Climate change and engineering

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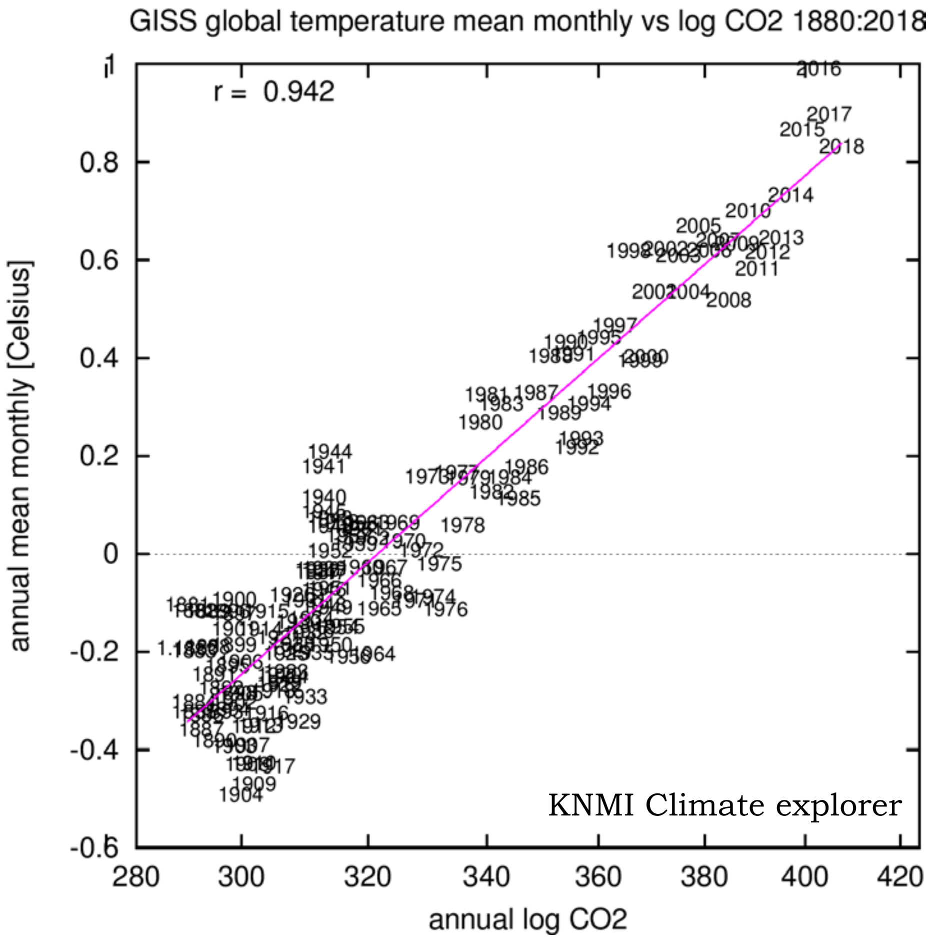
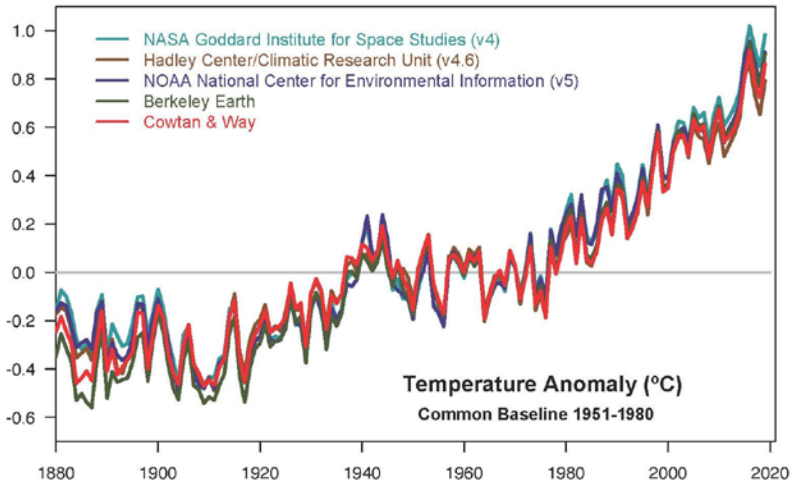
Climate 101: What has happened?

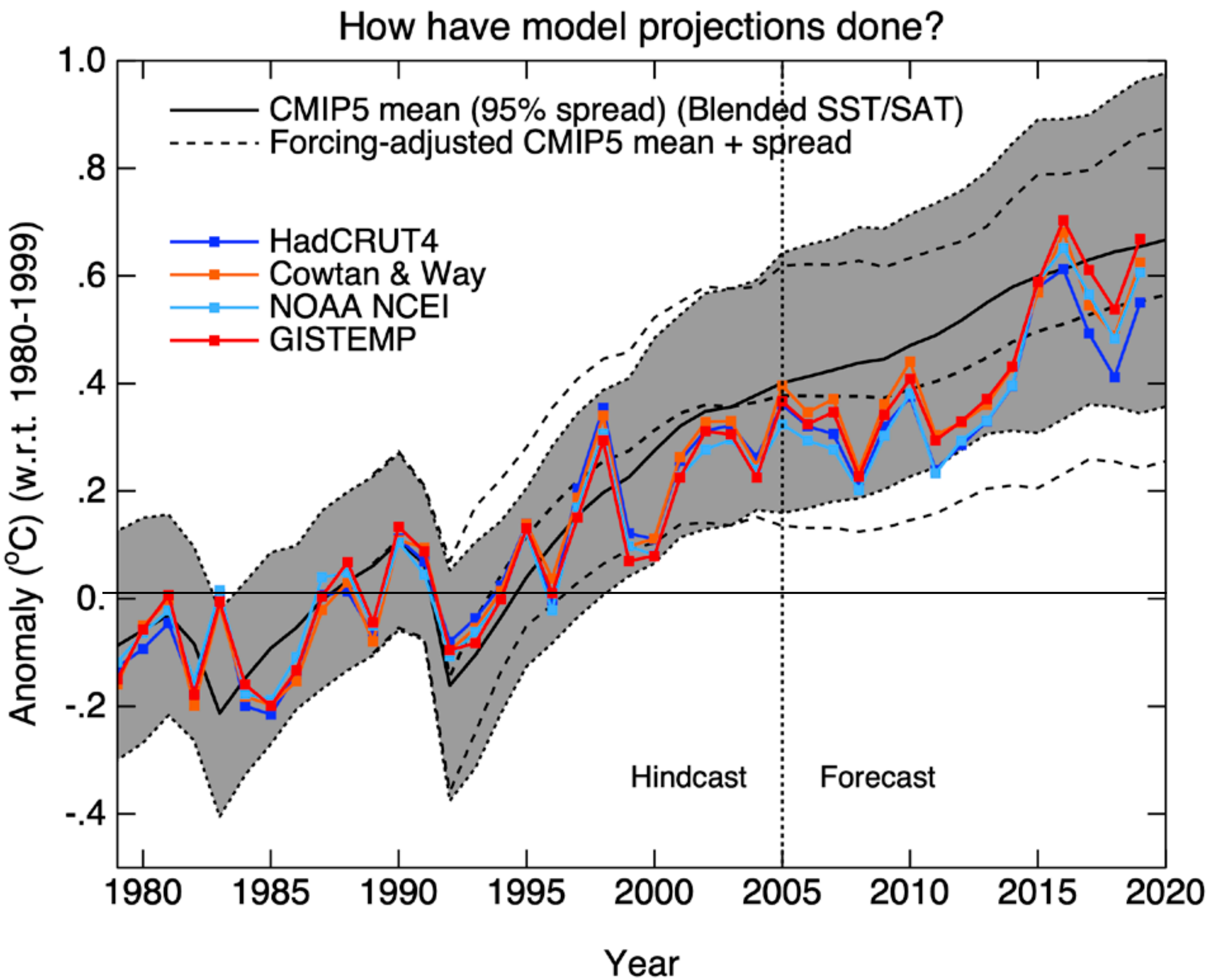


Temperature until 2019



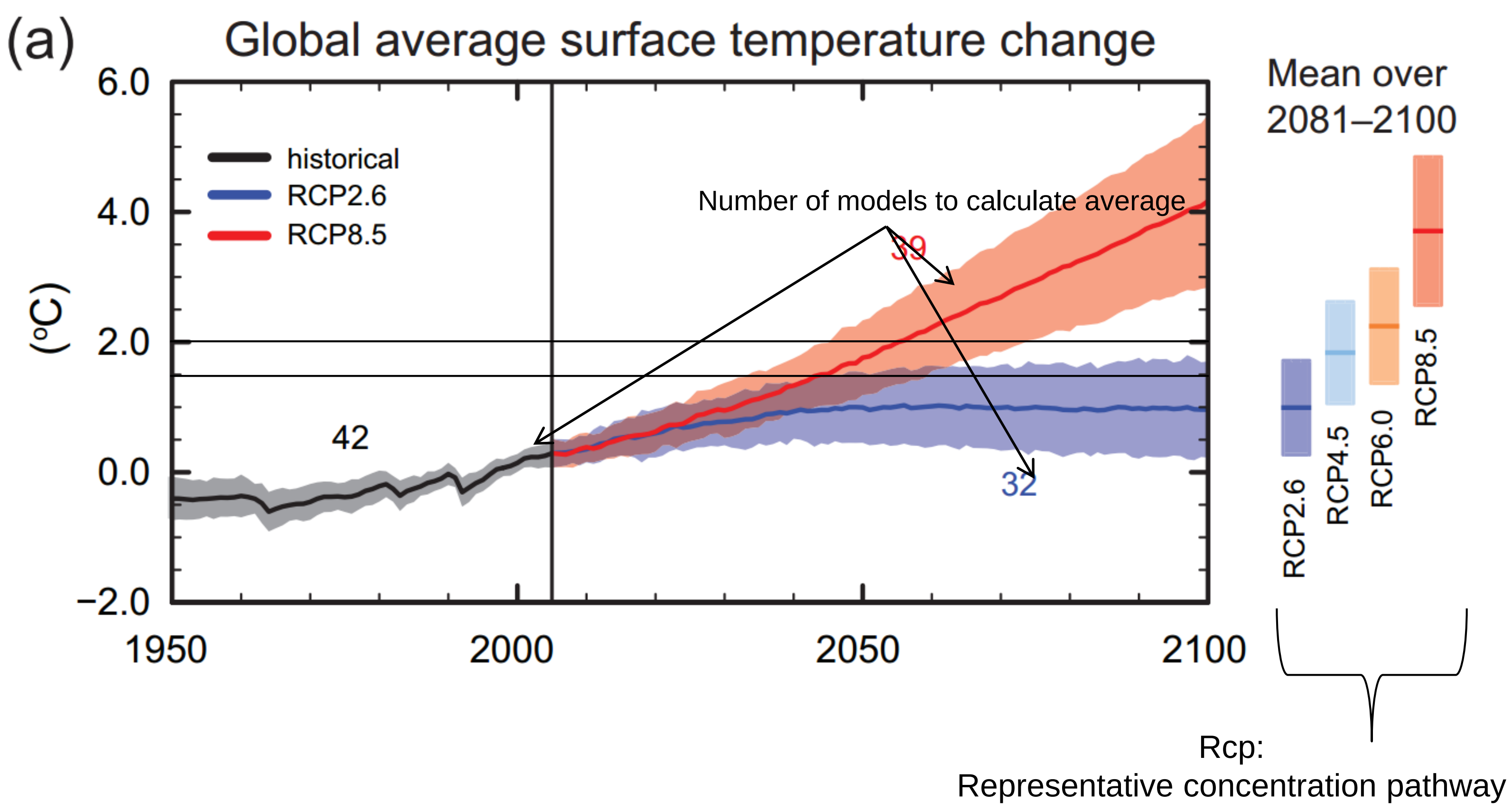
https://climate.nasa.gov/internal_resources/1986/

How good are climate models?



http://www.realclimate.org/images//cmp_cmip3_sat_blend_ann.png

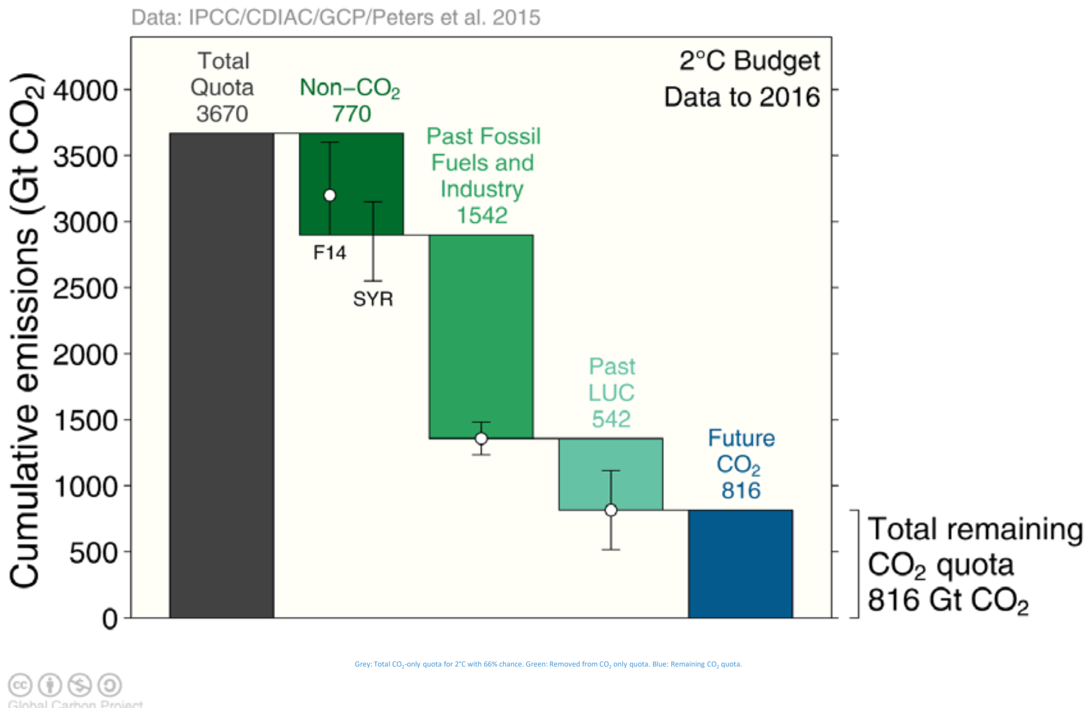
Climate 101: What might happen?



Carbon Quotas to Climate Stabilization

Carbon quota for a 66% chance to keep below 2°C

The total remaining emissions from 2017 to keep global average temperature below 2°C ($800GtCO_2$) will be used in around 20 years at current emission rates



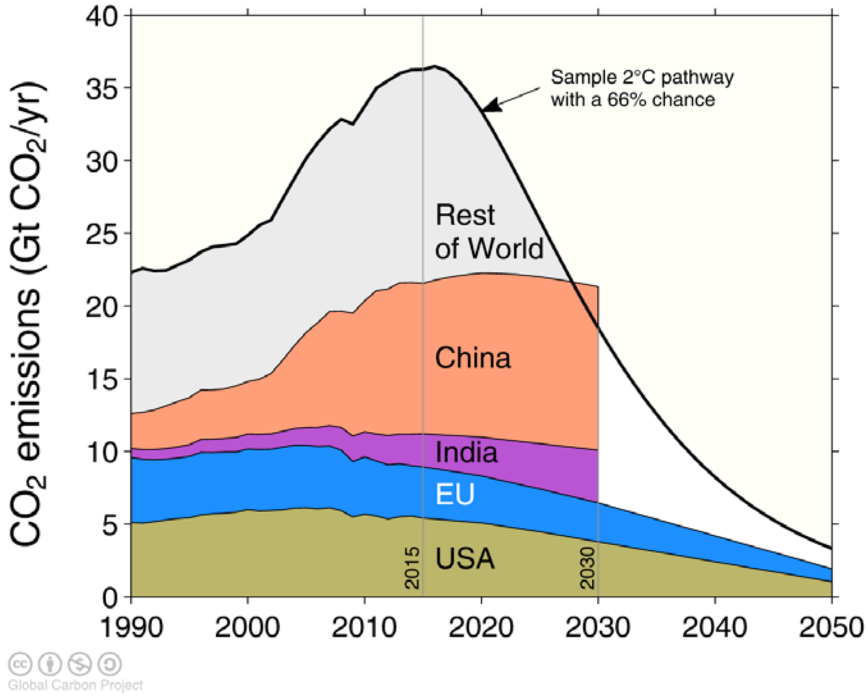
Grey: Total CO_2-only quota for 2°C with 66% chance. Green: Removed from CO_2 only quota. Blue: Remaining CO_2 quota.

The remaining quotas are indicative and vary depending on definition and methodology

Source: Peters et al 2015; Global Carbon Budget 2016

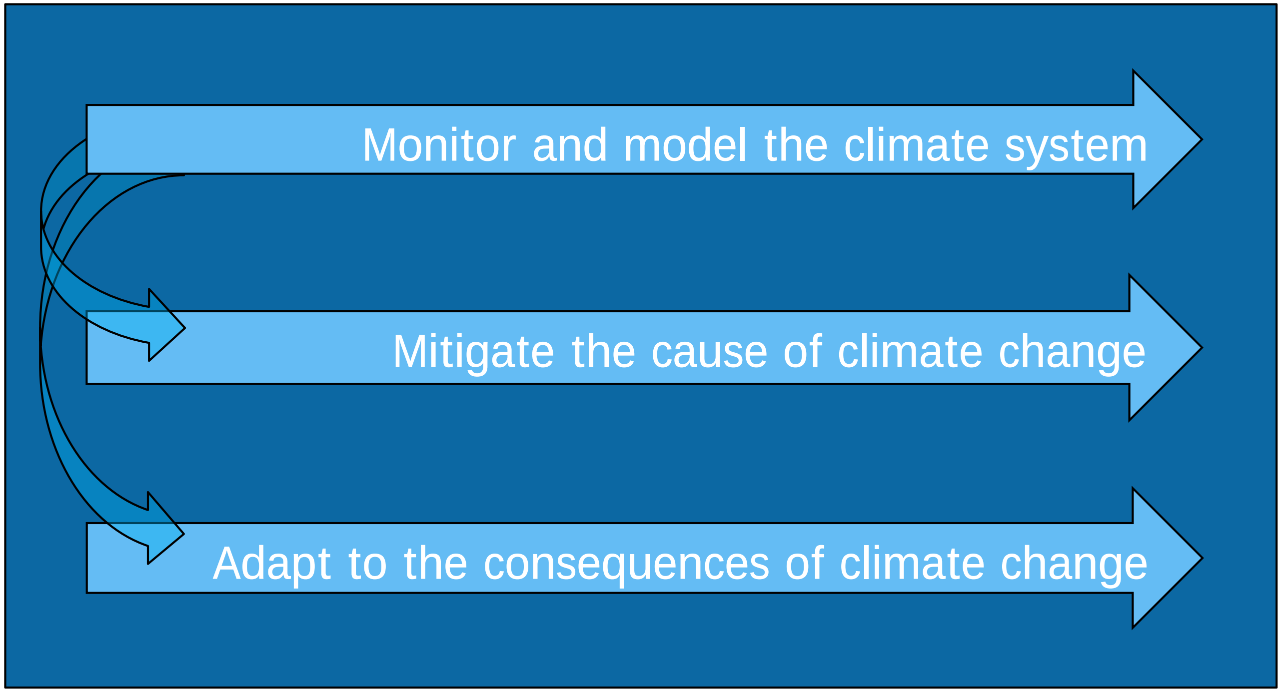
The emission pledges (INDCs) of the top-4 emitters

The emission pledges from the US, EU, China, and India leave no room for other countries to emit in a 2°C emission budget (66% chance)



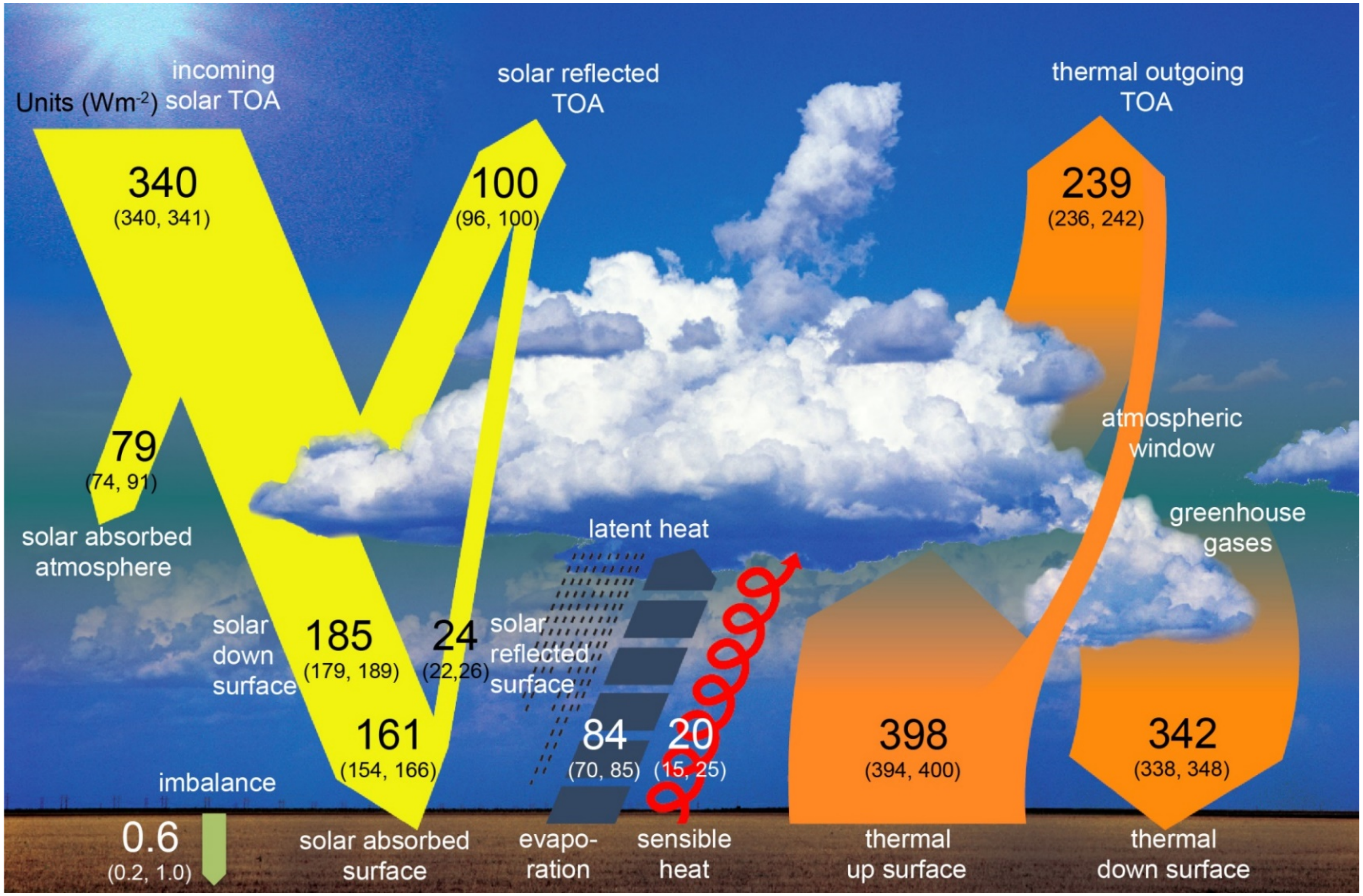
Source: Peters et al 2015; Global Carbon Budget 2016

Climate 101: What to do?



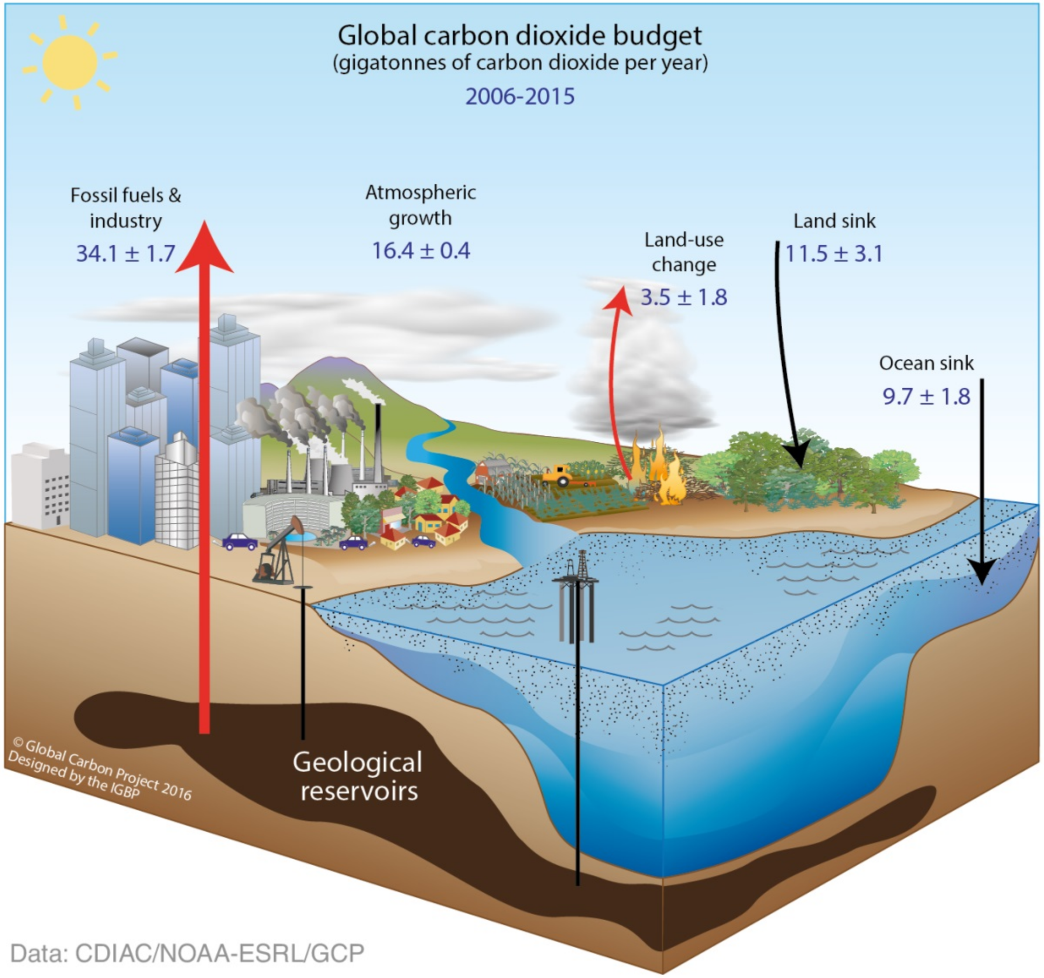
And if this doesn’t work out: geo-engineering?

Climate 101: energy balance



Anthropogenic perturbation of the global carbon cycle

Perturbation of the global carbon cycle caused by anthropogenic activities, averaged globally for the decade 2006–2015 ($GtCO_2$/yr)



Data: CDIAC/NOAA-ESRL/GCP

GLOBAL CARBON PROJECT

Fate of anthropogenic CO_2 emissions (2006-2015)

34.1 $GtCO_2$/yr

91%

9%

3.5 $GtCO_2$/yr

Sources = Sinks

16.4 $GtCO_2$/yr

44%

31%

11.6 $GtCO_2$/yr

26%

9.7 $GtCO_2$/yr

TU Delft

Source: CDIAC; NOAA-ESRL; Houghton et al 2012; Giglio et al 2013; Le Quéré et al 2016; Global Carbon Budget 2016

Climate engineering principles

Carbon dioxide removal

removal of greenhouse gases such that infrared radiation can escape into space

Solar radiation management

reduce the incoming solar radiation such that it compensates the enhanced greenhouse warming

Various geoengineering schemes for cooling the climate

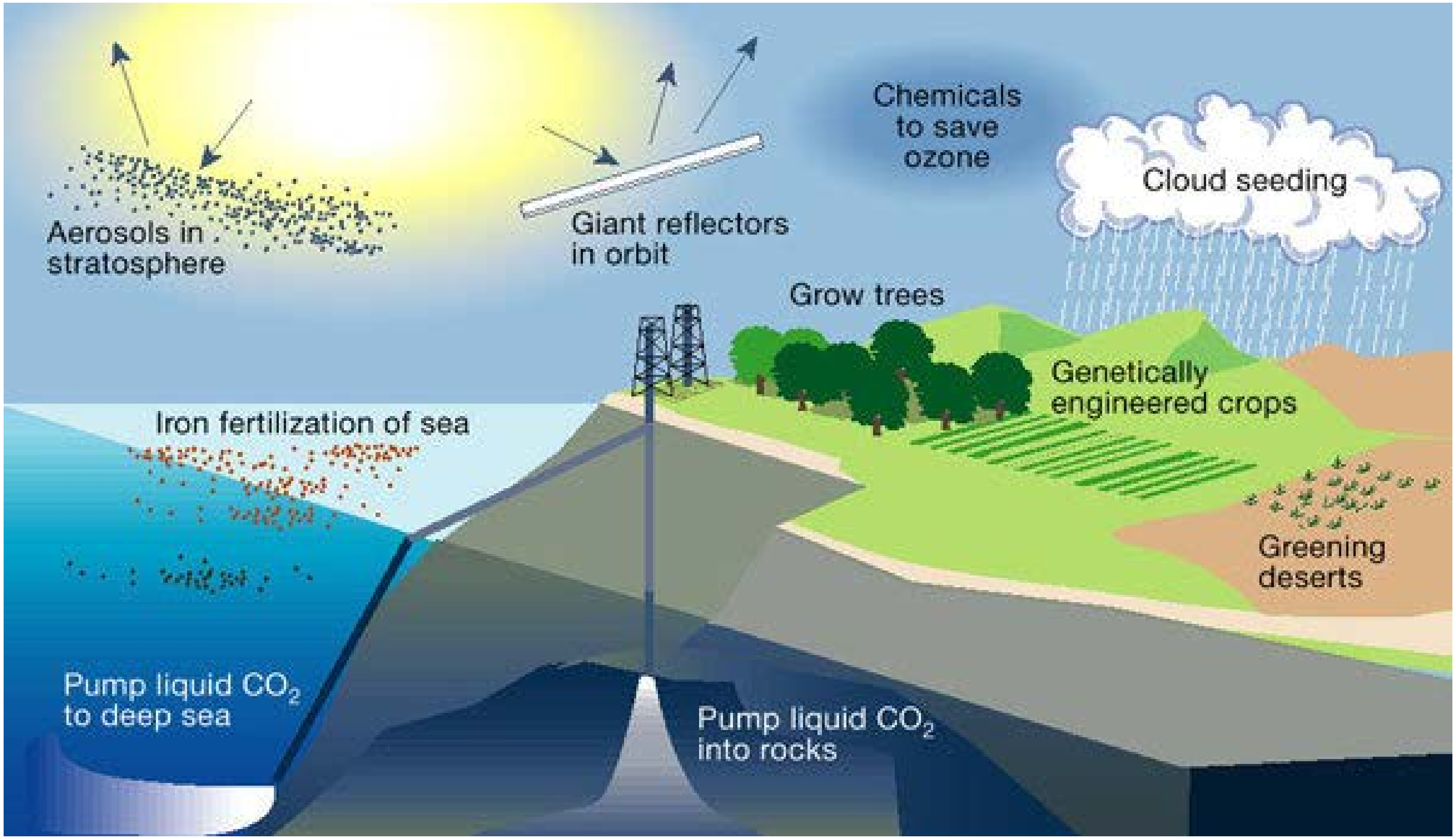
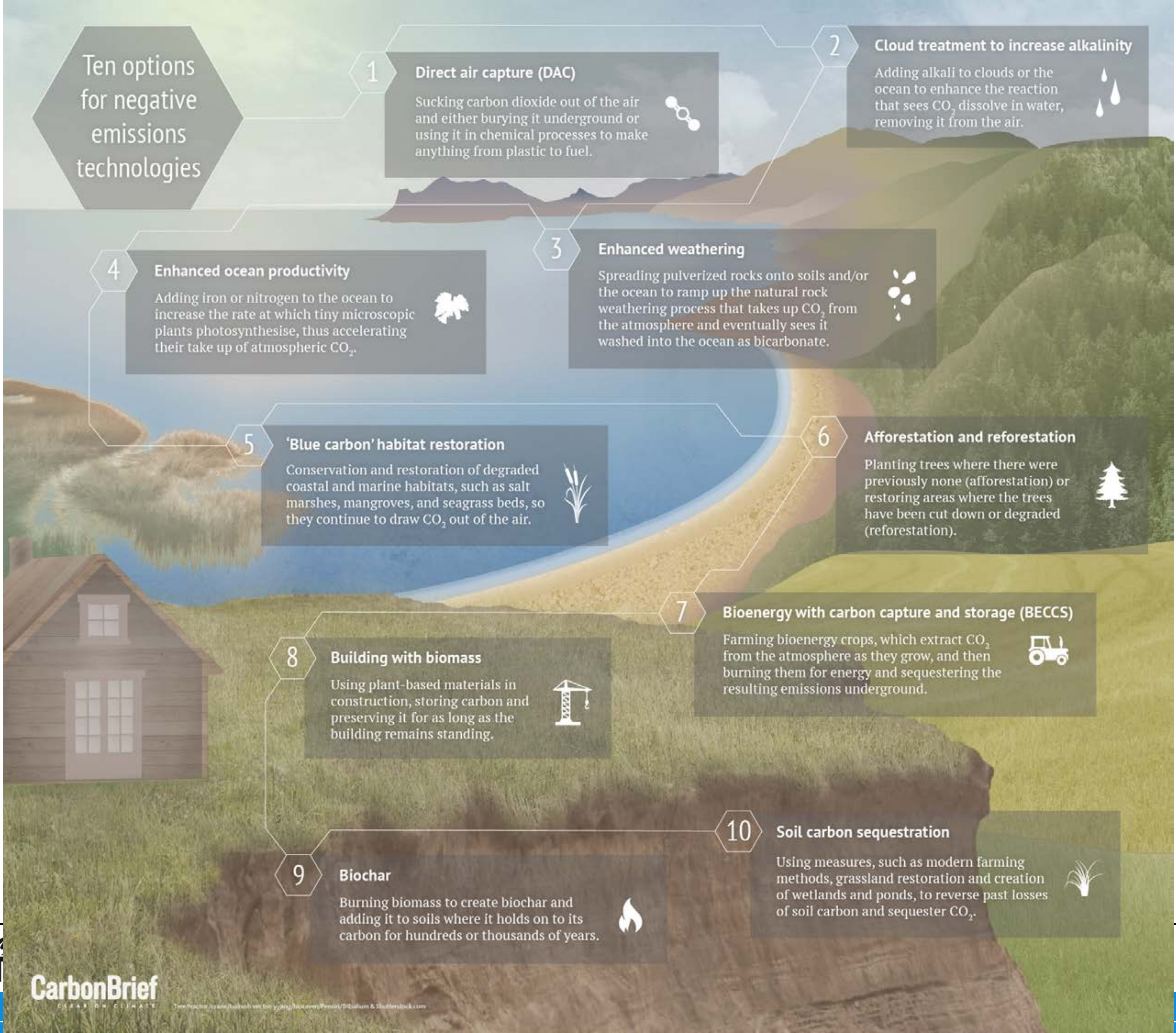
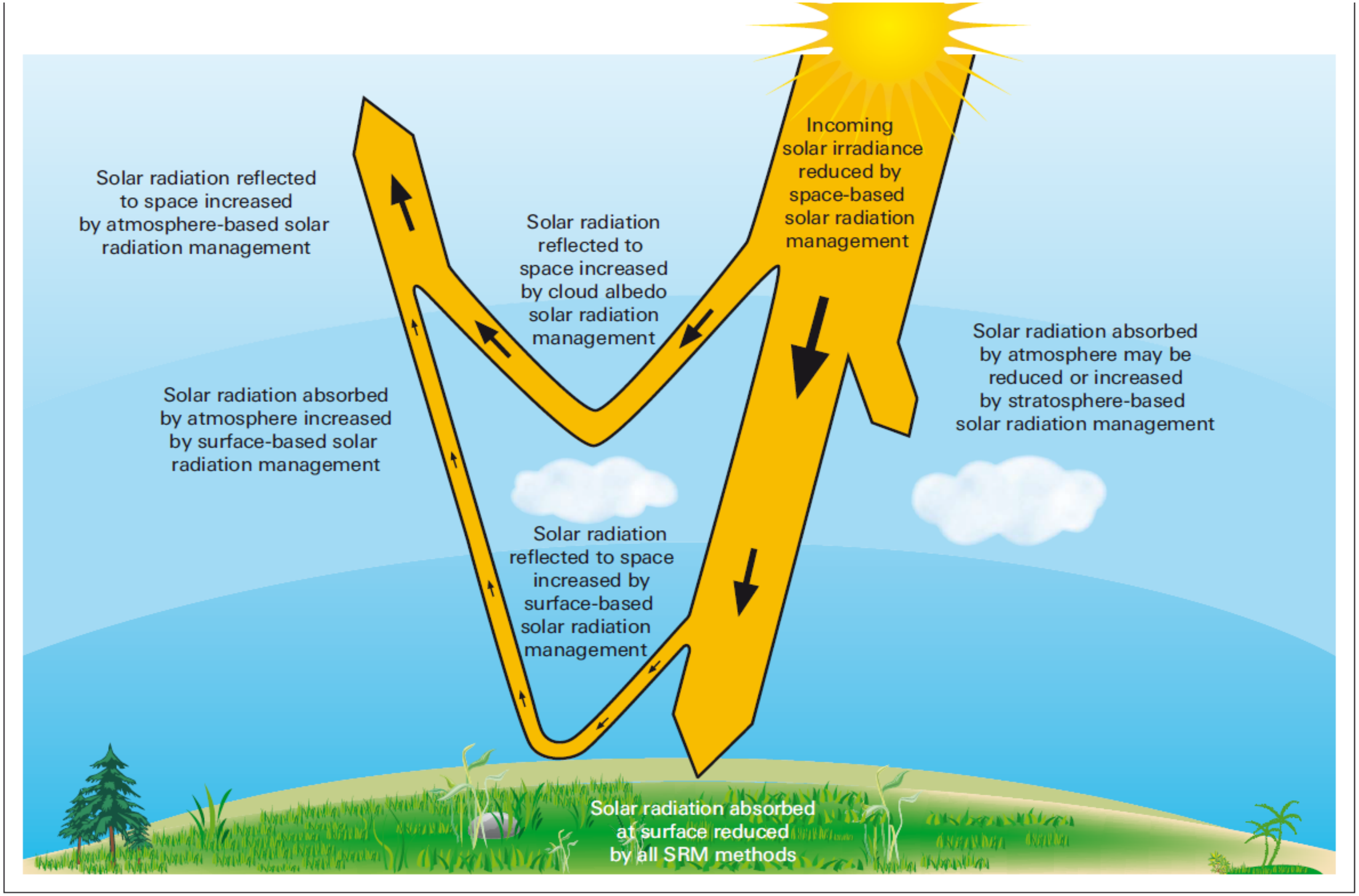


Image B. Matthews/Nature.



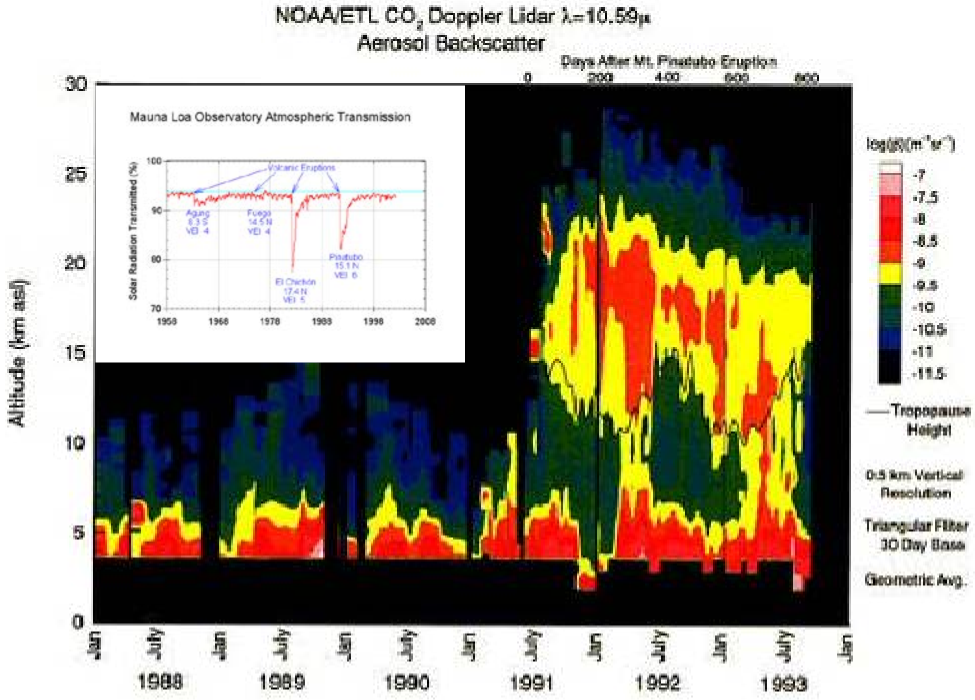
Ten options for negative emissions technologies
1 Direct air capture (DAC)
Sucking carbon dioxide out of the air and either burying it underground or using it in chemical processes to make anything from plastic to fuel.
2 Cloud treatment to increase alkalinity
Adding alkali to clouds or the ocean to enhance the reaction that sees CO_2 dissolve in water, removing it from the air.
3 Enhanced weathering
Spreading pulverized rocks onto soils and/or the ocean to ramp up the natural rock weathering process that takes up CO_2 from the atmosphere and eventually sees it washed into the ocean as bicarbonate.
4 Enhanced ocean productivity
Adding iron or nitrogen to the ocean to increase the rate at which tiny microscopic plants photosynthesise, thus accelerating their take up of atmospheric CO_2.
5 'Blue carbon' habitat restoration
Conservation and restoration of degraded coastal and marine habitats, such as salt marshes, mangroves, and seagrass beds, so they continue to draw CO_2 out of the air.
6 Afforestation and reforestation
Planting trees where there were previously none (afforestation) or restoring areas where the trees have been cut down or degraded (reforestation).
7 Bioenergy with carbon capture and storage (BECCS)
Farming bioenergy crops, which extract CO_2 from the atmosphere as they grow, and then burning them for energy and sequestering the resulting emissions underground.
8 Building with biomass
Using plant-based materials in construction, storing carbon and preserving it for as long as the building remains standing.
9 Biochar
Burning biomass to create biochar and adding it to soils where it holds on to its carbon for hundreds or thousands of years.
10 Soil carbon sequestration
Using measures, such as modern farming methods, grassland restoration and creation of wetlands and ponds, to reverse past losses of soil carbon and sequester CO_2.
CarbonBrief

Solar Radiation Modification



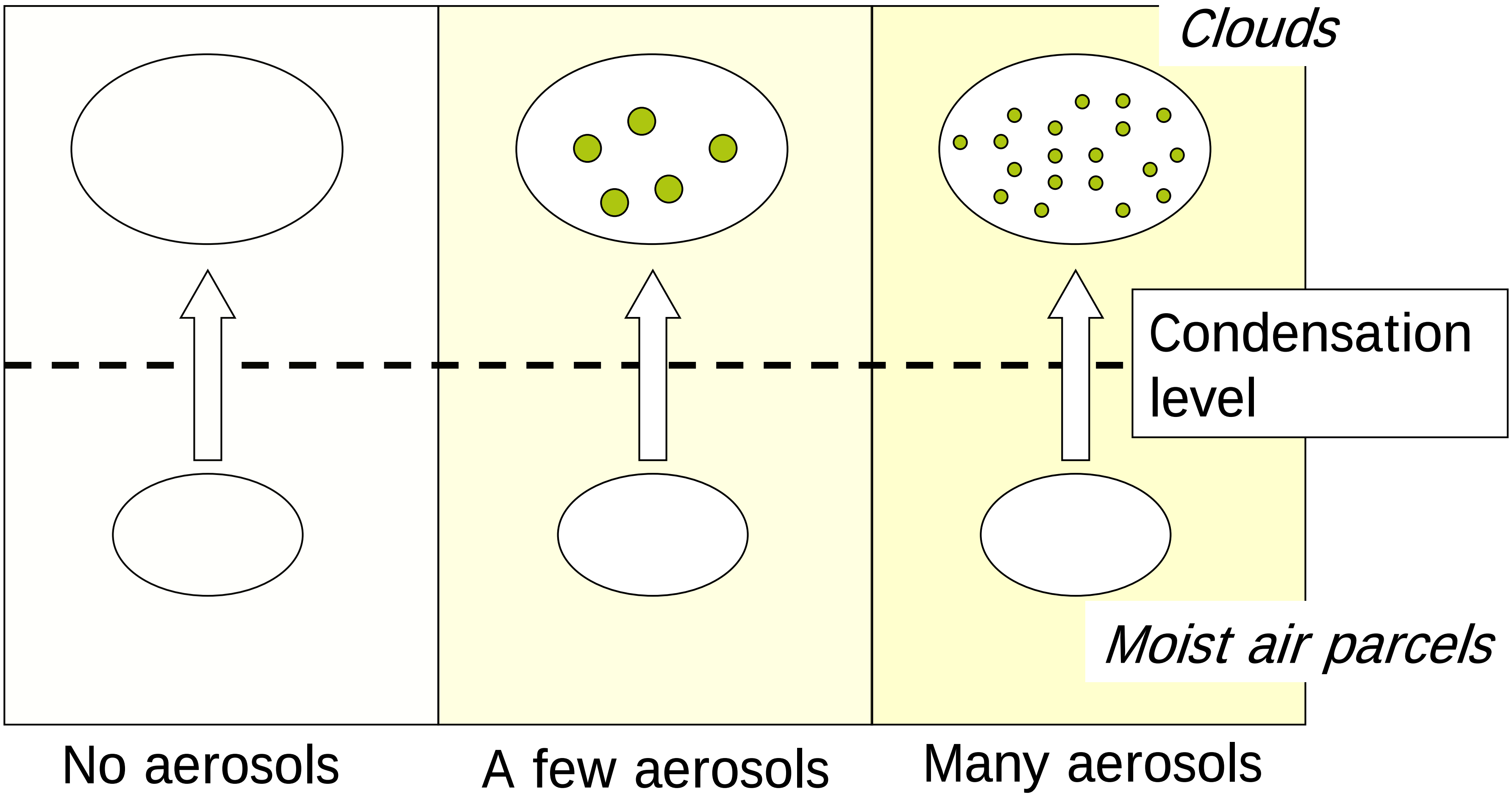
Shepherd et al. (2009)

Natural example of cooling by stratospheric aerosols

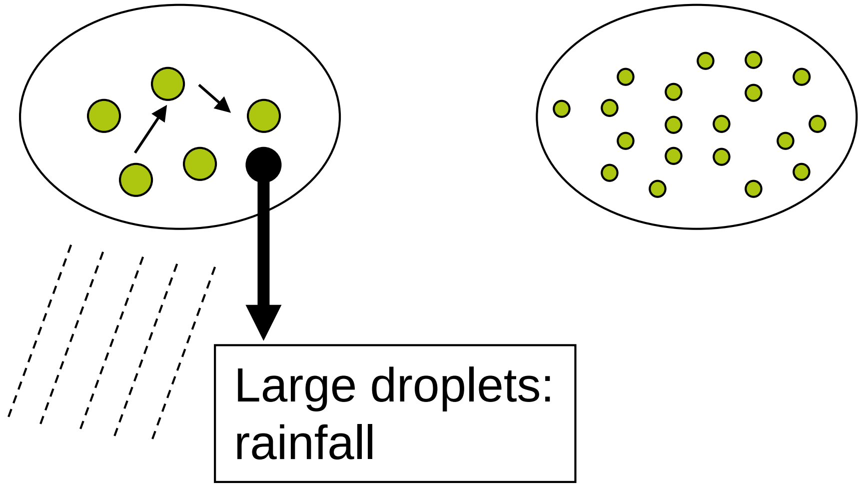


Eruption of Mount Pinatubo

A bit about cloud formation



rainfall formation



More aerosols

↓

Delayed rainfall

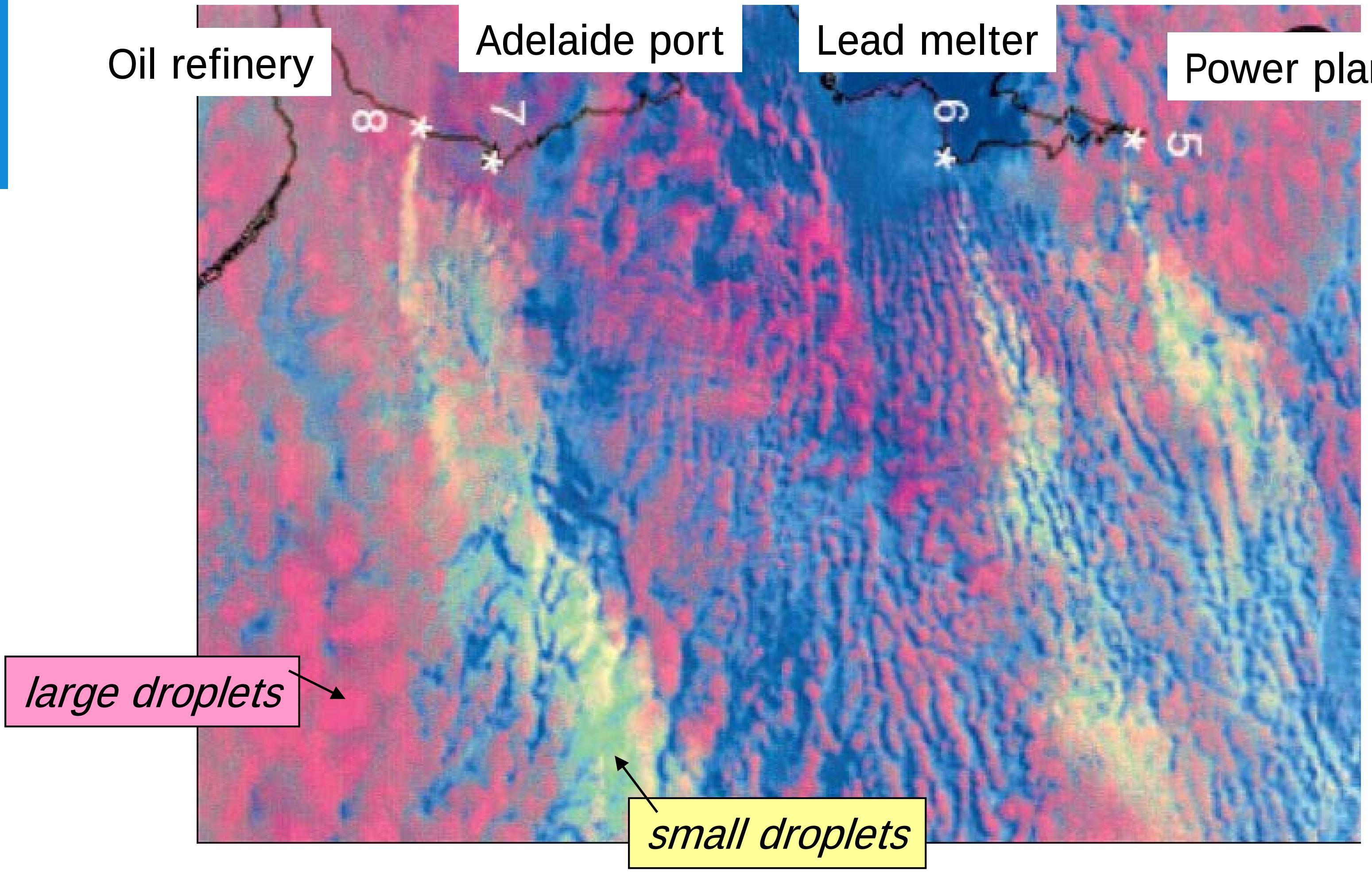
↓

Longer cloud lifetime

↓

Sustained impact
on radiation

Cloud changes due to air pollution



Source: NASA

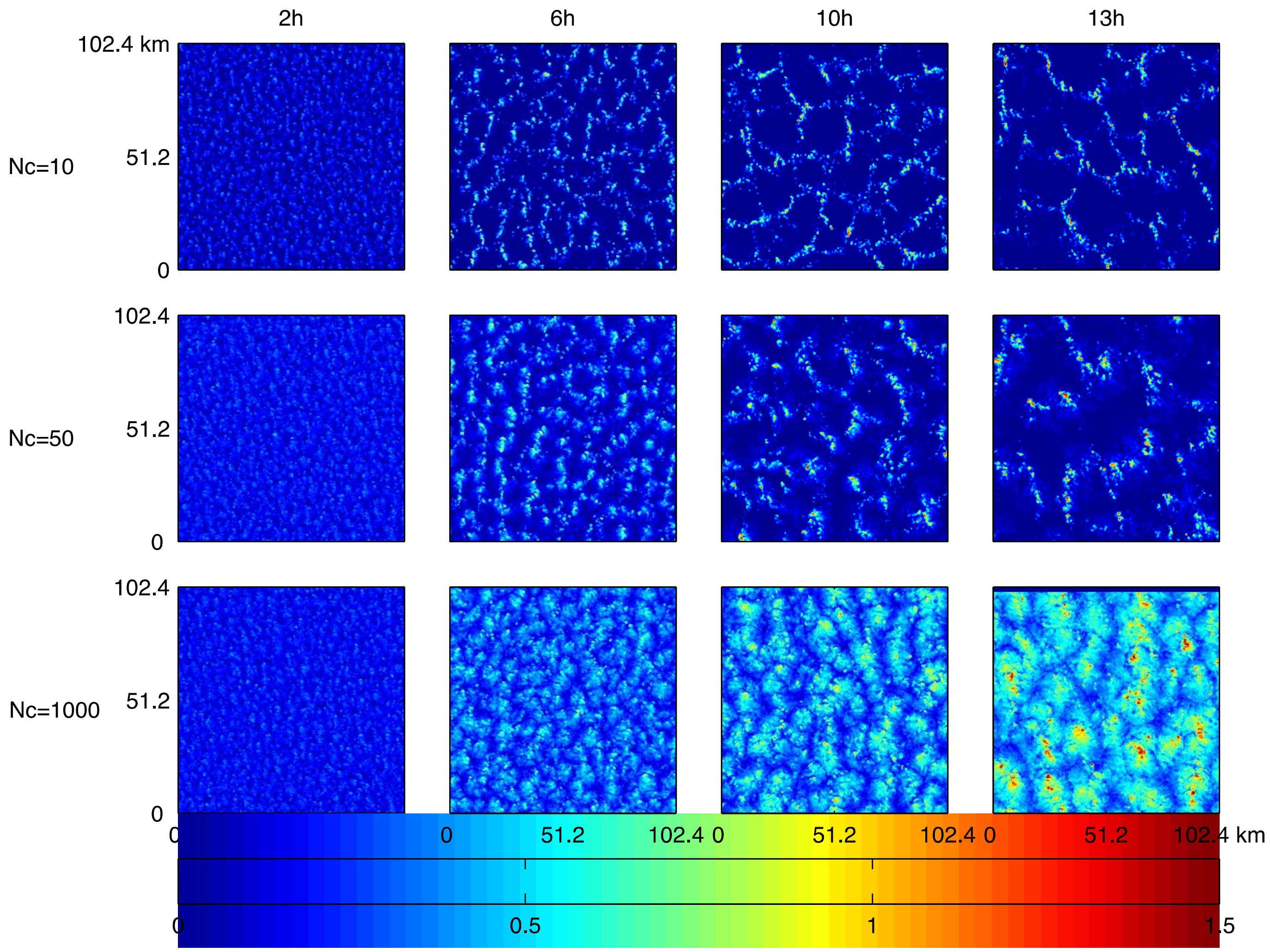
Cloud brightening by ship exhausts

http://earthobservatory.nasa.gov/IOTD/view.php?id=5488

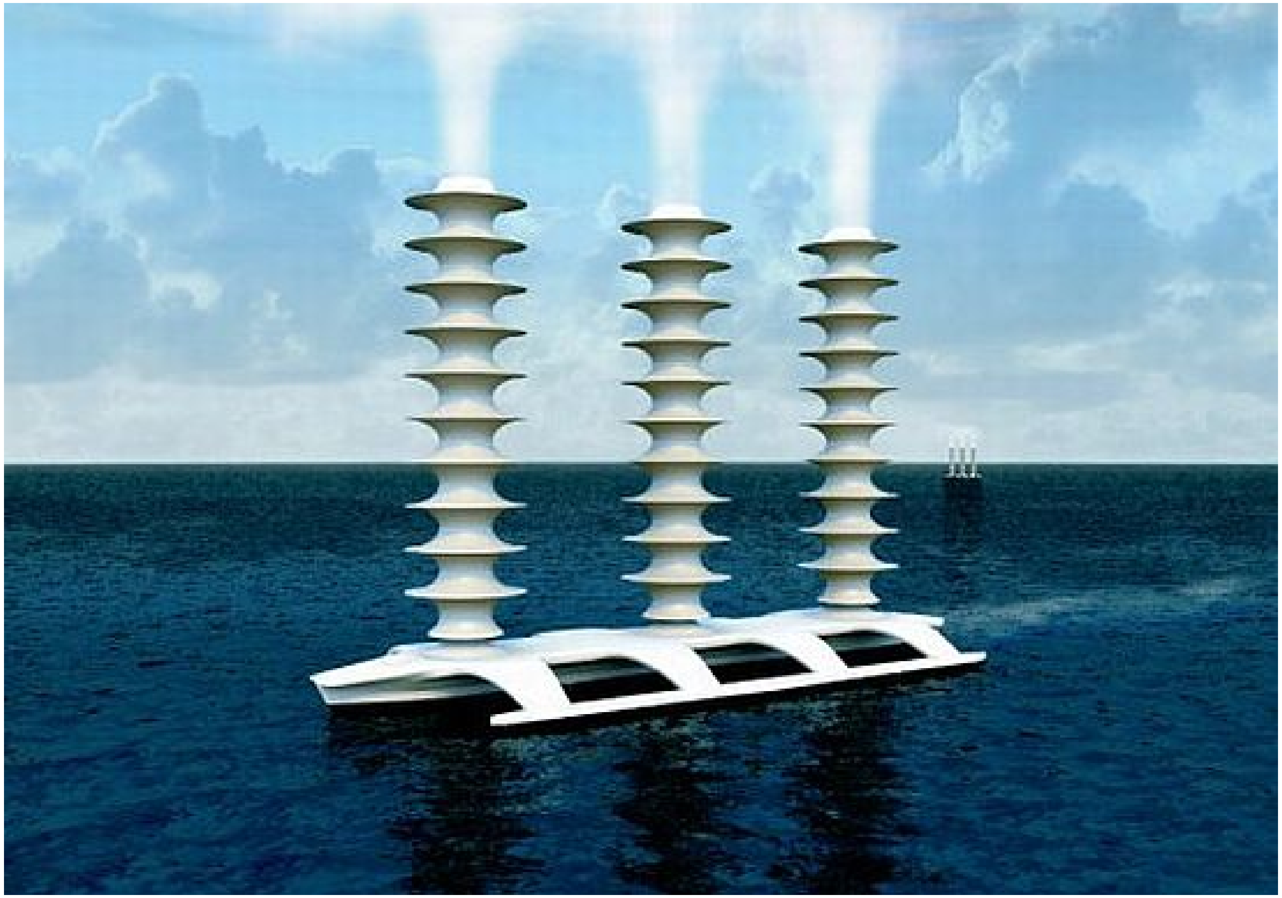
The effect of cloud droplet concentration on cloud evolution

low droplet concentration, **open cells**

high droplet concentration, **closed cells**



Seeding clouds with sea salt spray



Global effect of cloud brightening on radiation

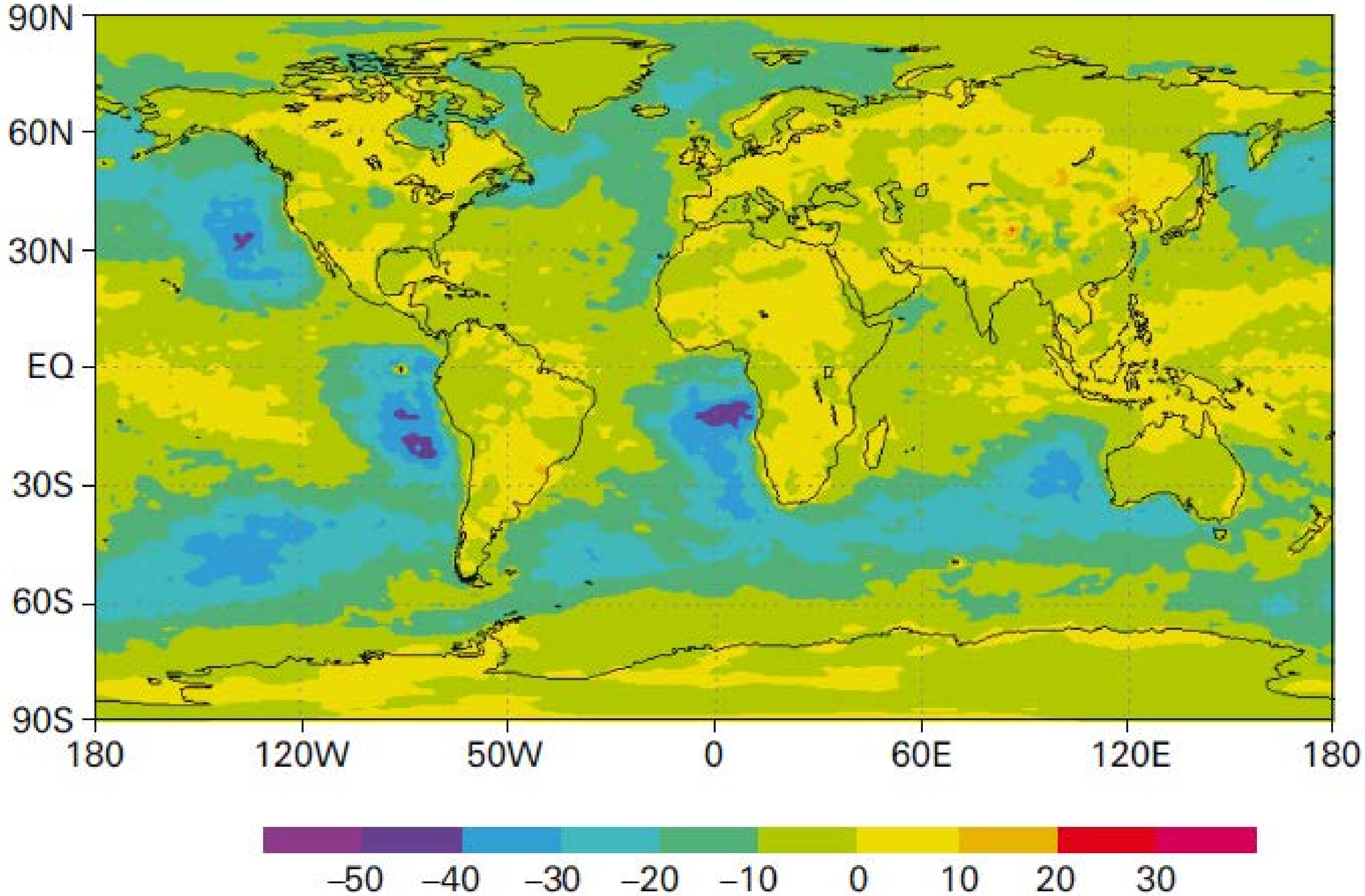
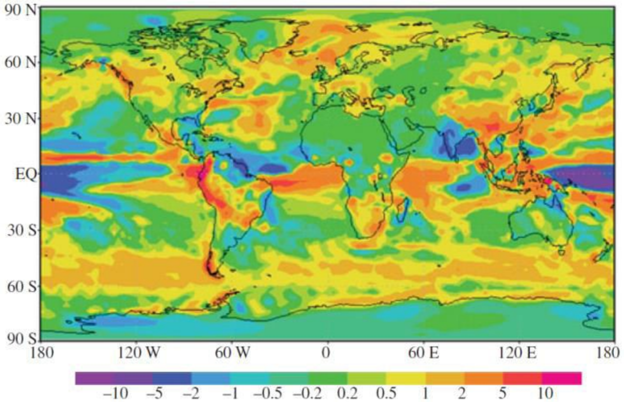


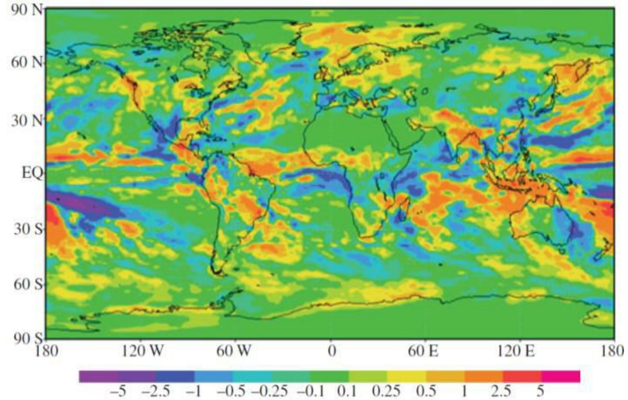
Figure 3.2. Five-year mean difference (W/m2) in radiative forcing at the top of the atmosphere between a control simulation (with CCN of 100/cm3) and a test run with CCN of 375/cm3 in regions of low-level maritime cloud (an extension of results from Latham et al. 2008)., Royal Society, 2009

Effect on precipitation

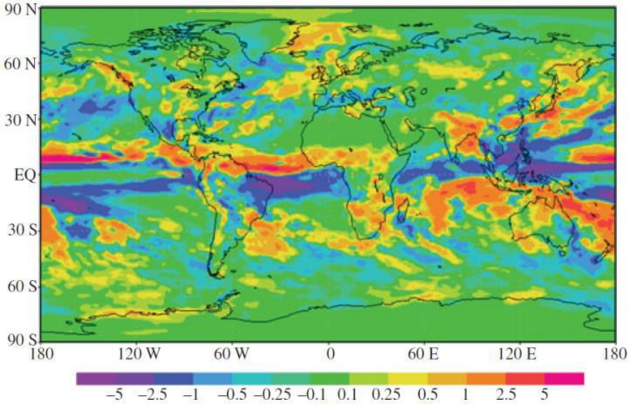
10 year sim – CMAP observations



$2CO_2$ - CON



MCB - CON



Total amount does not change much,
But the regional differences might increase

(Latham et al, 2012)

Mean effect of albedo changes

Option	Area (m^2)	Fraction of Earth f_{Earth}	Albedo change within area $\Delta\alpha$	Scaled albedo change of layer	Transmittance factor f_a	Planetary albedo change $\Delta\alpha_p$	Solar radiation at TOA S_0 ($W\,m^{-2}$)	Radiative forcing RF ($W\,m^{-2}$)
Increase marine cloud albedo				$\Delta\alpha_a$				
Mechanical	8.9×10^{13}	0.175	0.074	0.013	0.84	0.011	345	−3.71
Biological	5.1×10^{13}	0.1	0.008	0.000067*	0.84	0.000056	345	−0.019
Increase land surface albedo				$\Delta\alpha_s$				
Desert	1.0×10^{13}	0.02	0.44	0.0088	0.73	0.0064	330	−2.12
Grassland	3.85×10^{13}	0.075	0.0425	0.0032	0.48	0.0015	330	−0.51
Cropland	1.4×10^{13}	0.028	0.08	0.0022	0.48	0.0011	330	−0.35
Settlements	3.25×10^{12}	0.0064	0.15	0.00096	0.48	0.00046	330	−0.15
Urban areas	1.5×10^{12}	0.0029	0.1	0.00029	0.48	0.00014	330	−0.047

Lenton and Vaughan (2009)

Mean effect of carbon removal

Geoengineering Option	2050		2100			3000	
	ΔCO_2 (ppm)	RF ($W\,m^{-2}$)	ΔCO_2 (ppm)	RF ($W\,m^{-2}$)	ΣC_{seq} (PgC)	ΔCO_2 (ppm)	RF_{final} ($W\,m^{-2}$)
Enhance land carbon sink							
Afforestation	−41	−0.49	−34	−0.37	183	−16	−0.27
Bio-char production	−10	−0.12	−37	−0.40	399	−34	−0.52
Air capture and storage	−58	−0.74	−186	−2.5	>1000	>|−85|	>|−1.43|
Enhance ocean carbon sink							
Phosphorus addition	−5.9	−0.070	−12	−0.13	574	−52	−0.83
Nitrogen fertilisation	−4.5	−0.054	−9.3	−0.10	299	−25	−0.38
Iron fertilisation	−9.0	−0.11	−19	−0.20	227	−19	−0.29
Enhance upwelling	−0.1	−0.0017	−0.3	−0.0032	16*	−1.9	−0.028
Enhance downwelling	−0.08	−0.00095	−0.18	−0.0019	9*	−1.1	−0.016
Carbonate addition	−0.4	−0.0048	−2.3	−0.025	251*	−30	−0.46

Lenton and Vaughan (2009)

Criteria for techniques

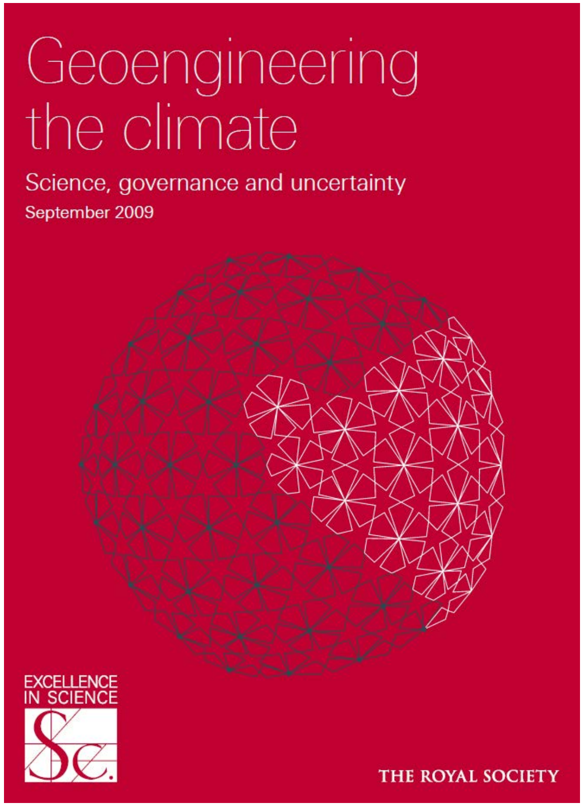
Effectiveness

Timeliness

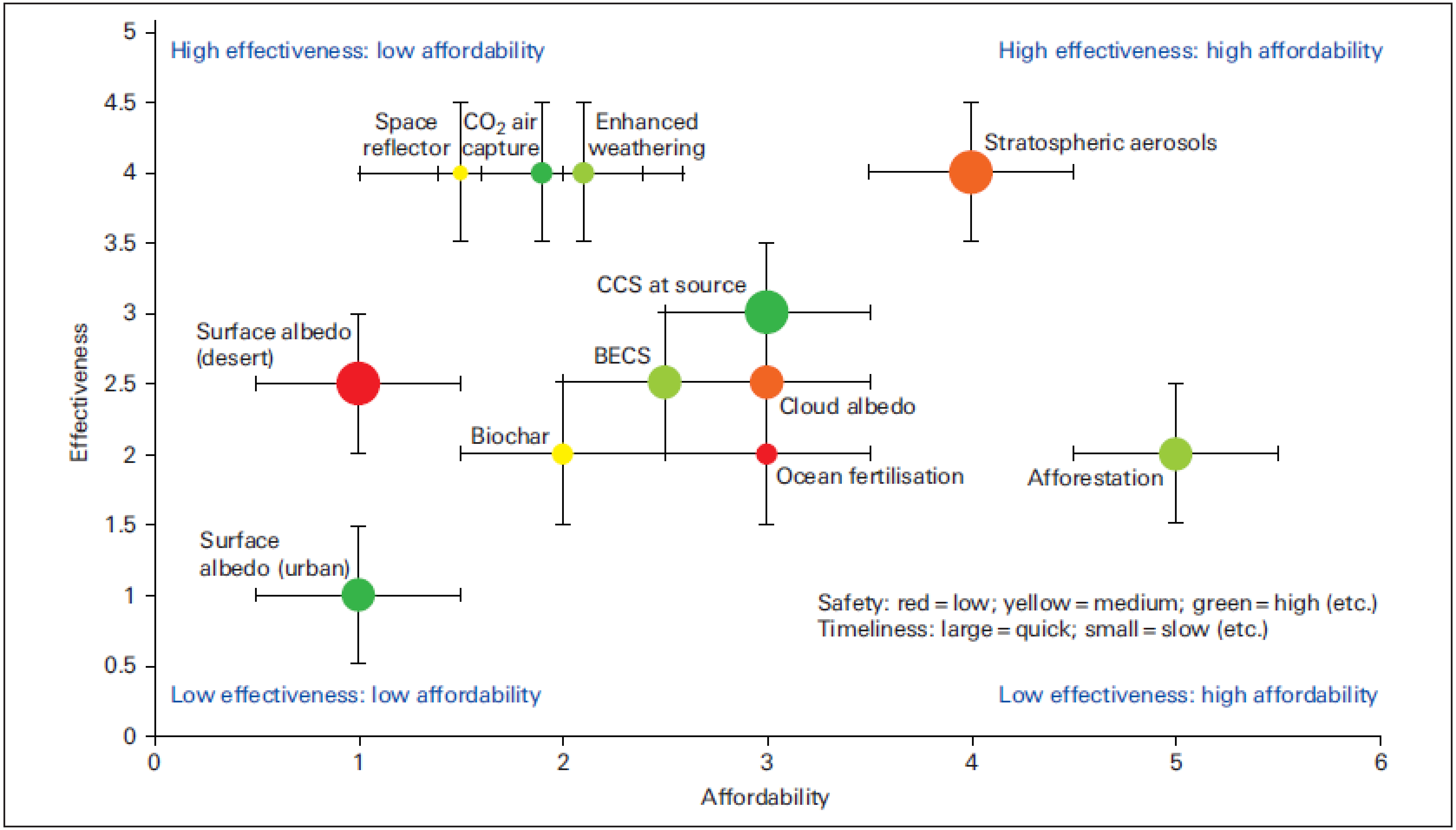
Safety

Costs

Reversibility



Overview of different techniques



Royal Society, 2009

Governance, policy and ethics

Moral hazard:

will thinking of geo-engineering stop mitigation?

Who's in charge of the Earth?

local geo-engineering has global impact

How much does it cost and who will pay?

risks, impact, prevention

Conclusion

Monitor and model the climate system

Mitigate the cause of climate change

Adapt to the consequences of climate change

Geo-engineering, when not fast enough

And organize a governance structure