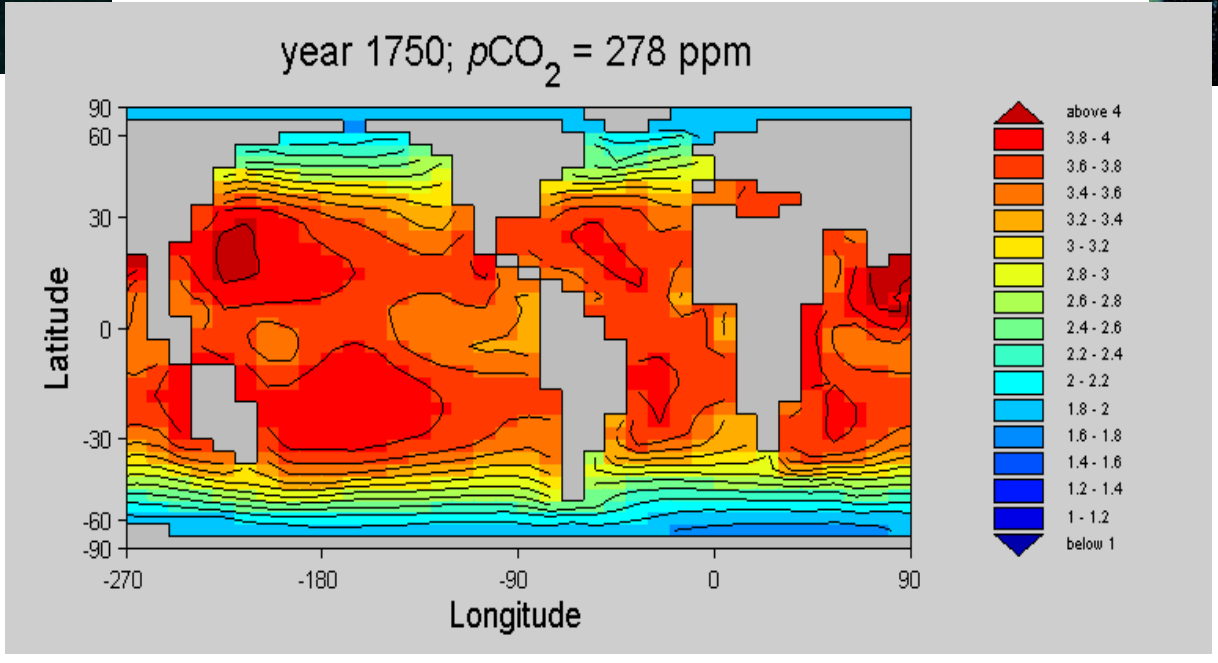
Increasing levels of CO_2 will result in acidification of the ocean.

The dark blue areas show regions where corals and some plankton will not be able to survive.

Sea Butterfly



Pillar Coral



Animation courtesy of Andy Ridgwell, Geographical Sciences

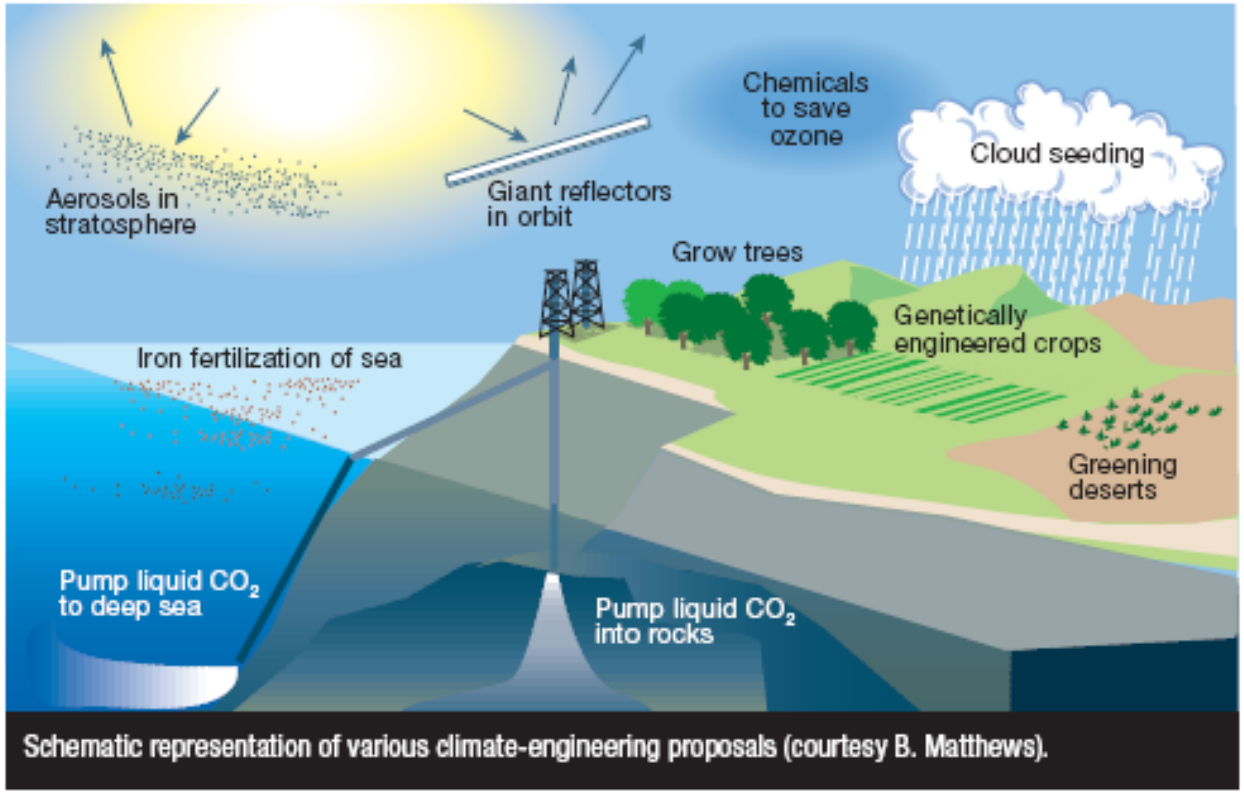
What is Bio-Geoengineering?

- Geoengineering is intentional large-scale manipulation of the global environment,
  - Means of mitigating the effects of fossil-fuel emissions on climate change, without necessarily abating fossil-fuel use.

- Bush administration favoured this line of thinking (Yang & Oppenheimer, 2007).

- Many would argue that climate risks are so high that reduced emissions AND biogeoengineering are needed

Type of Schemes



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

- Broadly speaking there are three types:
  1. (Carbon capture and storage)
  2. (Removal of atmospheric CO_2)
  3. Albedo modification schemes

Carbon Sequestration (Storage)

Sequestration Option	UK	World
Forestry	2 MtC/yr sink for next 20 years requires forest area to expand at about 30,000 ha/yr	38 GtC by 2050 assuming planting rate of 10 million ha/yr
Geological reservoirs		
- Disused oil and gas fields	9GtC	> 180GtC
- Deep saline reservoirs	66GtC	100GtC
- Unmineable coal measures		40GtC
Disposal to Deep ocean		1000GtC
Ocean Fertilisation		uncertain - modelling suggests maximum of 150GtC over a 100year period

Synthetic trees

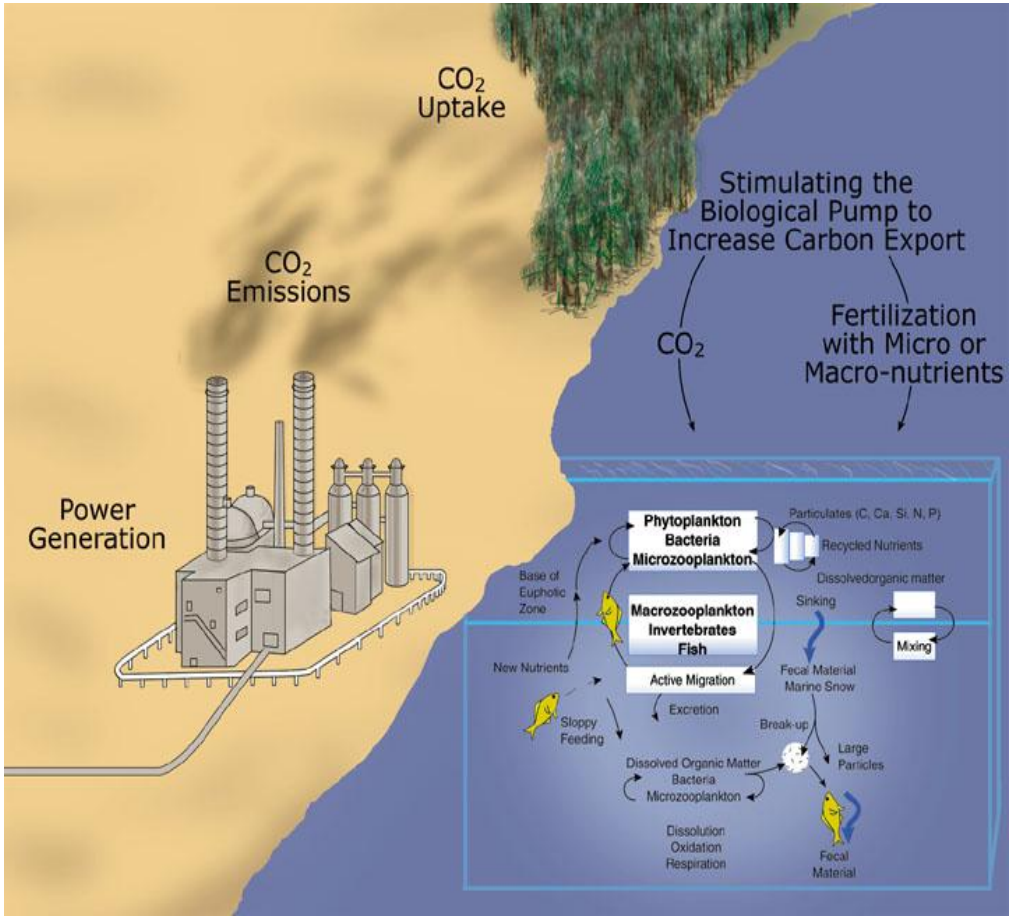
Sorbents (e.g. CaO, Lime) capture CO_2 from free-flowing air and release those molecules as a pure stream of carbon dioxide for sequestration,

100 m^2 can extract about 1000 tons of carbon dioxide from the atmosphere each

11 million devices would be required to remove 11 billion tons of carbon dioxide (emission levels at 2025).

Ocean Fertilisation

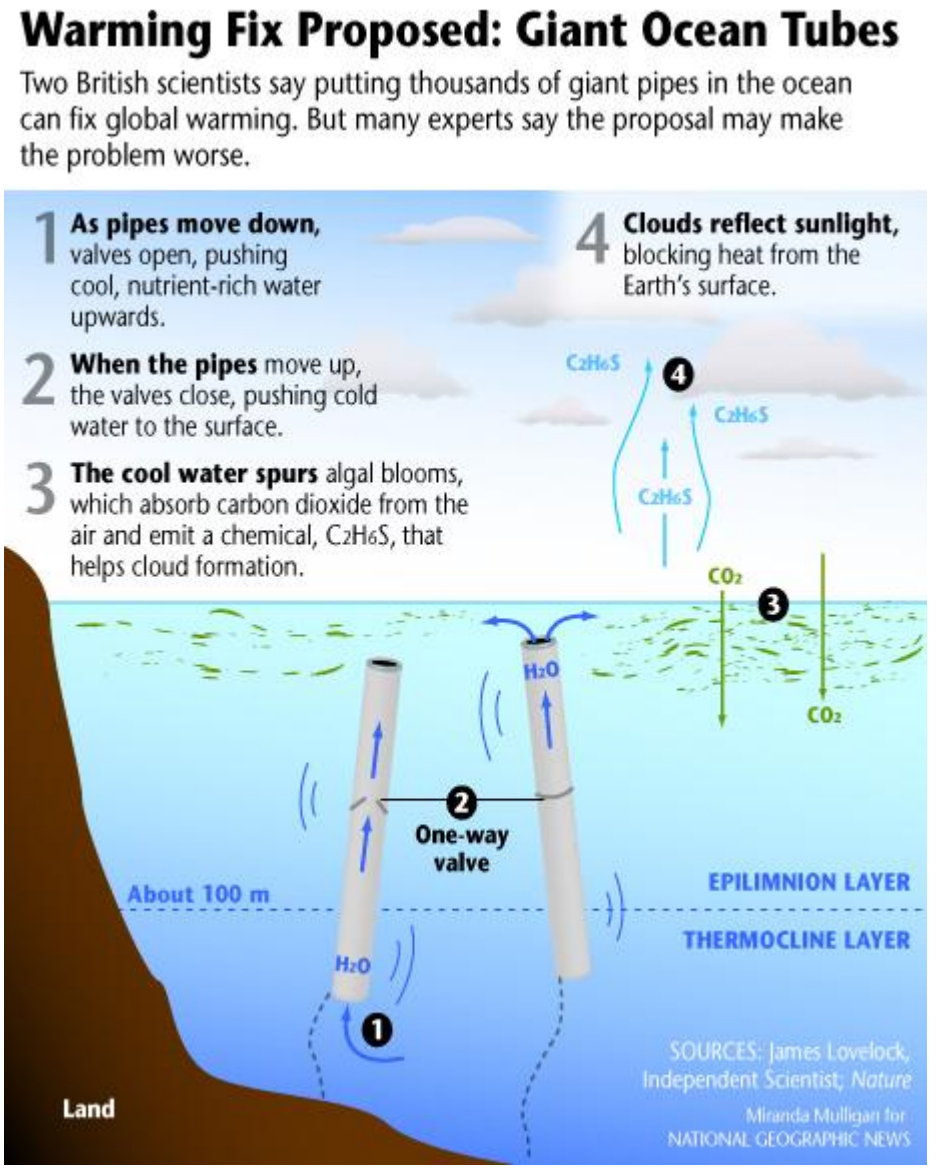
- Blooms of plankton and algae absorb carbon dioxide, die and then sink to the seabed carrying the carbon dioxide they absorbed during their lifetimes.
- Increase such plankton growth by using iron fertilisers.
  - many parts of the world iron in seawater is virtually non-existent and plankton levels correspondingly low.
  - Research is underway to better understand processes
- BUT US entrepreneurs have already begun experiments by pumping tonnes of soluble iron compounds into sea areas.



Ocean Pipes

Lovelock and Rapley suggested the idea of an ocean pipe

- Brings cold high nutrient water to surface
- Enhances biologic pump and hence removes CO_2
- But lots of potential flaws (e.g. ocean acidification)



Albedo Schemes

- Reflecting less than 1% of sunlight back into space could compensate for the warming generated by all greenhouse gases emitted since the industrial revolution.
- A quadrupling of CO_2 would require interception of about 3.6% of the sunlight incident on the Earth, a disk of roughly 1200 km in radius would be required.
- NOTE that these schemes might mitigate climate change but do not stop ocean acidification

Proposed Albedo-based schemes

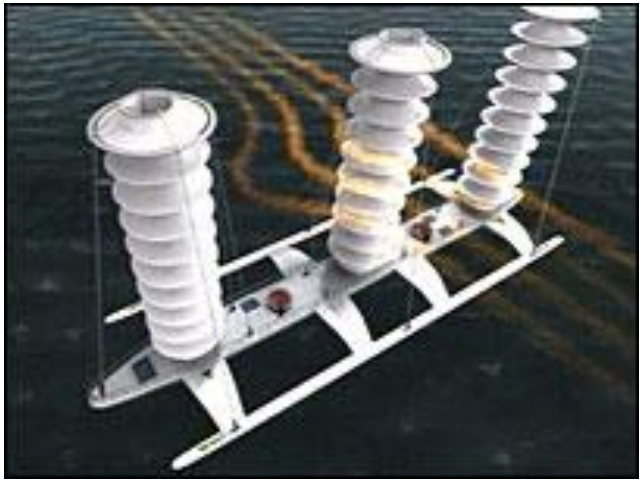
- Aerosols (in stratosphere and surface)
- Mirrors in Space
- Surface Albedo Enhancement
  - Cities
  - Deserts
  - Oceans

Stratospheric Aerosols

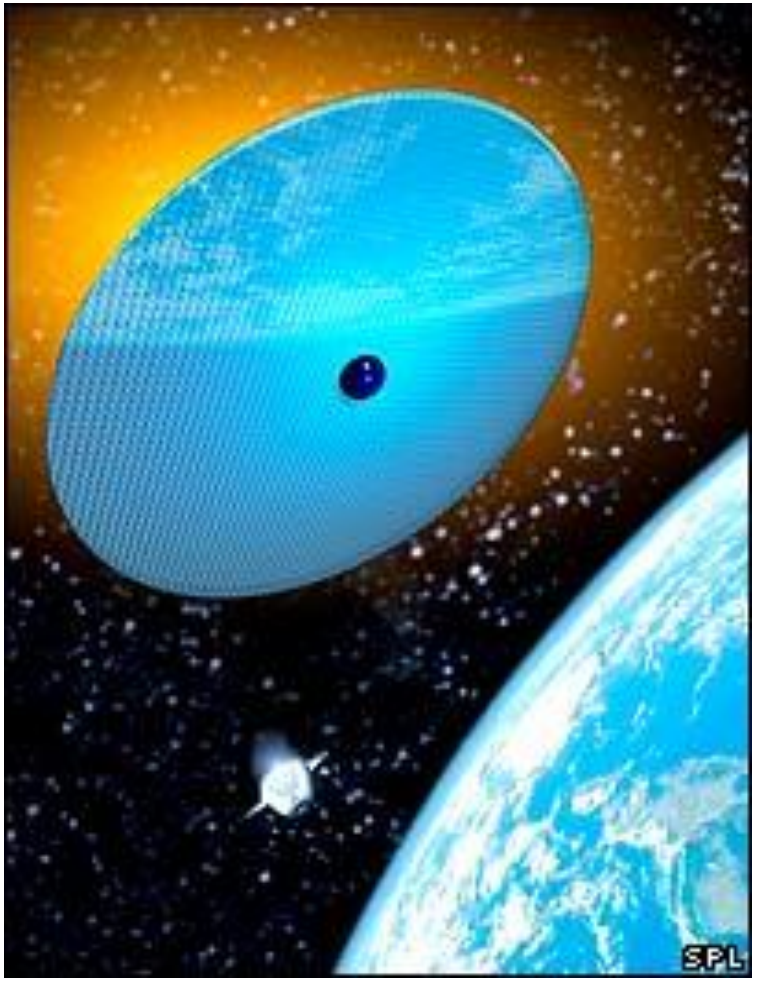
- During major volcanic eruptions, the Earth often undergoes significant cooling due to sulphur ejected into the stratosphere.
- Paul Crutzen suggests injecting copying this.
- He has proposed creating a 'blanket' of sulphur that would block the Sun's rays from reaching Earth; to do this, he envisages
  - hundreds of rockets filled with sulphur being blasted into the stratosphere.
  - About one million tonnes of sulphur would be enough to create his cooling blanket

More Cloudy

- John Latham (NCAR) and Stephen Salter (Edinburgh) suggest increasing cloud cover using a seawater spray 'seeding' process
  - increase cloud cover by 4 per cent counters a doubling of carbon dioxide
- Their plan is one of the cheaper ideas for countering rising carbon dioxide levels and is relatively low-tech



Large Mirror in Space

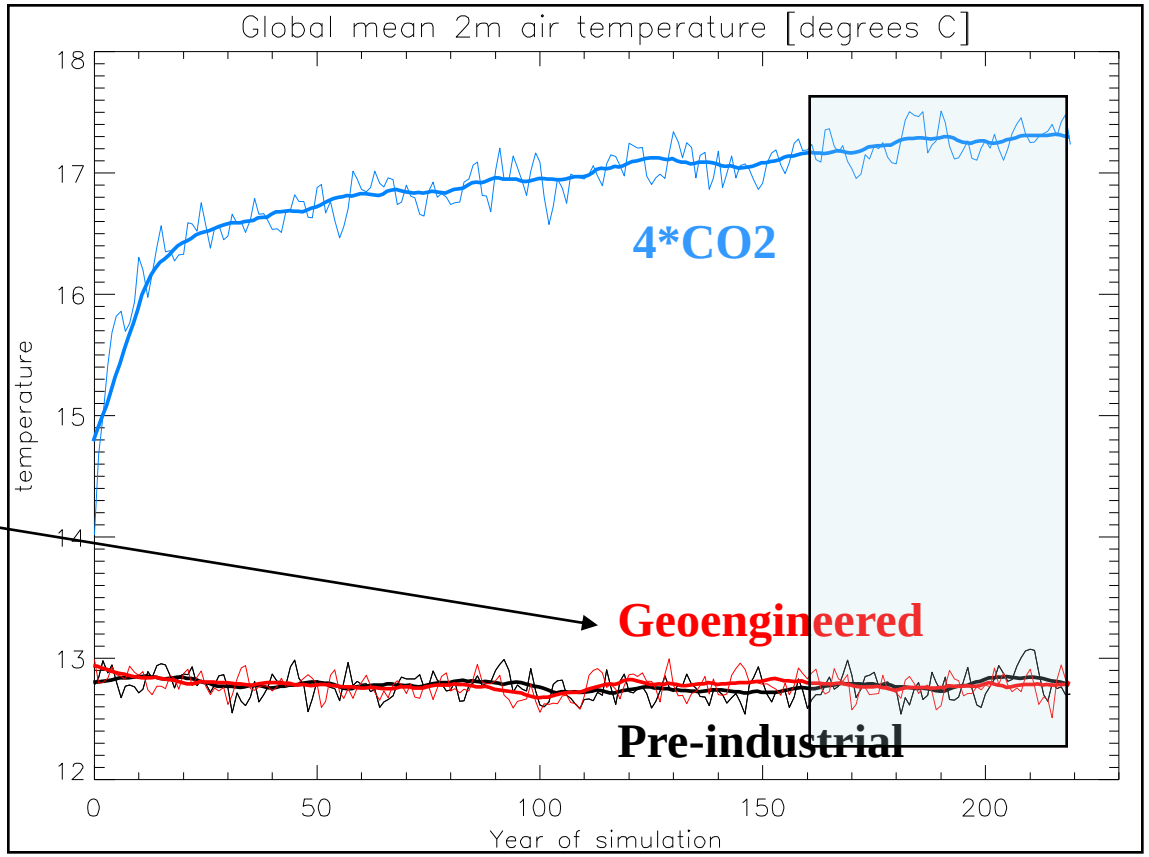


- Early (1989) proposed a solar deflector 2000km in diameter at the L1 point (1.5 million kilometers toward the Sun), where the gravitational pull from both earth and sun are equal.

- ***"It seems feasible that it could be developed and deployed in 25 years at a cost of a few trillion dollars" Angel, 2006, PNAS***

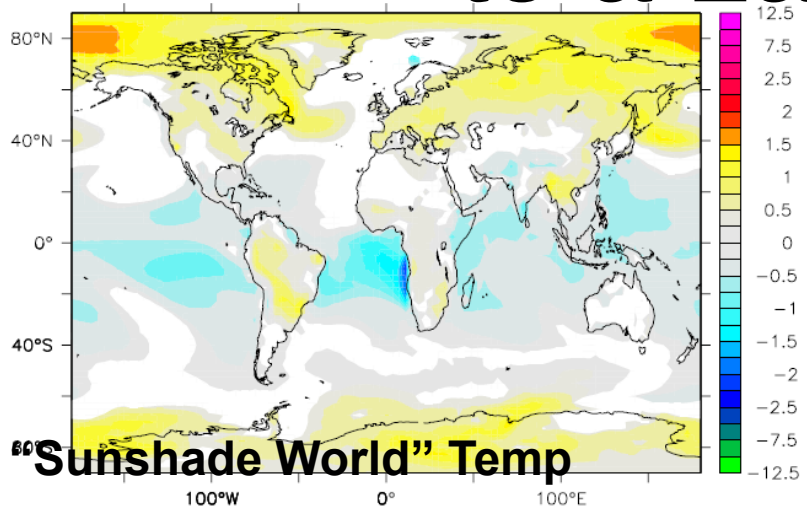
Global Effects of a Large Mirror

4.2% reduction in solar constant = 57 W/m2

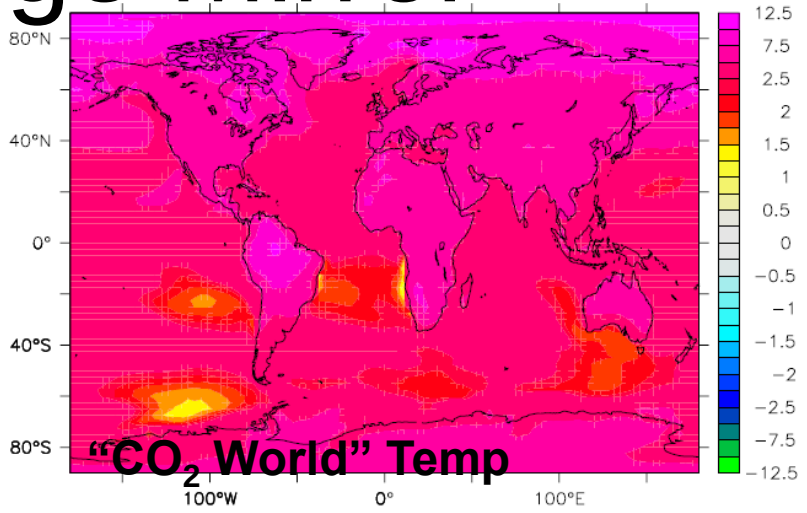


Lunt, Ridgwell, Valdes and Seale, 2008, GRL.

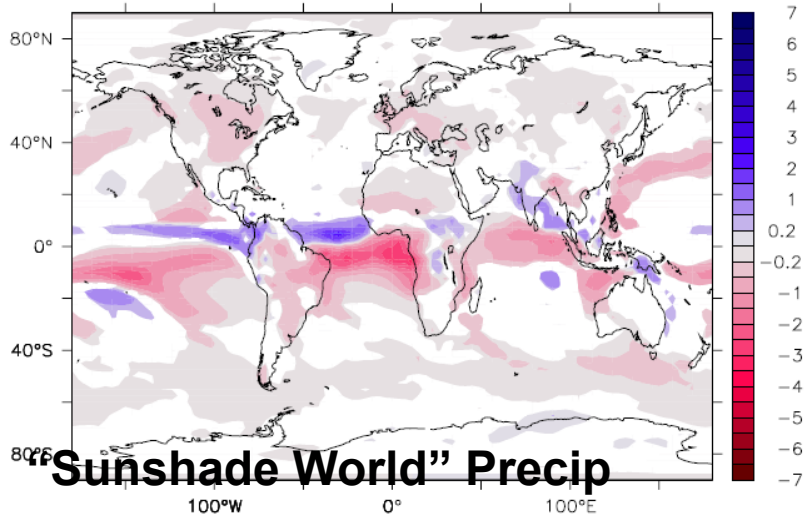
Regional Response to a Large Mirror



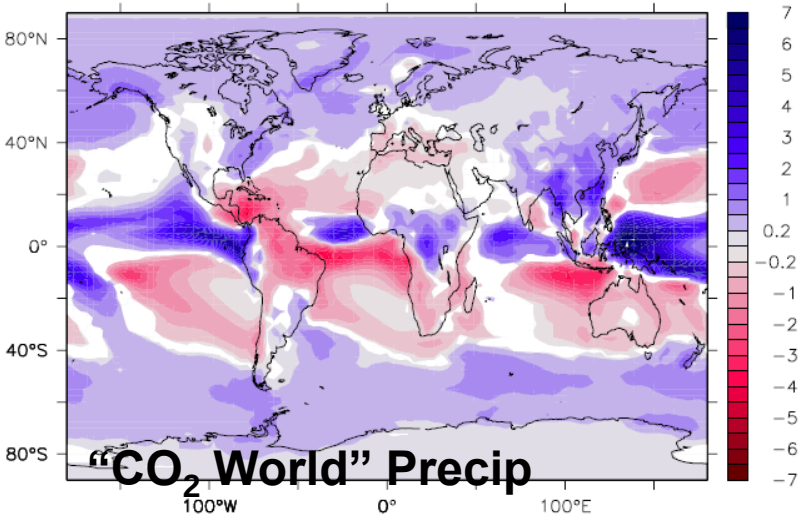
"Sunshade World" Temp



"CO_2 World" Temp



"Sunshade World" Precip



"CO_2 World" Precip

Surface Albedo Enhancements

- Cover Desert Problems in high albedo material
  - 45% of all deserts area needed to offset all of the forcing from 2010-2070
  - Predicted cost at the end of 150 years would be $75 trillion
  - Side effects include major changes to hydrological cycle.
- Paint Cities White
  - Whitening of roofs and pavements
  - Effective for urban heat island but little impact on global problem
- Increase albedo of oceans!
  - with white floating plastic islands, white spheres or white foam
  - Almost certainly unfeasible and with huge impacts elsewhere.

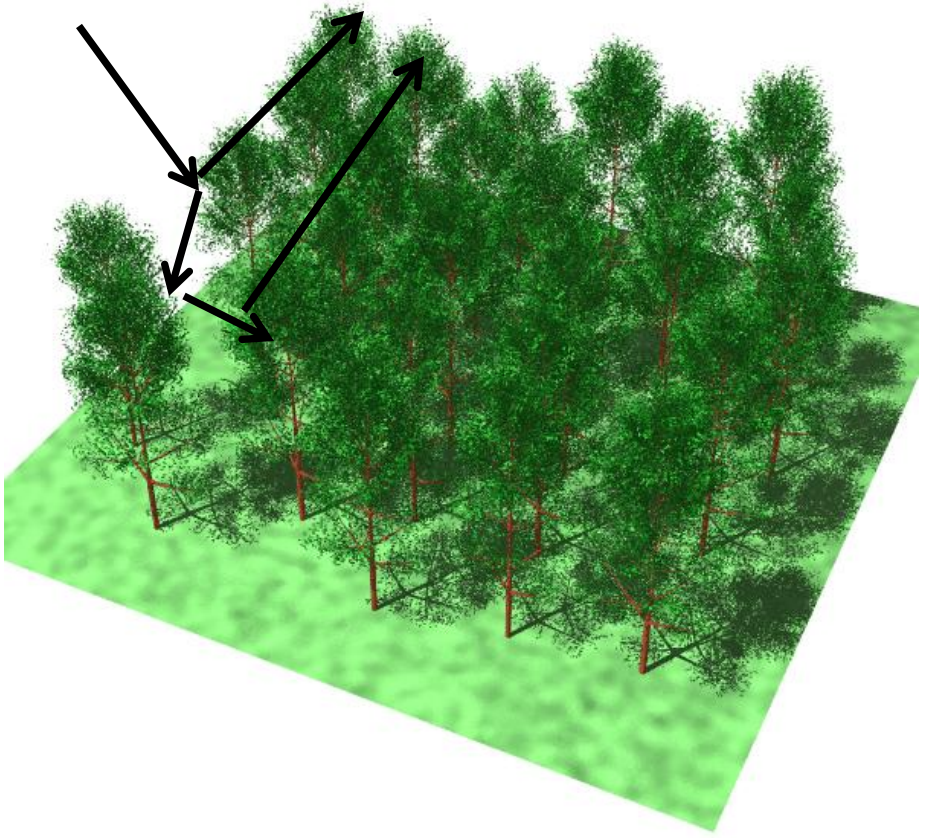
Modifying Plant Albedo

- Waxy versus non-waxy varieties of barley can exhibit albedo differences of up to 0.16 (with respect to photosynthetically active radiation [PAR] wavelengths)

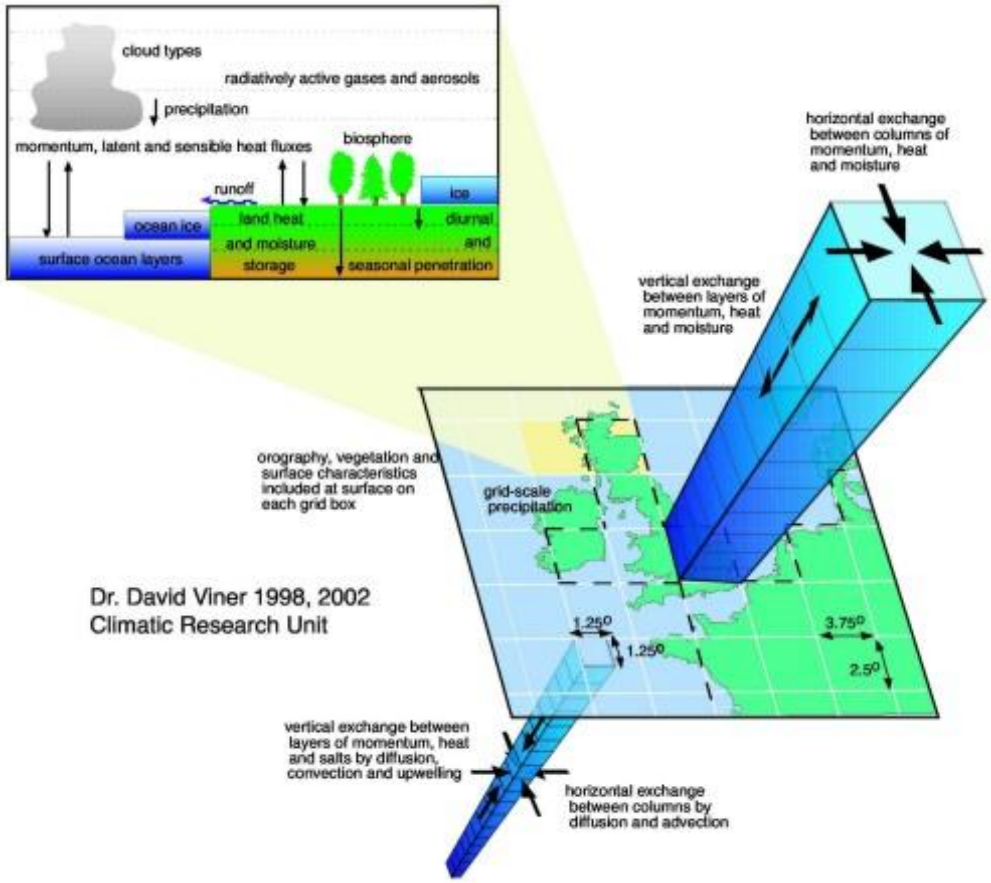
- Observed mutants of sorghum have albedo differences of 0.19 (UV-A + UV-B)

Modifying Canopy Albedo

- Canopy albedo depends on morphology of canopy (leaf albedo, orientation, structure etc).
- Different varieties of maize have been observed to differer by up to 0.08.



Hadley Centre Climate Model



Climate are models based on representing the key physical and biological components of the earth System:

Newton's Laws of Motion

1st Law of Thermodynamics

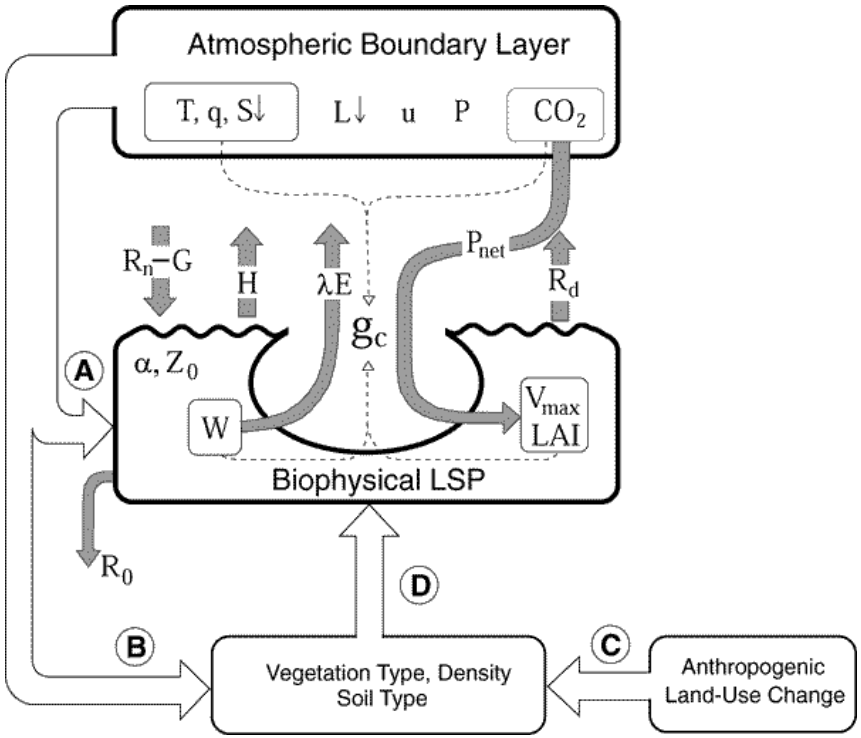
Conservation of Mass and Moisture

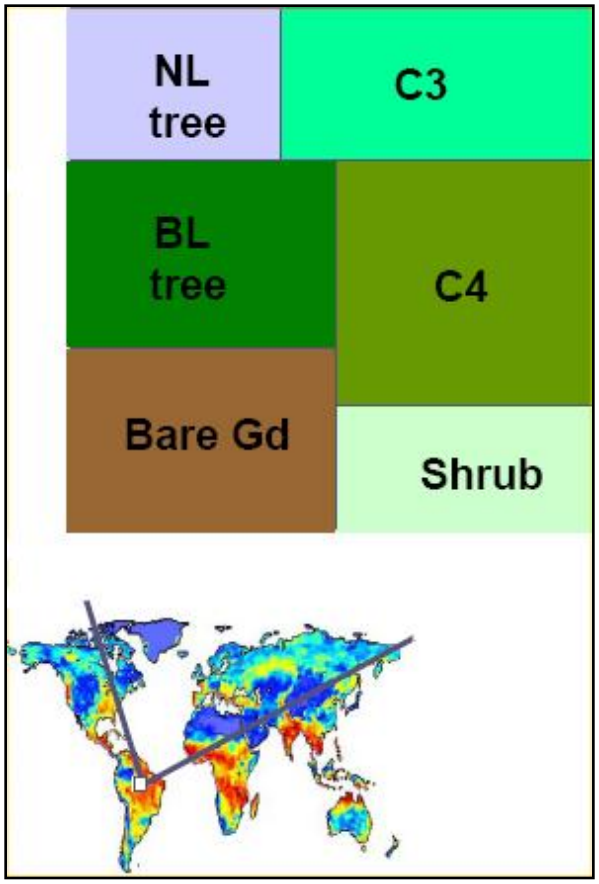
Hydrostatic Balance

Ideal Gas Law

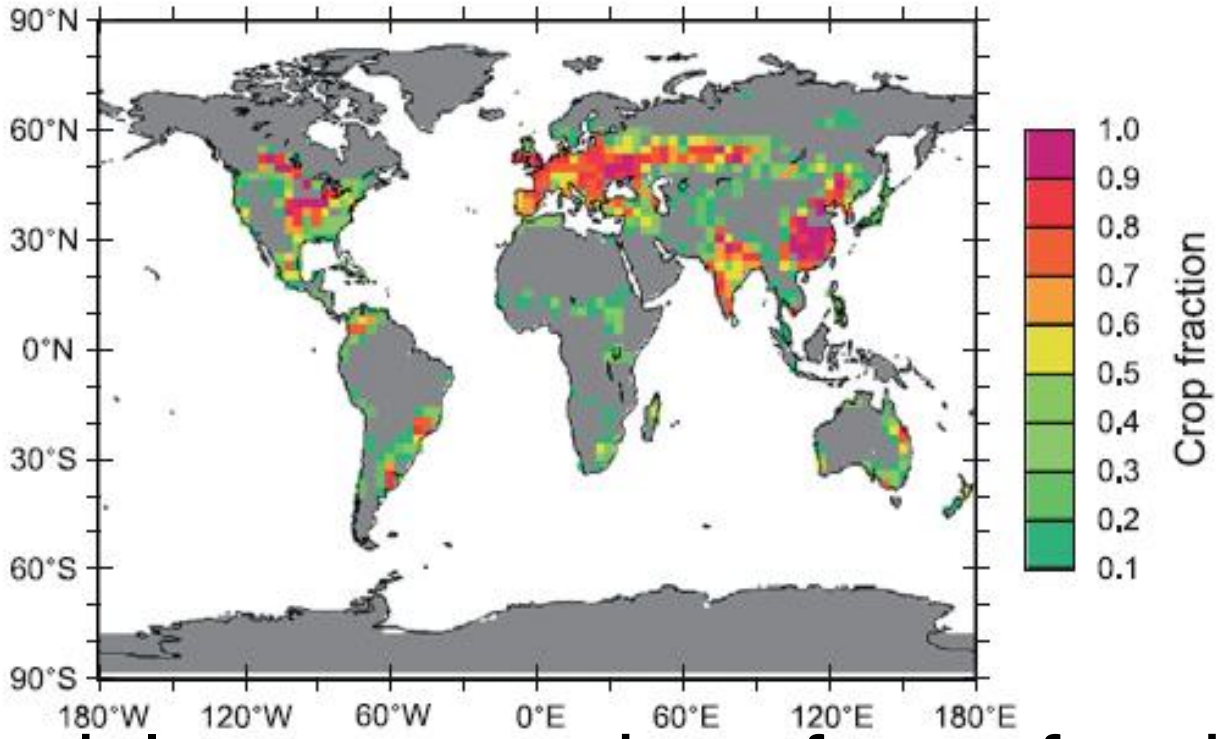
HadCM3 – represents the atmosphere-ocean-icesheets-terrestrial vegetation, marine carbon cycle

Representation of Vegetation: The Big Leaf Model!





Modify the albedo of all crops in the model

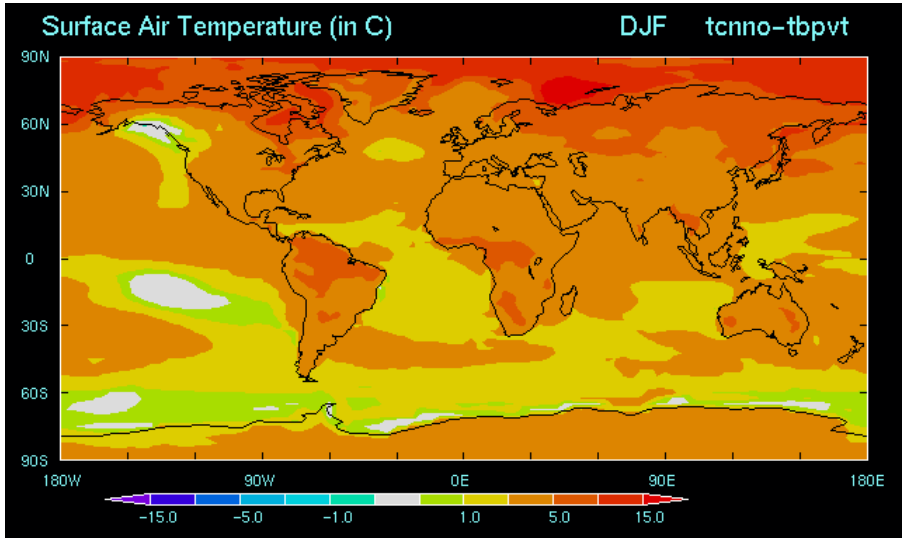


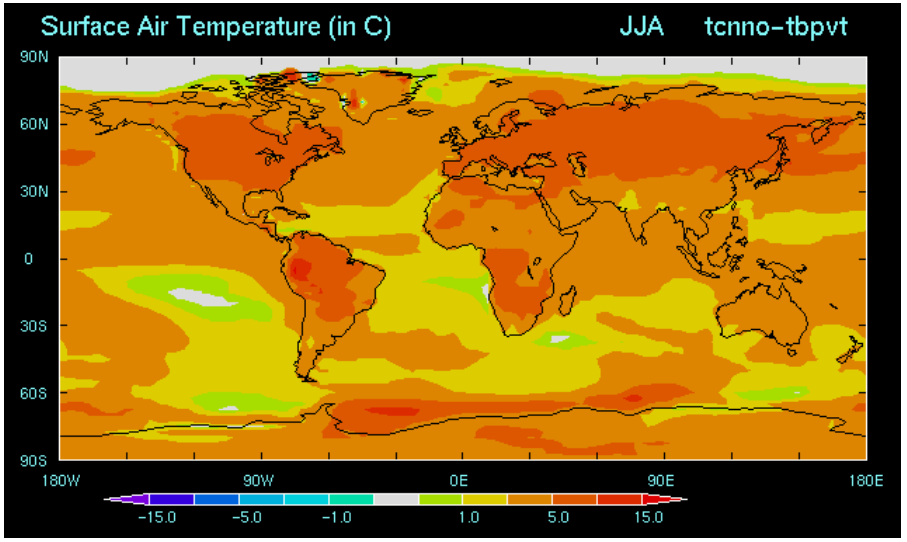
Model representation of crop fraction

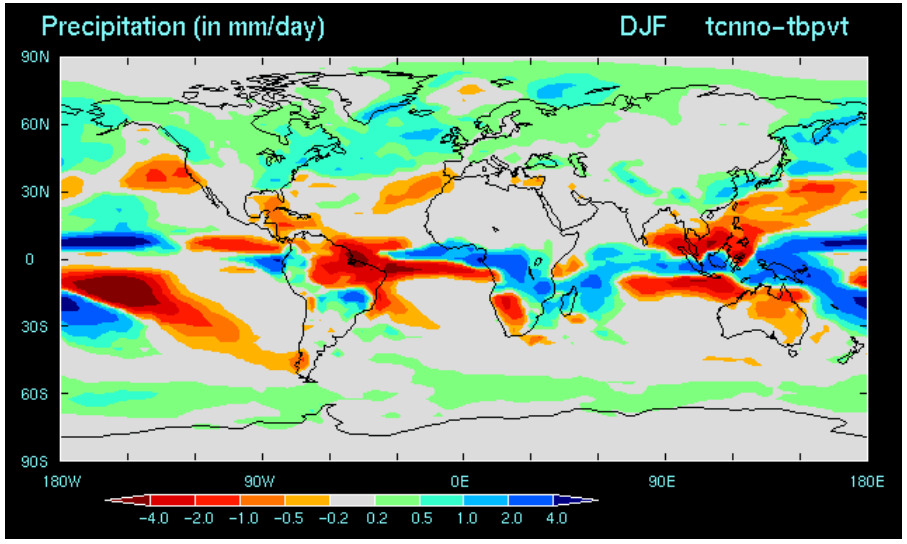
(does not include deforestation)

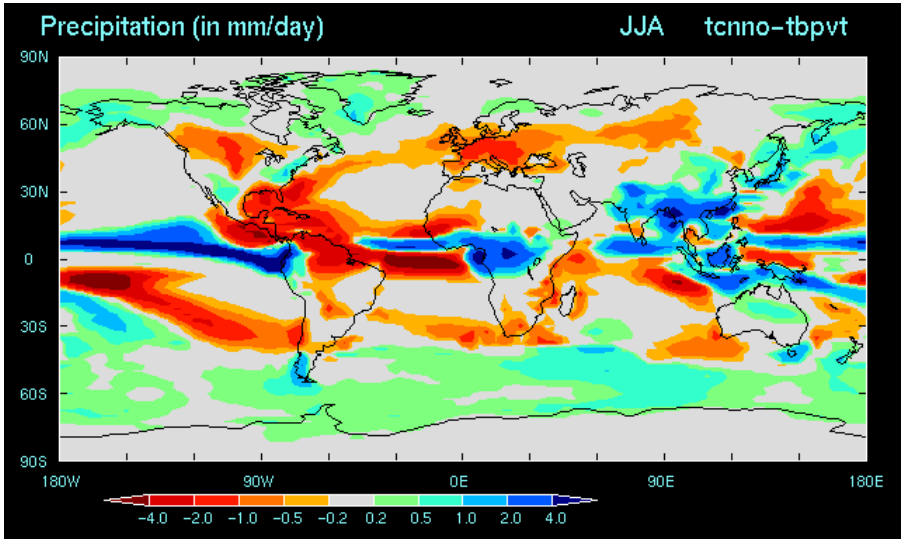
- Andy Ridgwell, Joy S. Singarayer, Alistair M. Hetherington, and Paul J. Valdes Current Biology (2009), doi:10.1016/j.cub.2008.12.025

Predicted climate change without crops

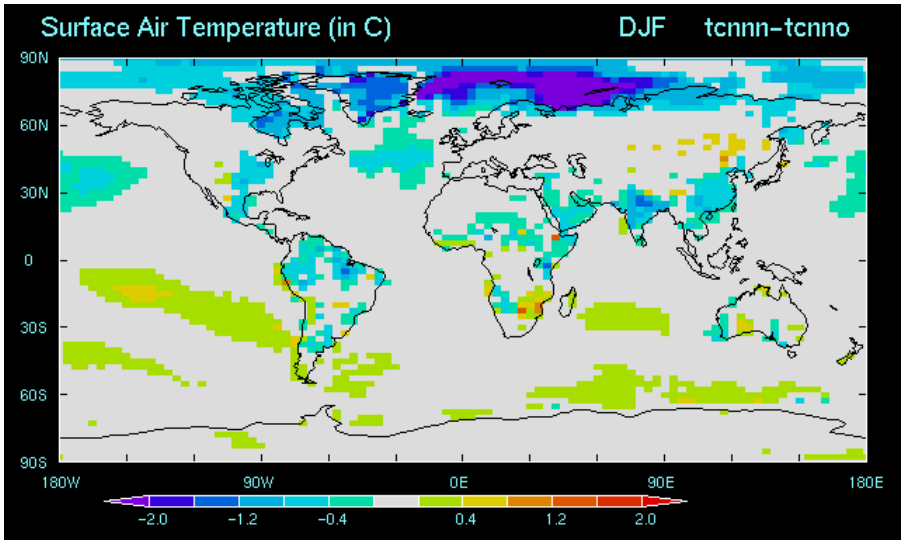


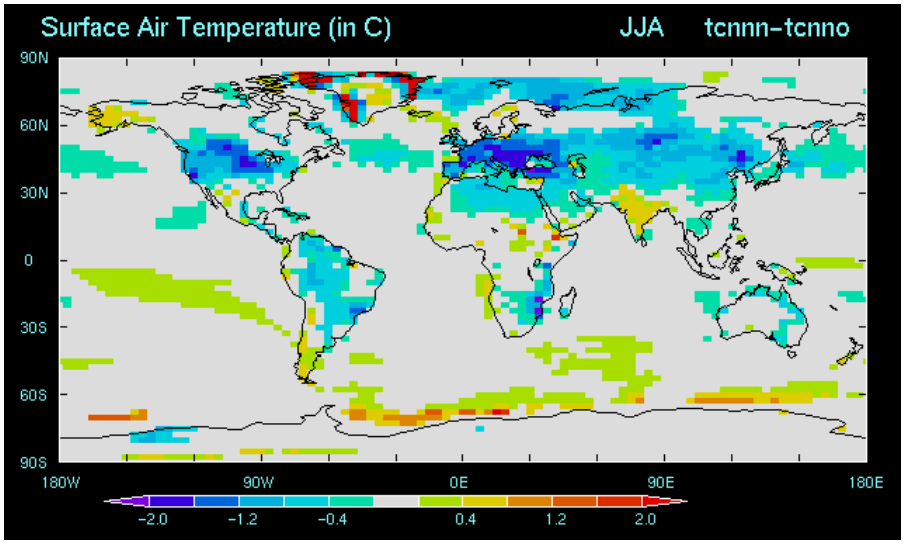






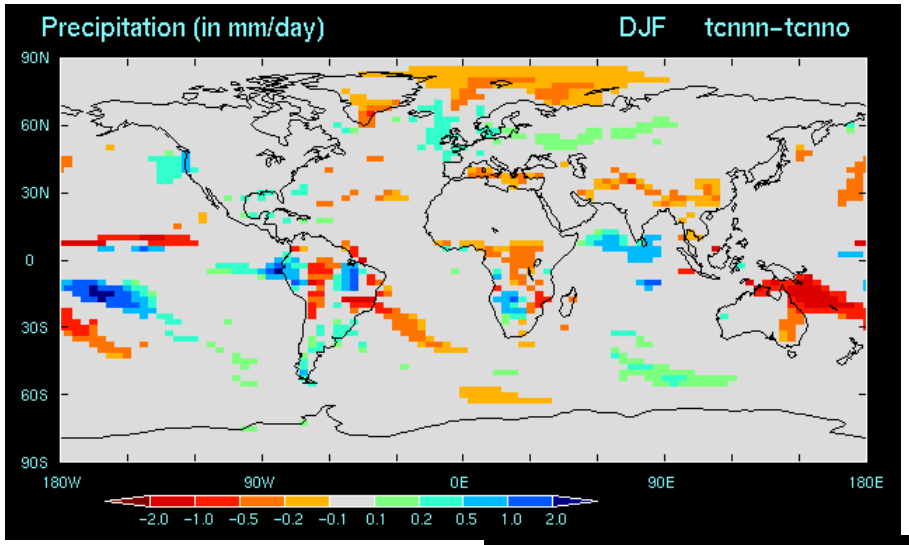
Effects of high crop albedo.

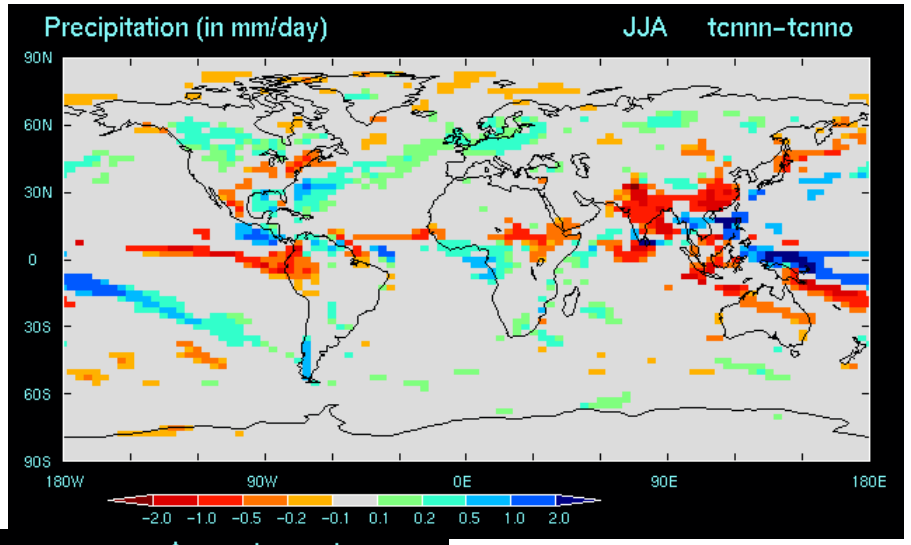


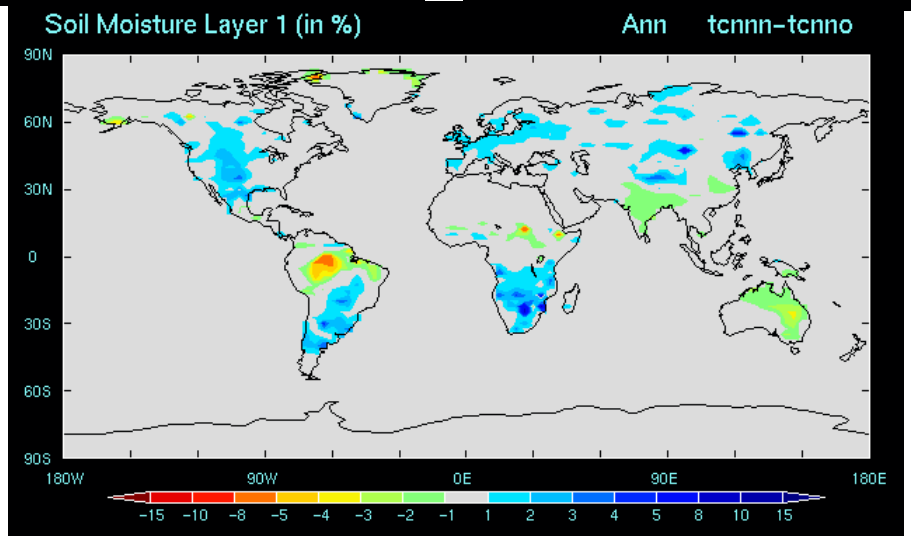


- Cooling caused by crops:
- Biggest effects in Northern Hemisphere
  - Maximum cooling (~1C) is approximately 25% of CO2 induced warming
  - Some teleconnections to other regions.

Also changes hydrological cycle

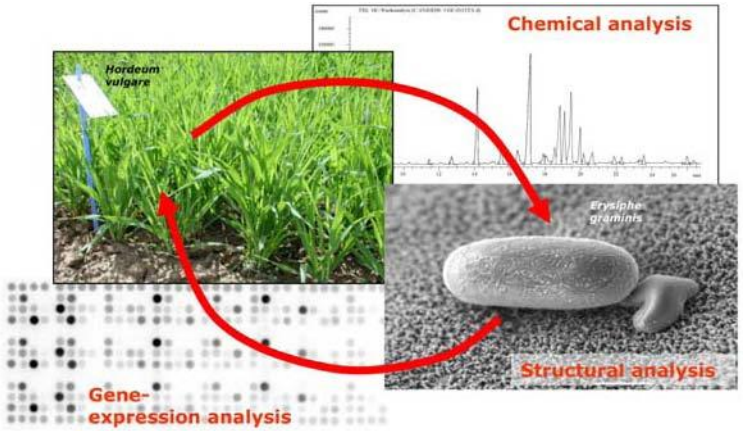


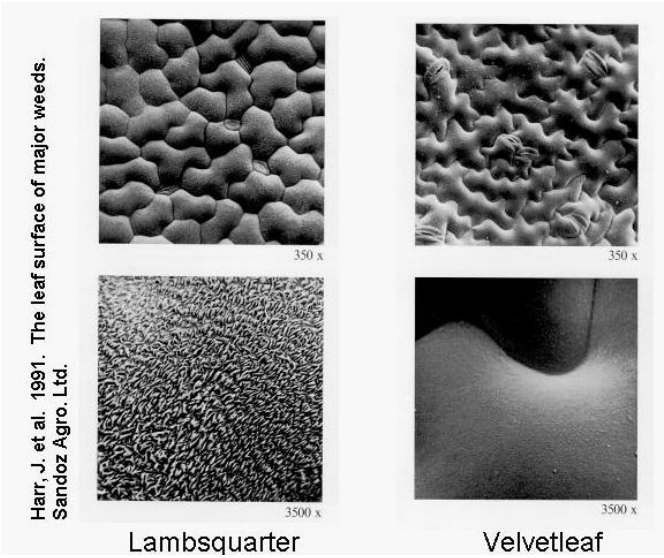




Next Stages

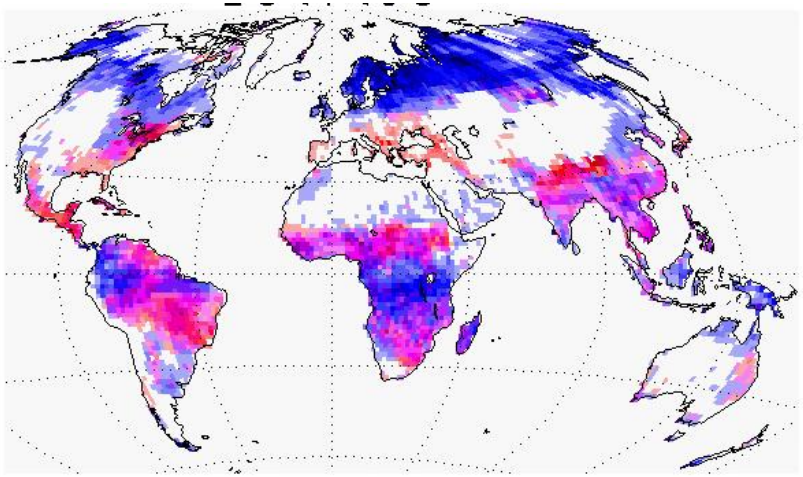
- Investigate existing cultivars and mutants to identify varieties with high leaf albedo
- Similarly for high canopy albedo
- Grow to check impact on yield
  - Few experiments so far on this, but one study using kaolin showed no effect





Other Possibilities

- Modify leaves to increase water use efficiency
  - Via waxes, hairs etc
- Some existing studies but these mainly focussed on adaptation rather than mitigation



Regions expected to experience change in fresh water supply if climate change is in the range 2K < ΔT < 3K

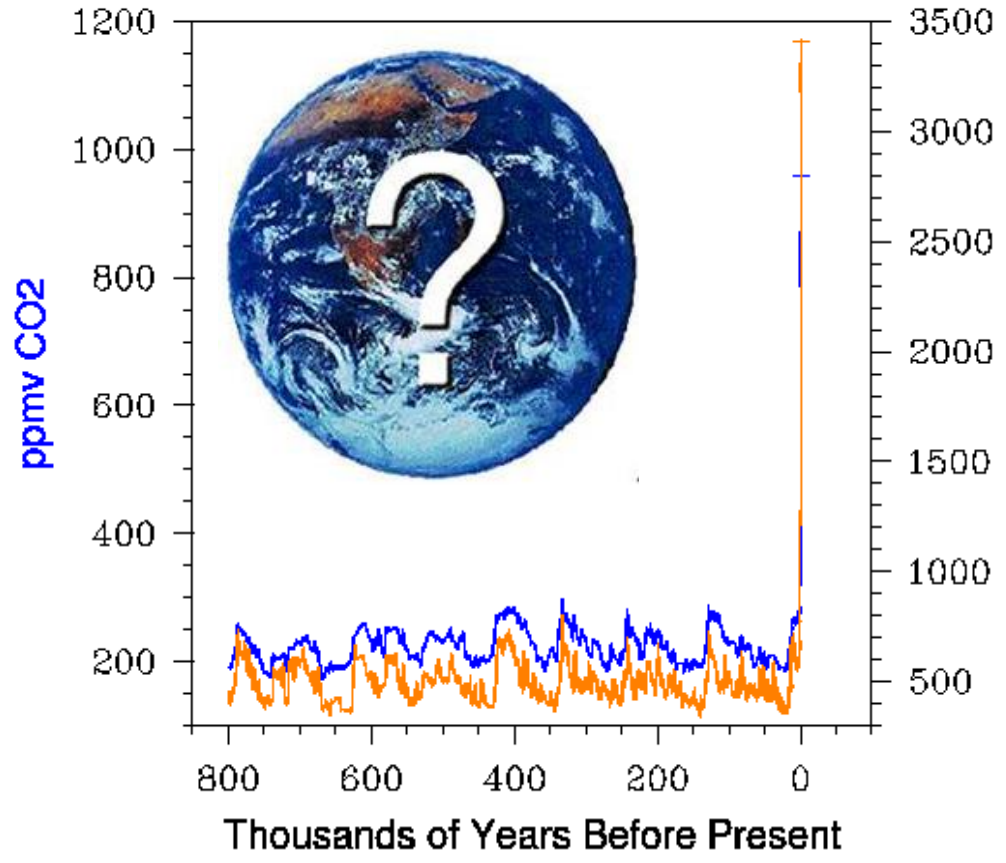
Scholze et al. (2006) PNAS

Summary

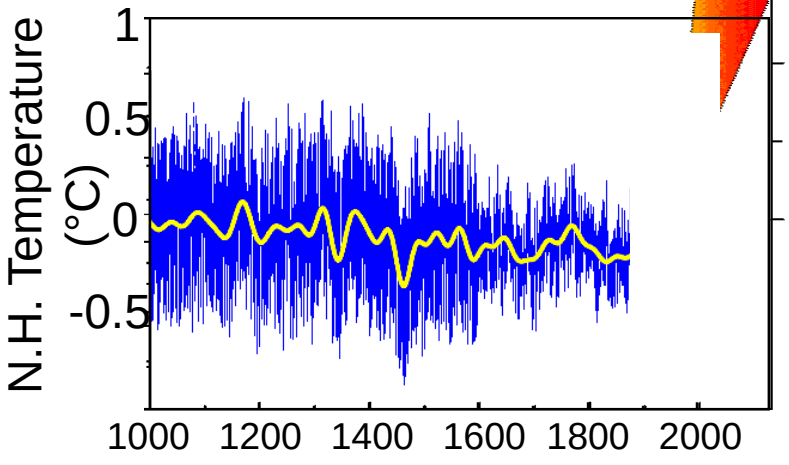
- Many large scale Geoengineering and Bio-Geoengineering solutions proposed
  - Almost all large scale albedo projects are either financially impractical, or poorly researched, or both
- Smaller scale schemes are probably more realistic, and are more open to entrepreneurship,
  - But it is early days as yet.

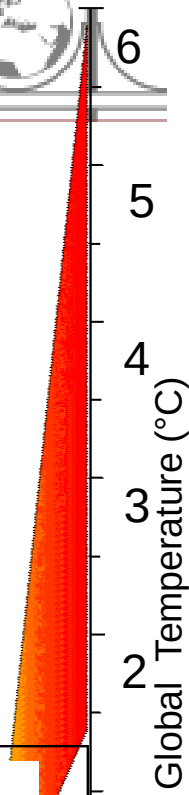
Peering into the Future

Epica Ice Core + Present Day + Future



IPCC Projections 2100 AD



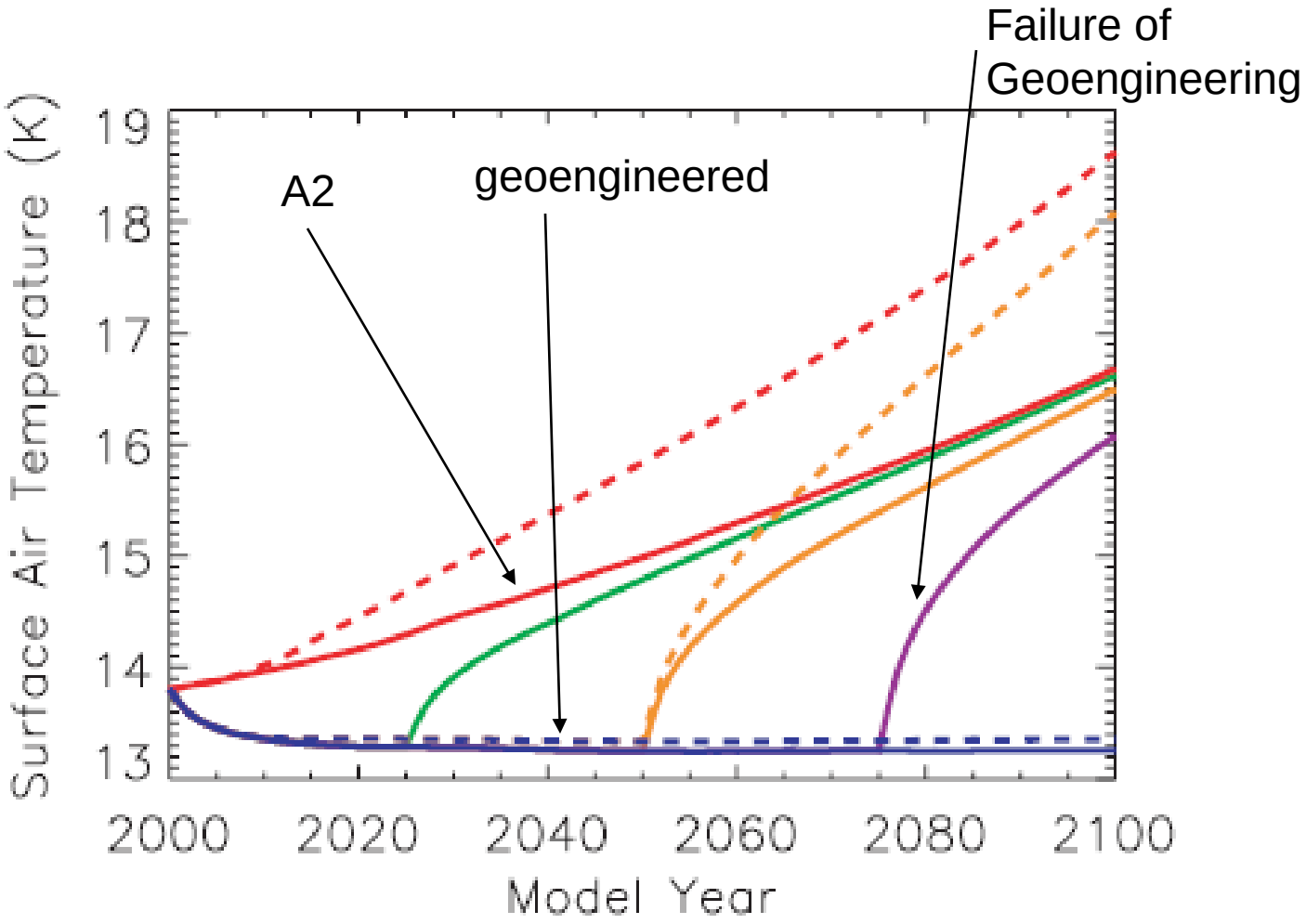


Both emission reductions AND biogeoengineering solutions are needed


University of
BRISTOL


BRIDGE

Potential Catastrophic Impact if mirror fails



H. Damon Matthews† and Ken Caldeira
PNAS | June 12, 2007 | vol. 104 | no. 24 | 9949–9954

SWOT Analysis

Option	Strengths	Weaknesses	Opportunities	Threats
Space Shades/ Mirrors*	Semi-permanent	V expensive, unproven	Existing/new technology	Unknown effects
Stratospheric aerosols*	Rapid cooling	High maintenance	'Buys' time	Unknown effects
Tropospheric aerosols*	Relatively cheap	Very short lived	Targeted use	Deposition
Seawater aerosols*	Relatively cheap	Science uncertain	Targeted use	Unknown risks
Land surface albedo*	Technically feasible	Limited scope	New developments	Feedback effects
Ocean fertilisation	Relatively cheap	Limited effect	Targeted use	Environmental risks
Ocean pipes	Relatively cheap	Limited effect	Targeted use	Environmental risks
Synthetic trees	Simple technology	High maintenance	Flexible use	Physical/local impact
Marine algae cultivation	By-products	Very limited scope	Biofuel production	Feedback effects
Heavy oil breakdown	Not assessed	Very early research stage	Oil treatment	Not assessed

Characteristics of Bioengineering

There are a few key issues when considering the viability of a given Biogeoengineering proposal:

1) The idea has to work (i.e. reduce global warming)
2) The side effects need to be minimal
3) It has to be cheaper than simply reducing emissions at the source

Such schemes may weaken the resolve to reduce the CO_2 emissions.

Could lead to conflict of interests between countries

e.g. if one country experiences more extreme warming whilst another country experiences less warming