

Cloud brightening & stratospheric aerosol geoengineering schemes: results from the Hadley Centre climate model

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Outline

What is geo-engineering?

Met Office research in geoengineering

Some personal thoughts



Definition of geoengineering (or climate engineering / planetary engineering / climate intervention)

Geoengineering is usually defined as the **intentional large-scale manipulation** of some element of the Earth system, in an attempt to **counteract anthropogenic climate change**.

Two main categories:

solar radiation management (SRM)

carbon dioxide removal (CDR)

but potentially many other things as well

How does it fit in the wider picture of policy responses to climate change?

Geoengineering

Heat mixing

Transfer heat from the surface to the deep ocean

Transfer heat from the land surface to the deeper layers (e.g. in permafrost)

SW radiation management

Solar reflectors

Scattering / absorbing stratospheric aerosols

Reflective bio-crops

Reflective urban roof

Cloud brightening

Ocean foam

LW radiation management

Suppressing cirrus clouds

Suppressing UT water vapour

Greenhouse gas removal

Methane air capture or conversion to CO₂

Enhancing methane sink in soils

Chemical CO₂ air capture with CCS

Technological CDR

Enhanced weathering

Lime in ocean

Geological CDR

Biochar

Ocean fertilisation

Biological CDR

Many region-specific and sector-specific policies

Adaptation

Climate research

Energy research

Geo-engineering

Improve information basis

Categorisation existing and proposed approaches to climate change

Emissions reductions of short-lived species (BC, O₃ precursors, CH₄)

CO₂ emissions reductions (energy conservation)

CO₂ emissions reductions (nuclear & non-biomass renewables)

Reduced deforestation

Biofuels without CCS

Conventional mitigation

Large-scale reforestation / afforestation

Biofuels with CCS

CCS Fossil-fuel with CCS

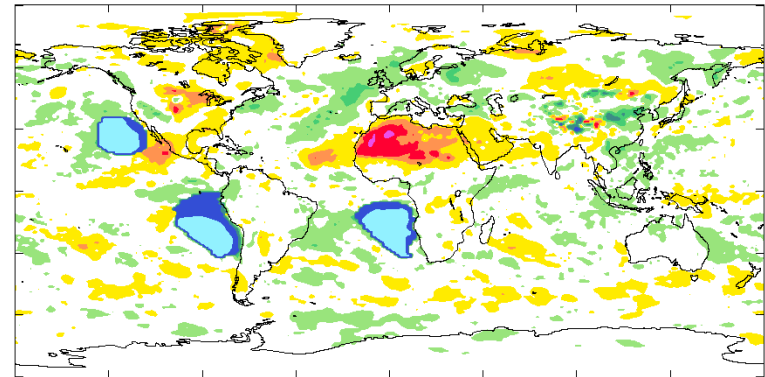


The Met Office has investigated the potential impacts of two geoengineering strategies:

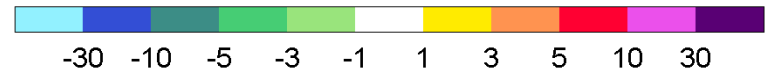
1. Modification of semi-permanent stratocumulus by enhancing the cloud droplet number concentration in the three main stratocumulus sheets (Jones et al., *JGR*, 2009).
2. Stratospheric aerosol injection to enhance the reflection of sunlight back to space (Jones et al., *ACP*, 2010 ; Jones et al., *ASL*, 2011).
3. Design and contribution to the GeoMIP exercise

Radiative Flux Perturbation (\approx radiative forcing)

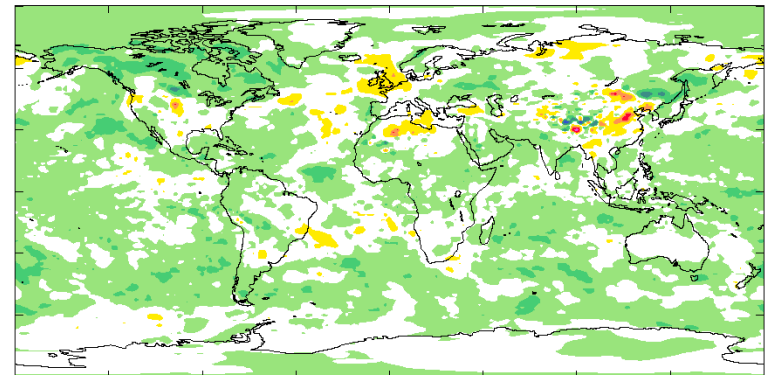
Stratocumulus
forcing: very
inhomogeneous



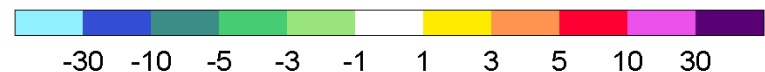
Mean = -0.97 Wm^{-2}



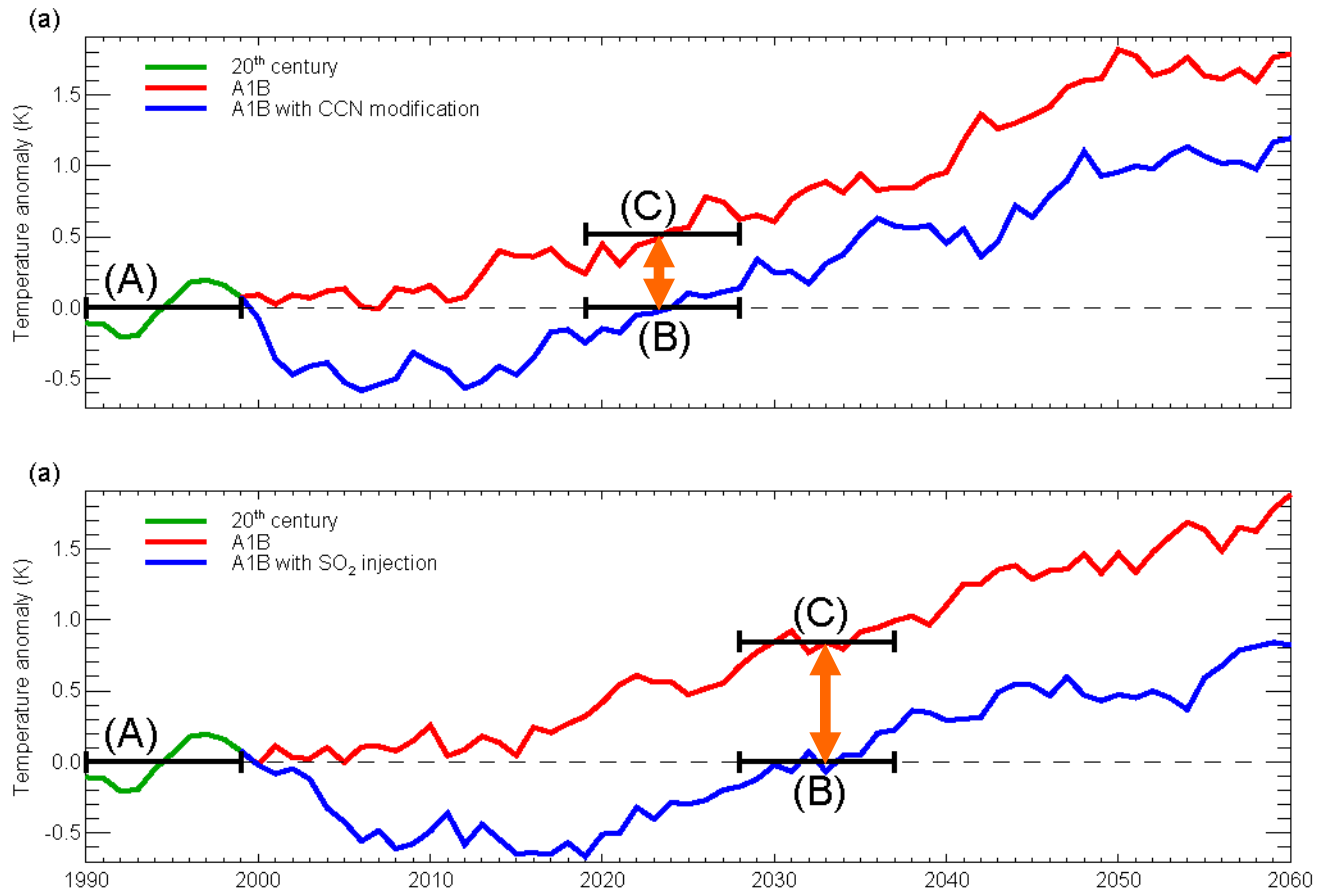
Stratospheric
forcing: fairly
homogeneous



Mean = -1.23 Wm^{-2}



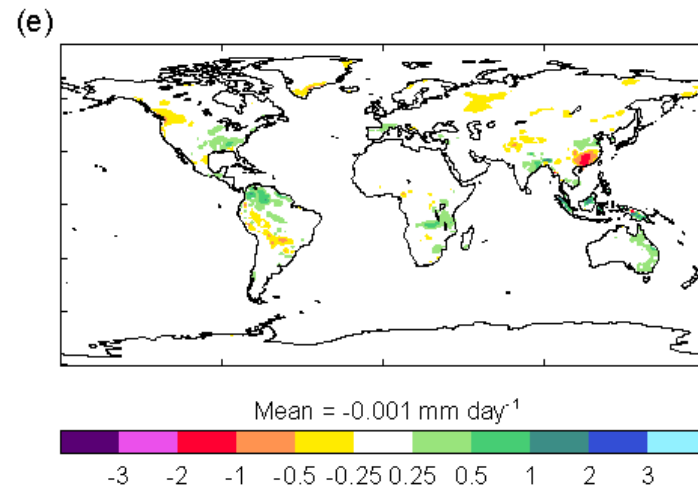
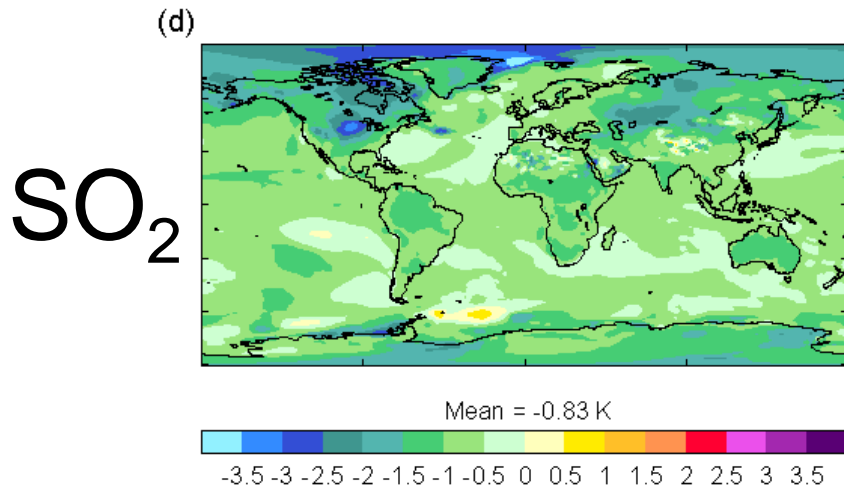
Comparison of the regional response: Impact of geoengineering B-C



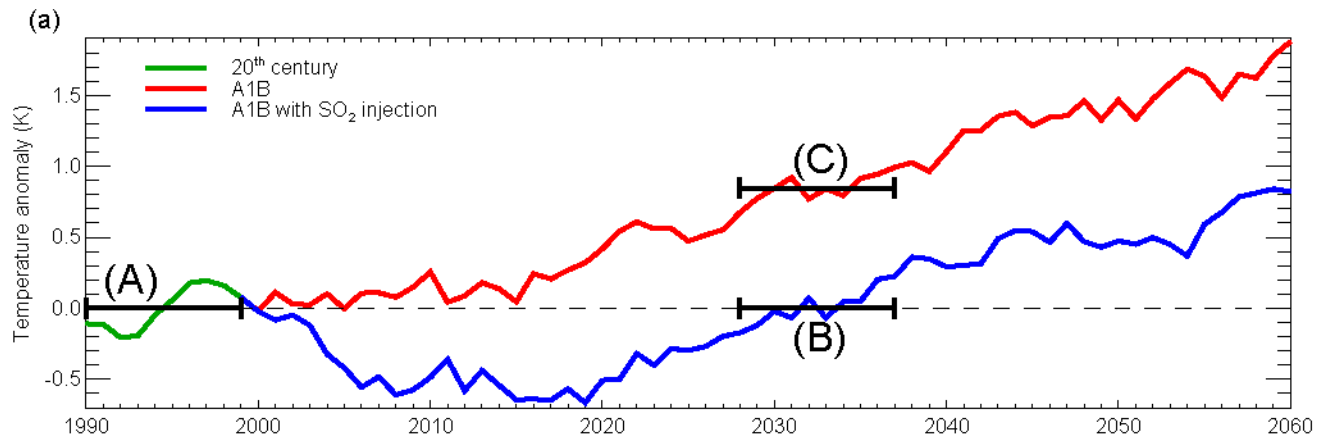
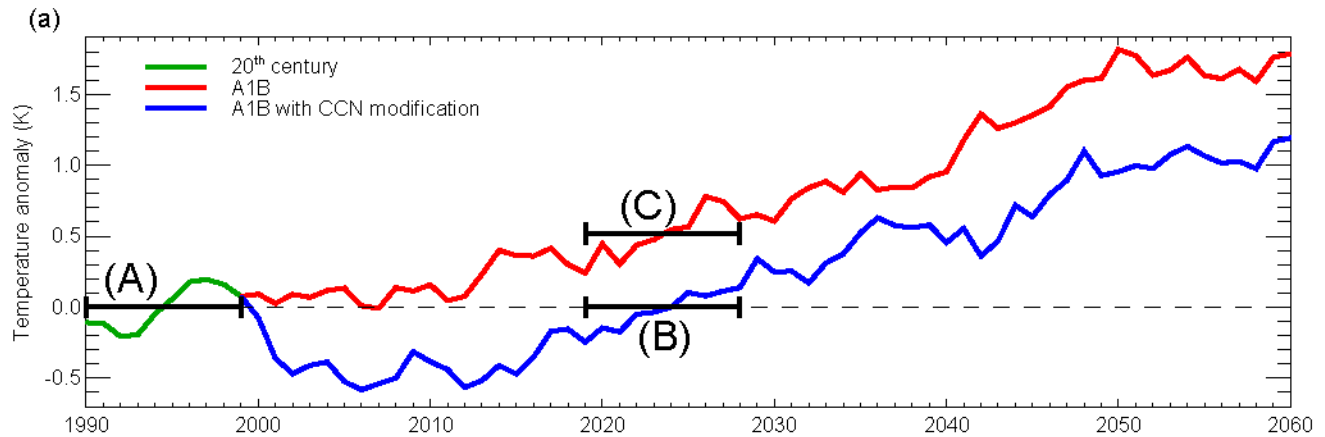
B-C: effectiveness but unintended consequences

Temperature Change (K)

Precipitation Change (mm/day)



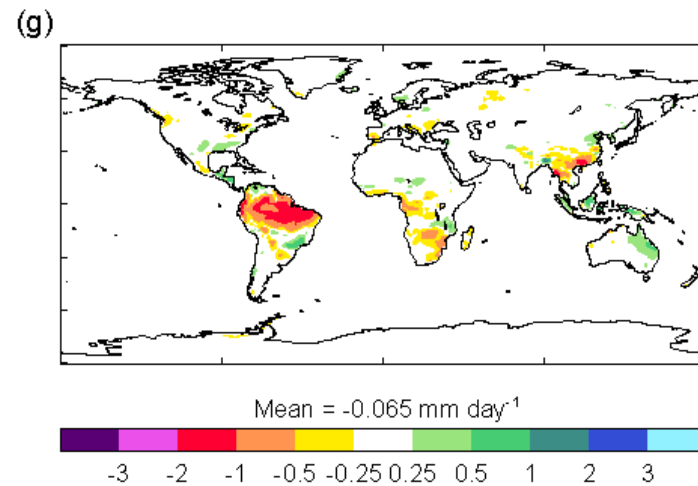
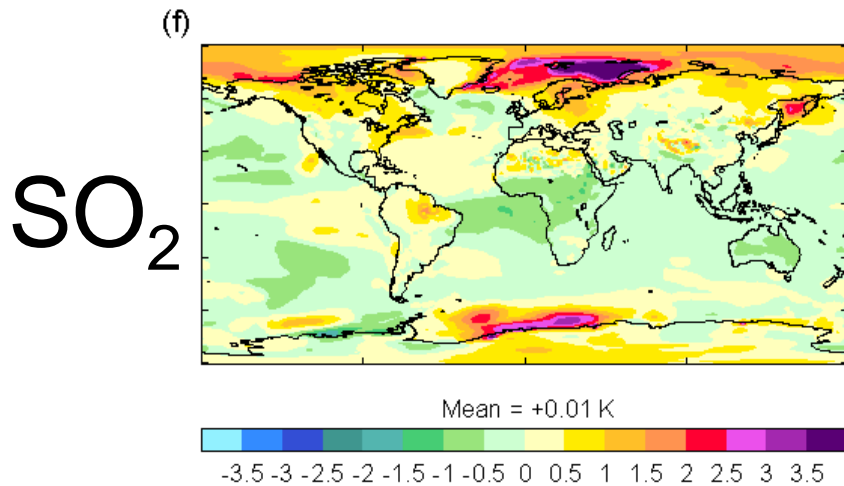
Comparison of the regional response: what would a geoengineered world look like? B-A



B-A: residual impacts

Temperature Change (K)

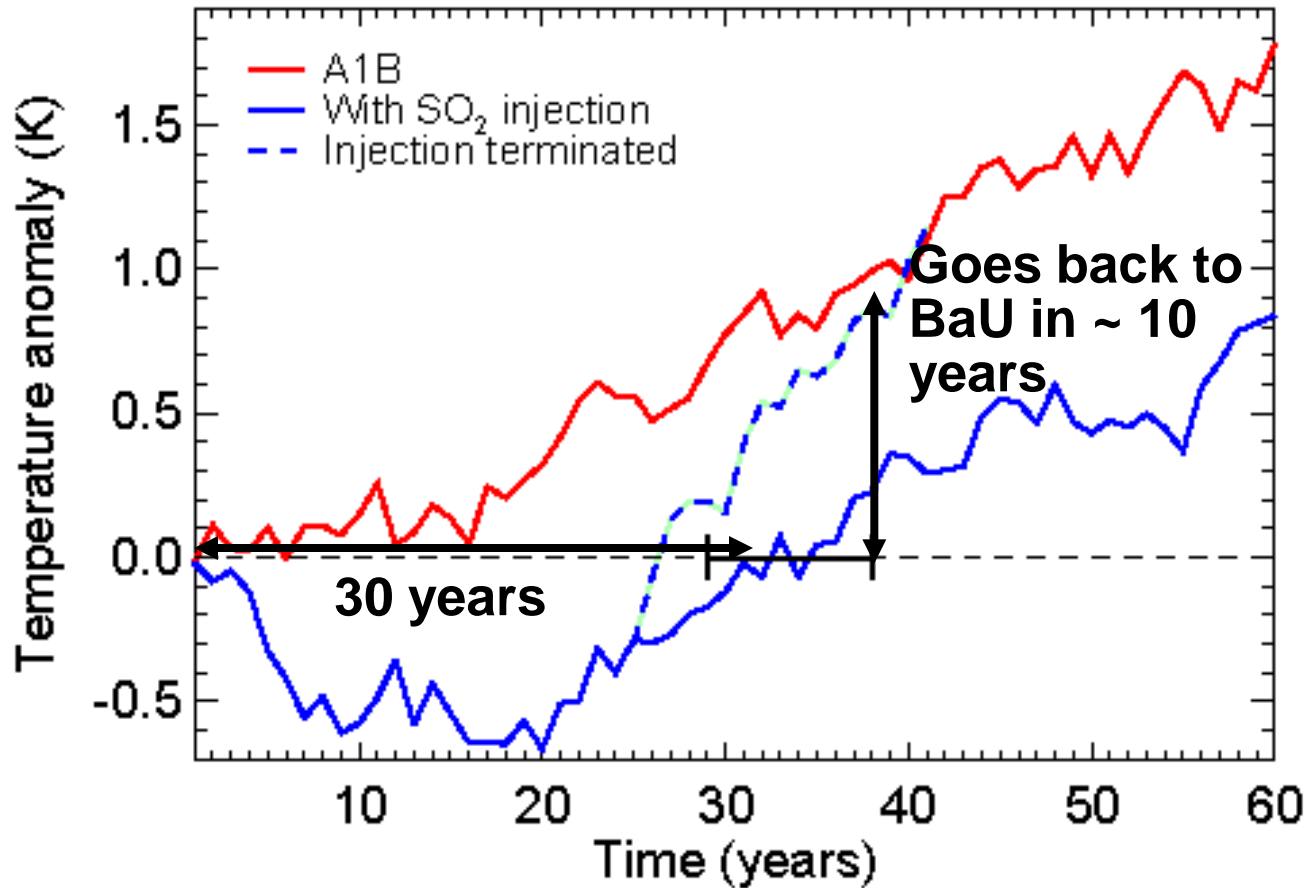
Precipitation Change (mm/day)



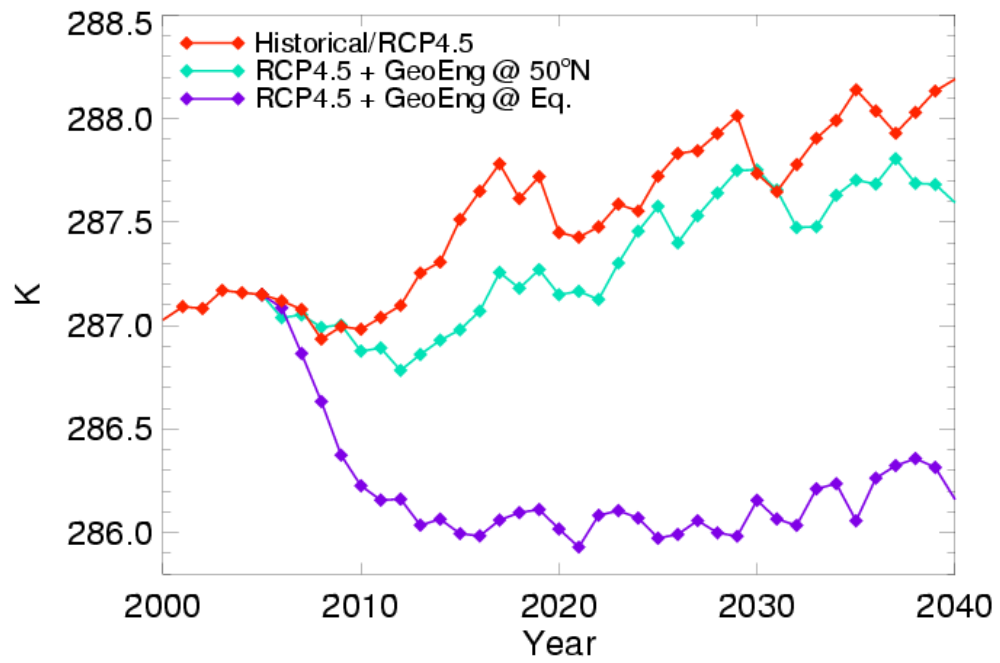
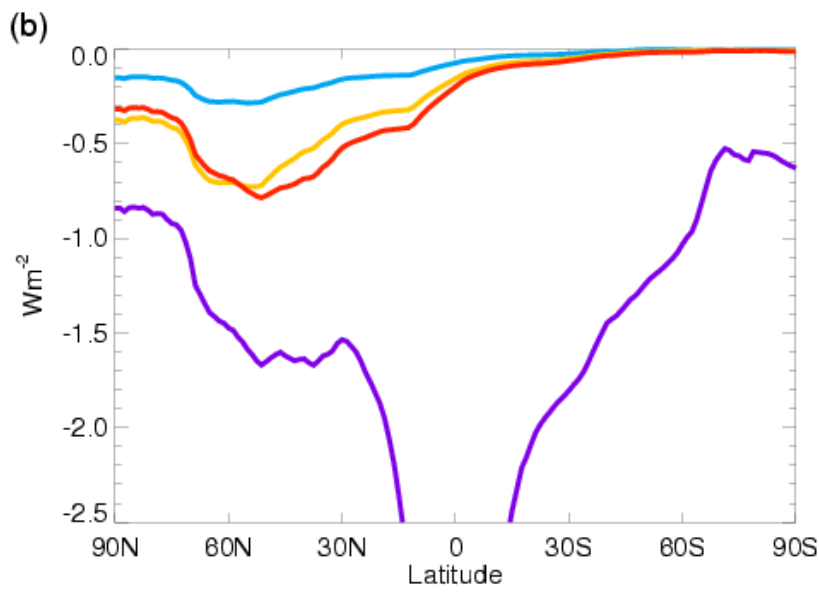
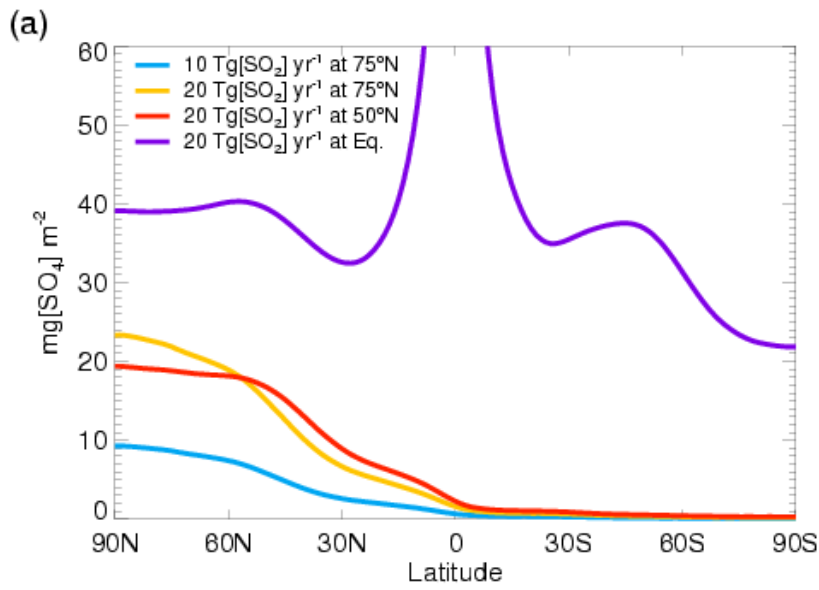
Climate simulations: stratospheric SO₂ injection

Control (BaU), GEO, GEO off at 2025

(a)



Effectiveness of injecting SO_2 at different latitudes





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GEOMIP experiments

HadGEM2-ES Earth System model

- ocean / atmosphere / sea-ice
- terrestrial and oceanic ecosystems
- aerosols and tropospheric chemistry

N96L38 resolution, CO₂ physiological forcing

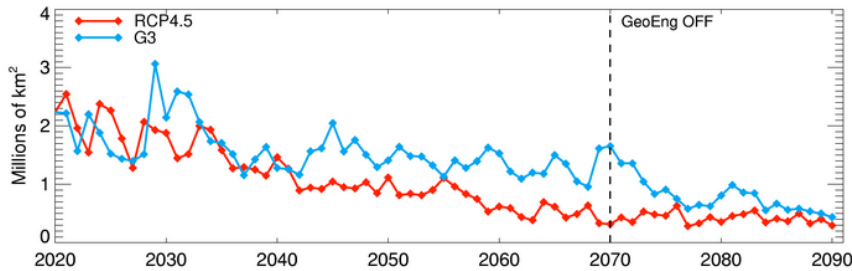
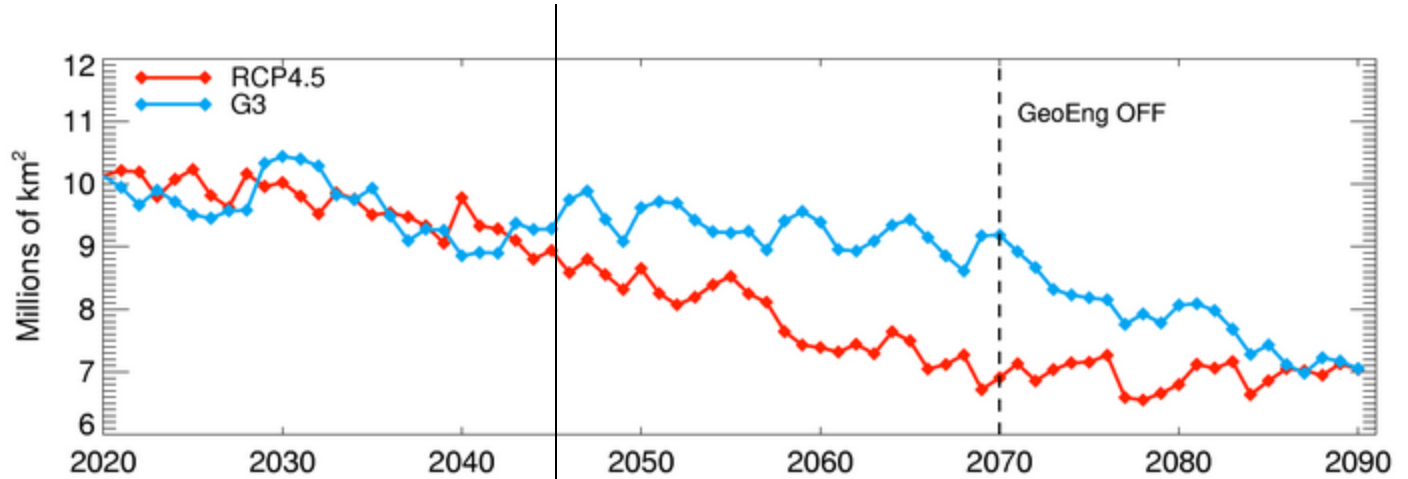
G1: 4xCO₂ RF+Earth's albedo => S reduction

G2: S reduction estimated from G1

G4: fixed and uniform injection rate of SO₂

G3: diagnosed RF at 10 yr intervals relative to 2020
and adjusted injection rate accordingly to offset RF

Change in Arctic sea-ice

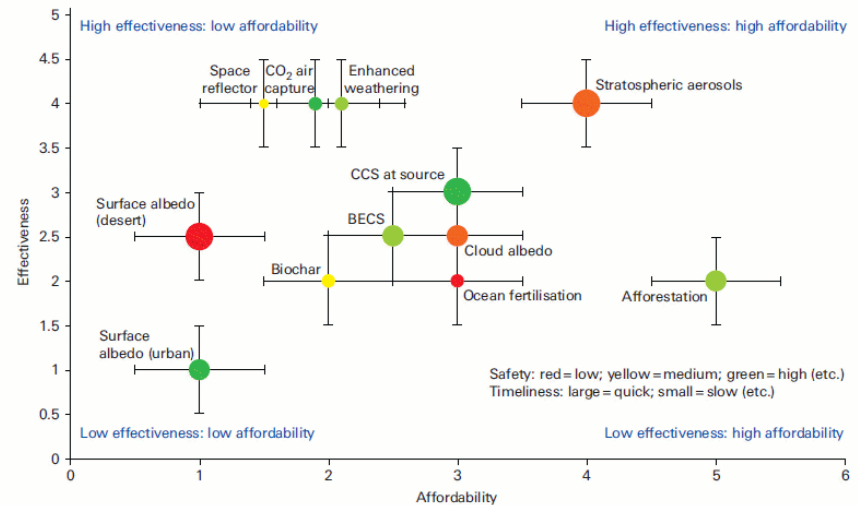


In G3 it wouldn't be possible to tell that geoengineering has a positive impact on Arctic sea ice before 2050.

Personal thoughts

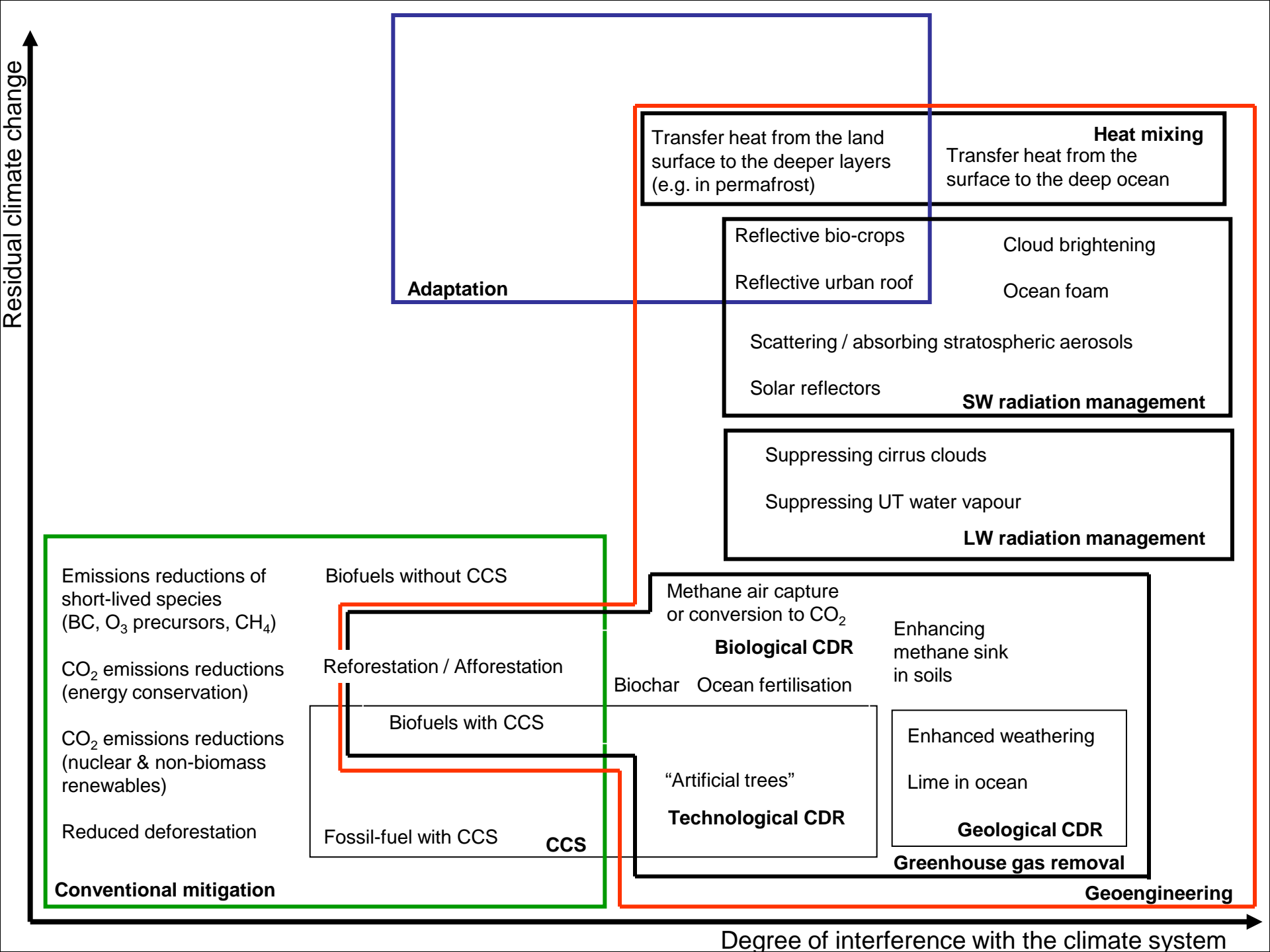
One has to consider all pluses and minuses of geoengineering vs other policies:

- technological maturity
- effectiveness
- scalability
- timescale for implementation
- associated risks
- residual climate change
- unintended consequences
- degree of interference with the climate system
- policy and governance challenges
- affordability / cost



Cost-benefit framework

Risk analysis framework



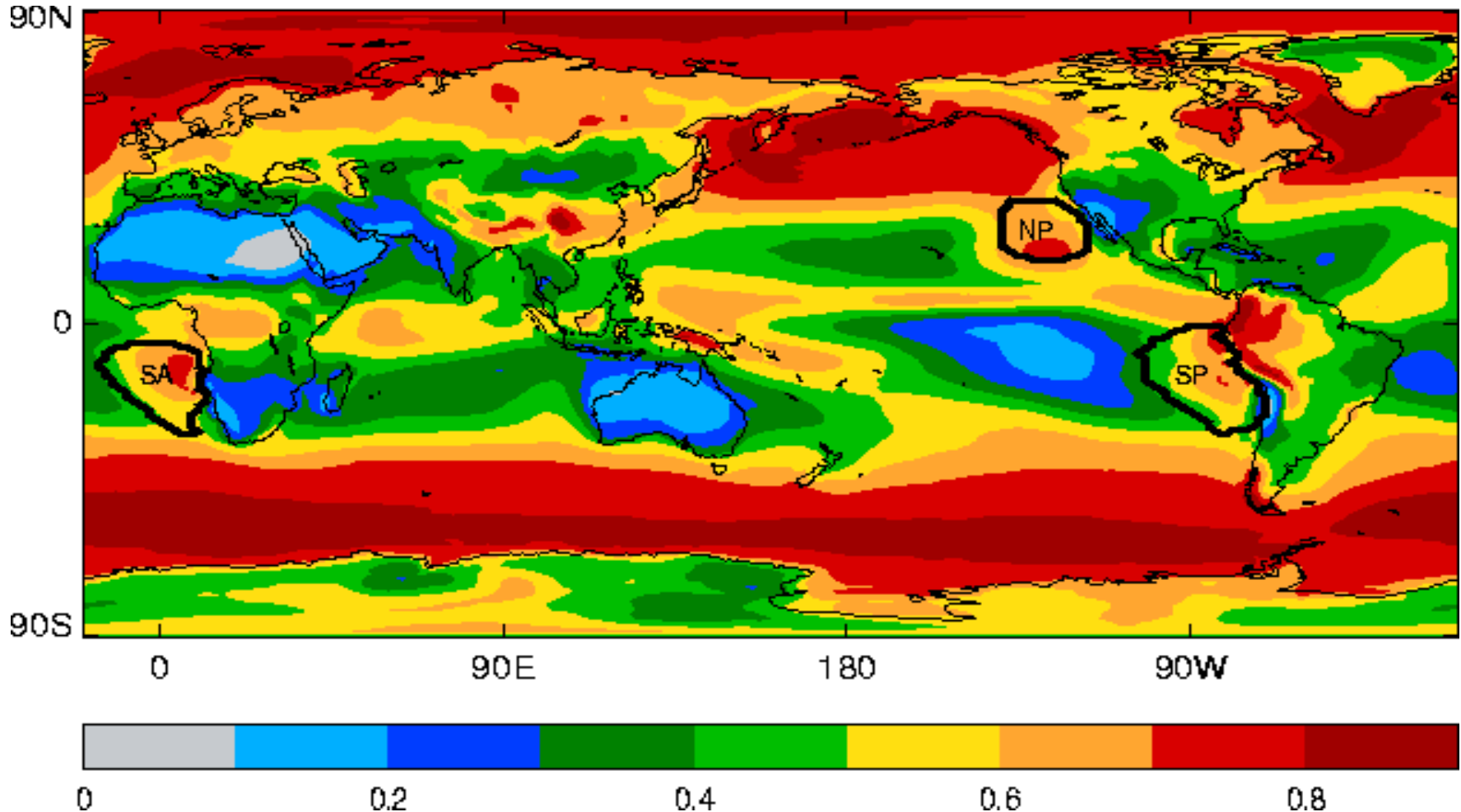


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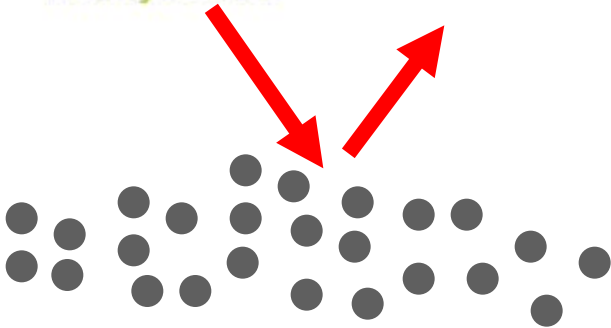


Questions

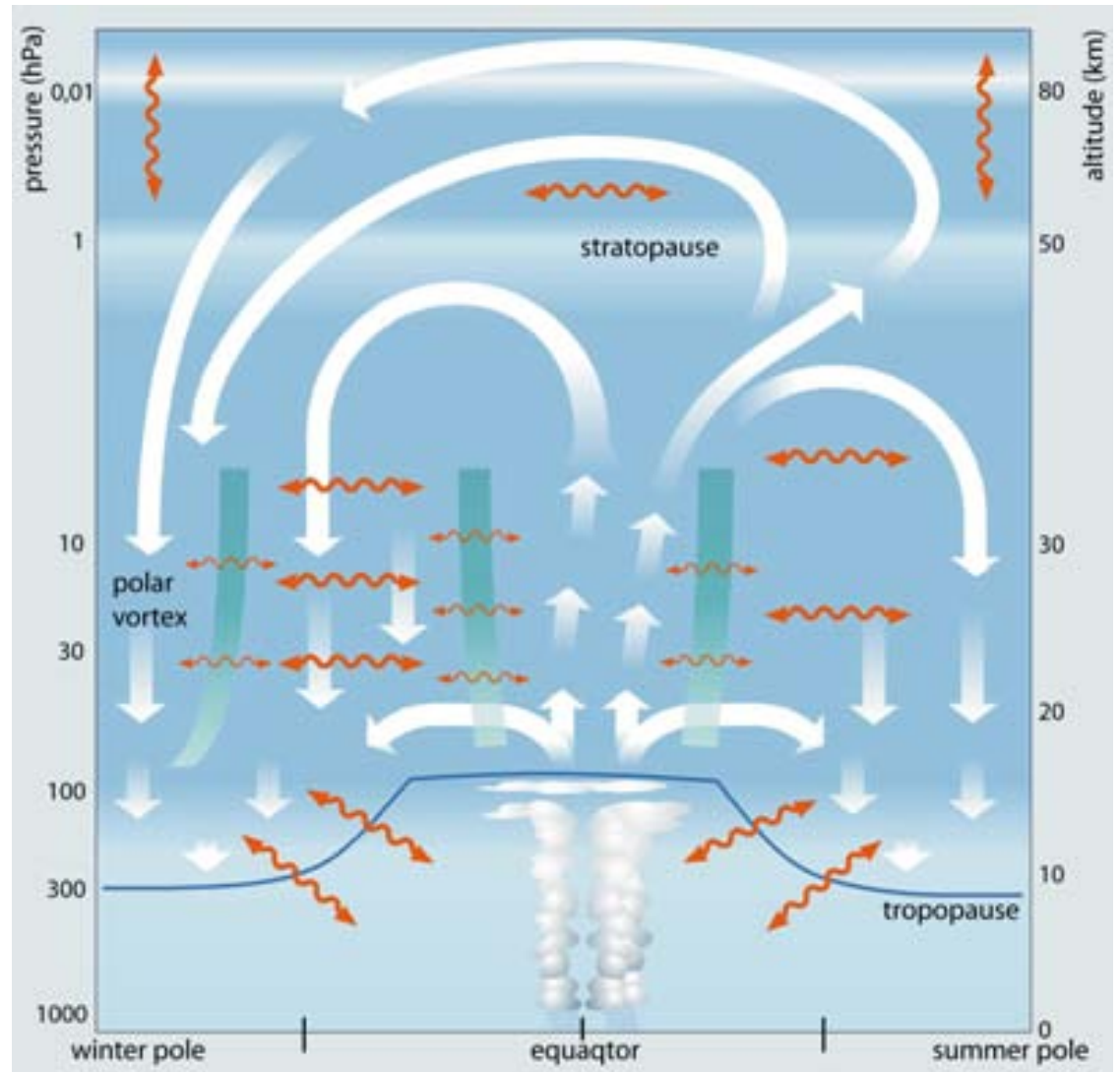
Climate simulations with stratocumulus clouds brightened: shows the cloud fraction



Stratospheric aerosols

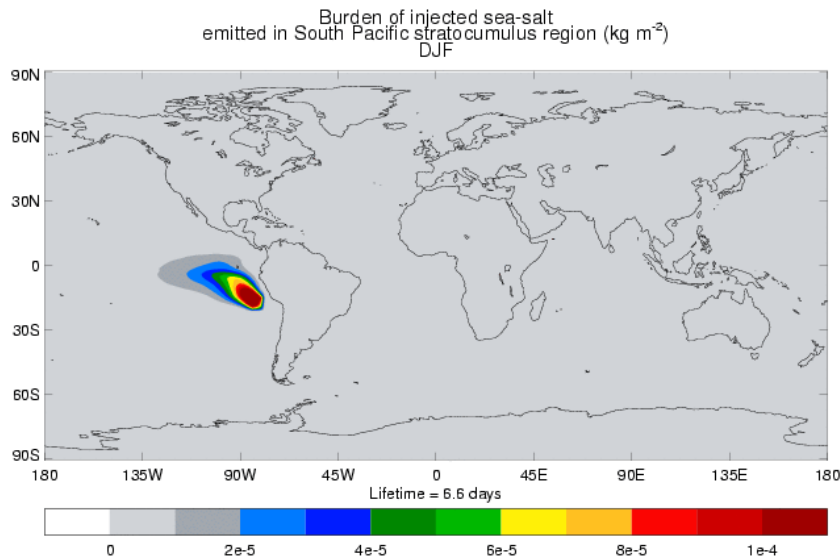


- Uniform injection rate of SO_2
- Point injection to test sensitivity to height, latitude and phase of the QBO

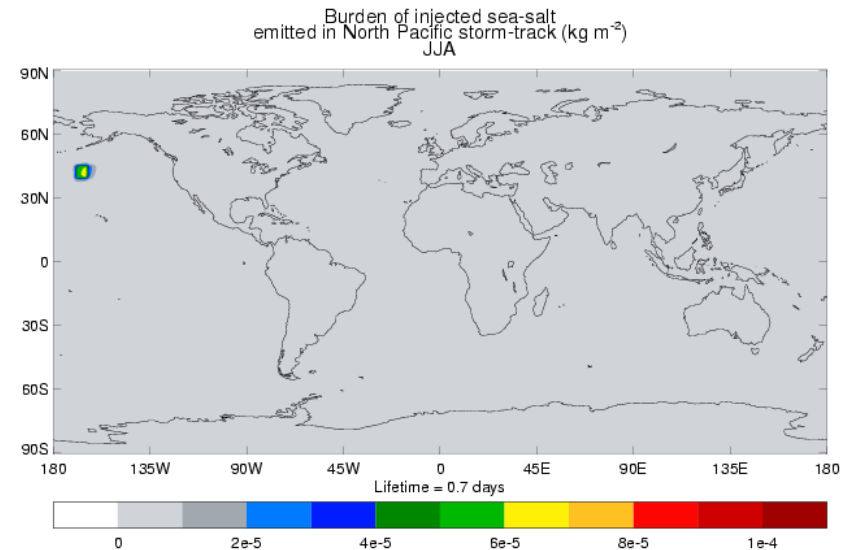


Residence time of sea-salt aerosols

This is important and relevant for all the modification of cloud studies to date (e.g. Jones et al., Rasch et al., 2009) because they all simply perturb the CCN.



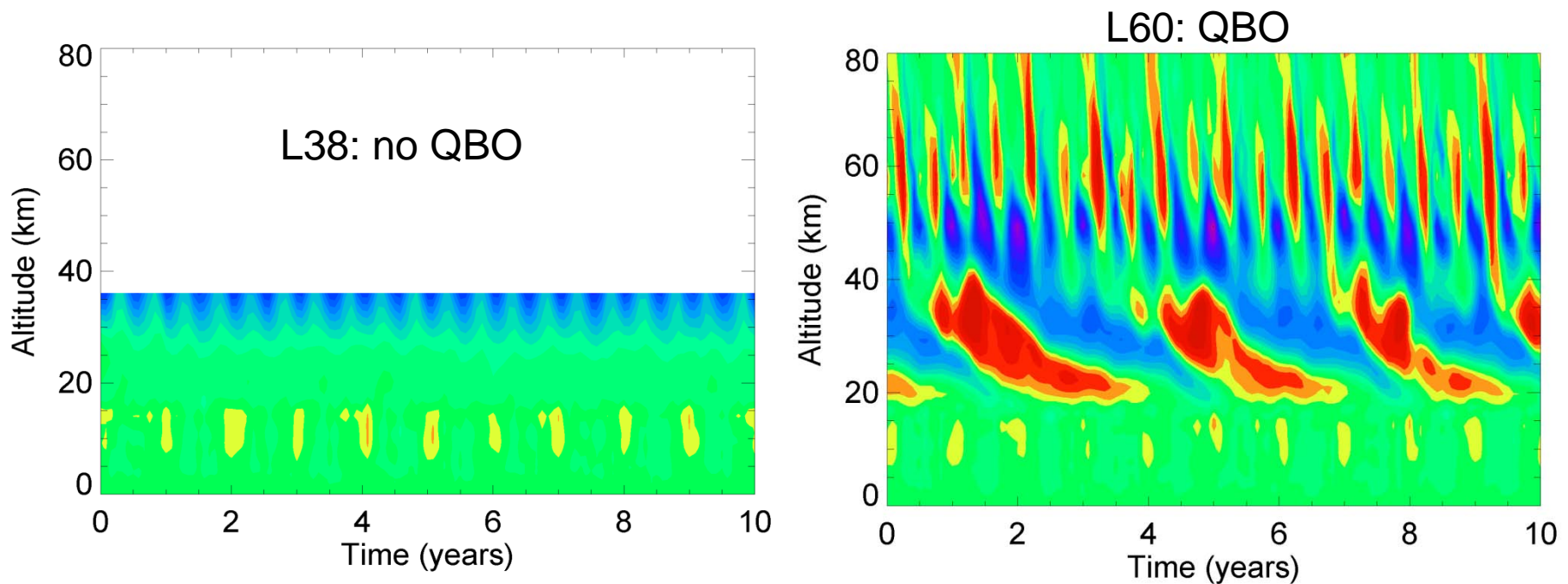
6.6 days



0.7 days

The stratospheric injection of SO₂ was uniform to get round limitations of stratospheric dynamics.

Mean zonal wind (contour interval 5ms⁻¹):



Easterlies, westerlies. Only in westerly phase is their significant transport from the tropics

