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Modifications of cirrus clouds in a geoengineering framework.

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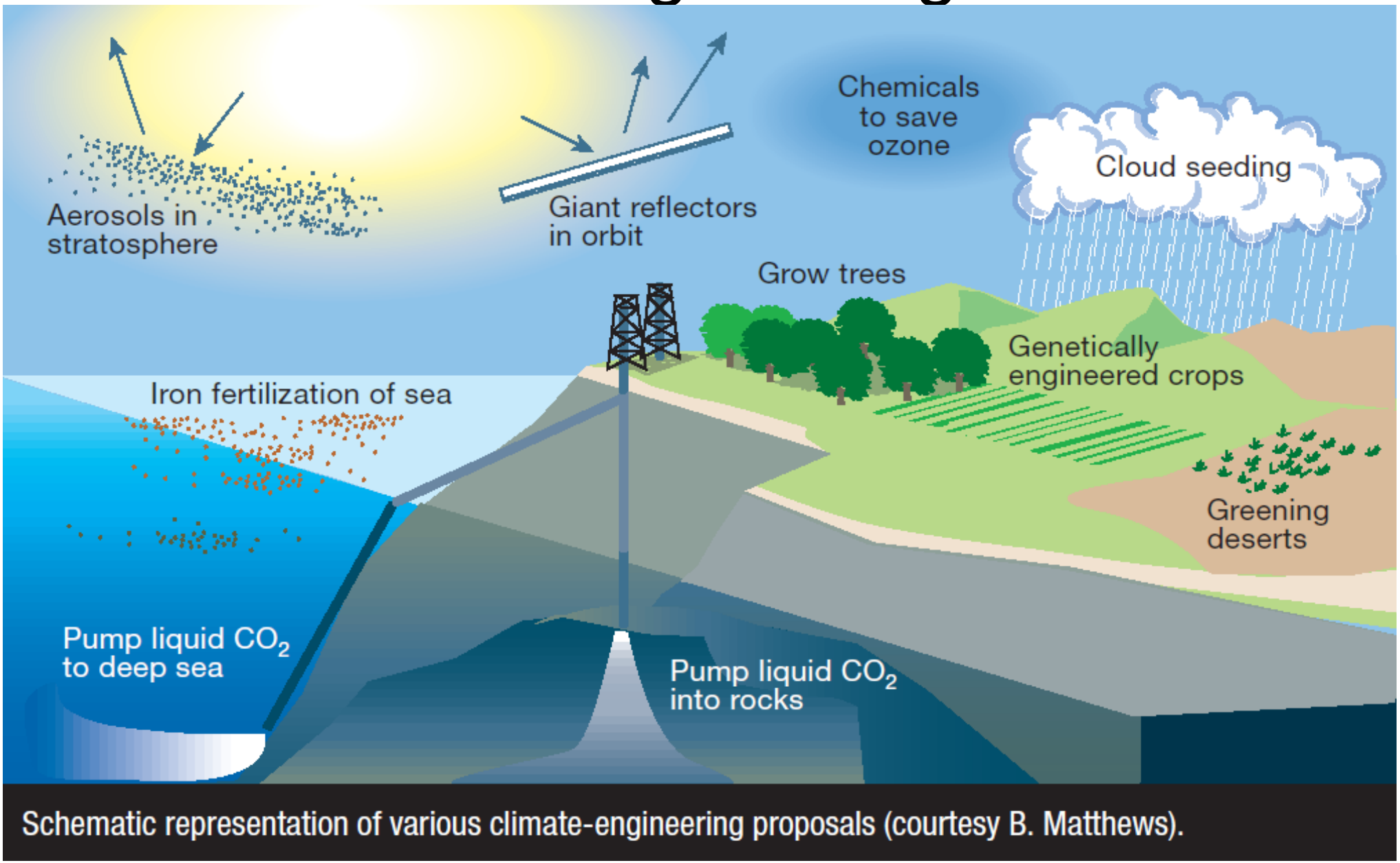
Geoengineering:

- Involves deliberately modifying the climate.
- Fixes the climate symptoms, but not necessarily the underlying problem.
- If ever employed, probably alongside adaptive and mitigation measures.
- Viewed as a last resort by some or an excuse to keep emitting CO_2 by others.
- Raises ethical, political and jurisdiction issues
  - i.e. a wasp's nest ...

Geoengineering methods

- CDR – Carbon Dioxide Removal
- SRM – Solar Radiation Management
  - Space reflectors
  - Stratospheric sulphur injections
  - Brightening of marine clouds
- TRM – Thermal Radiation Management
  - Removal of high, cold cirrus clouds

Geoengineering



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

TRM: Cirrus cloud seeding

- Idea: inject highly efficient ice nuclei into cirrus forming regions.
- Create competition effect between homogeneous and heterogeneous ice formation.
- Larger and heavier ice crystals can form
  - Ice cloud depletion
- Removal of longwave trapping cirrus and upper tropospheric water vapour.

Homogeneous vs. heterogeneous freezing

- At T< -40ºC:
  - Homogeneous freezing of haze droplets occurs at a supersaturation higher than 50% w.r.t. ice.
  - Heterogeneous freezing requires a lower supersaturation and can therefore more freely happen.
    - Depletes water vapour before homogeneous freezing can occur.
    - Creates larger and heavier ice crystals that fall out of the cloud.

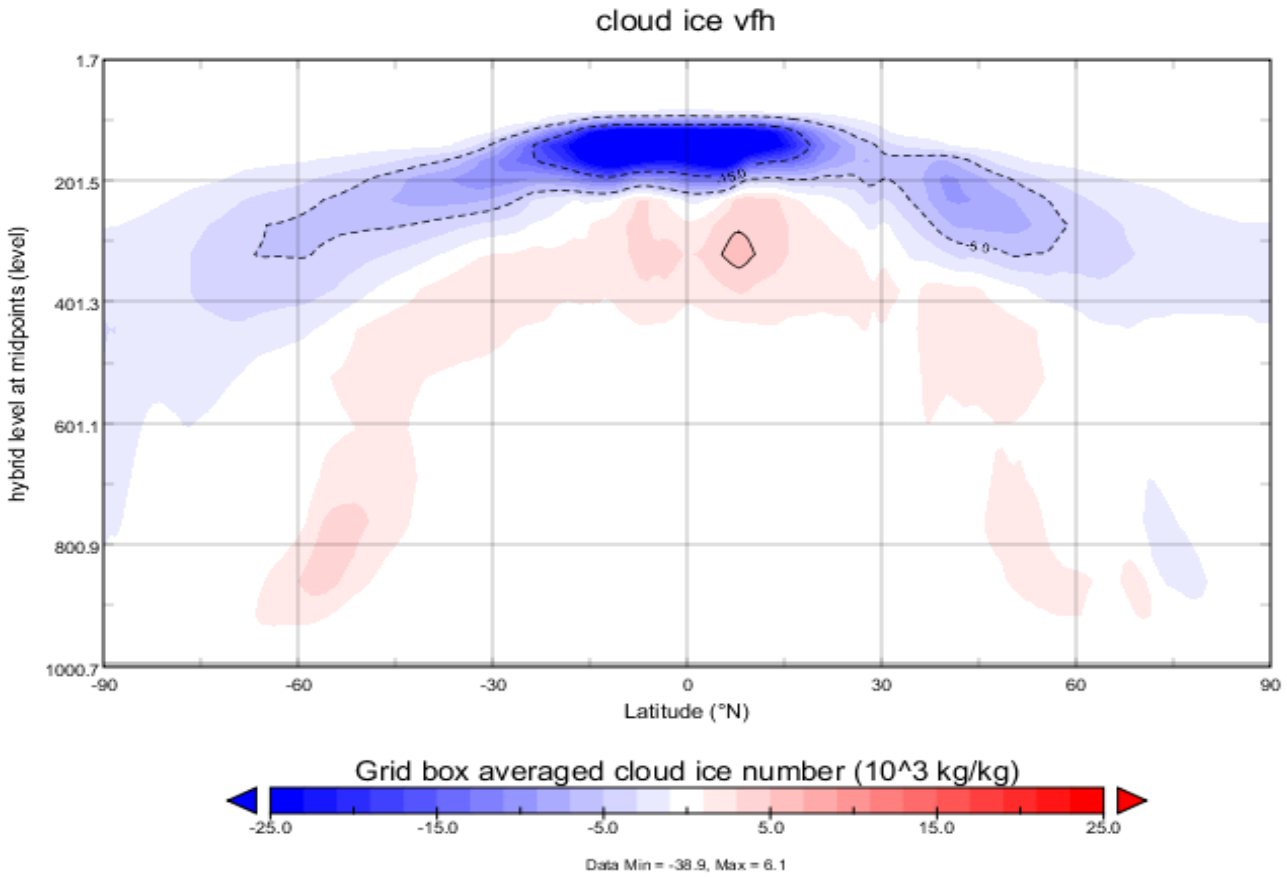
Cirrus cloud seeding

- Suggested seeding material:
  - Bismuth tri-iodide, BiI_3
  - Cheap'ish and non-toxic.
- Seeding via commercial airliners?
- Advantage: seeding aerosol residence time is relatively short in the troposphere.
- Drawback: does not address ocean acidification issue.

Model experiments

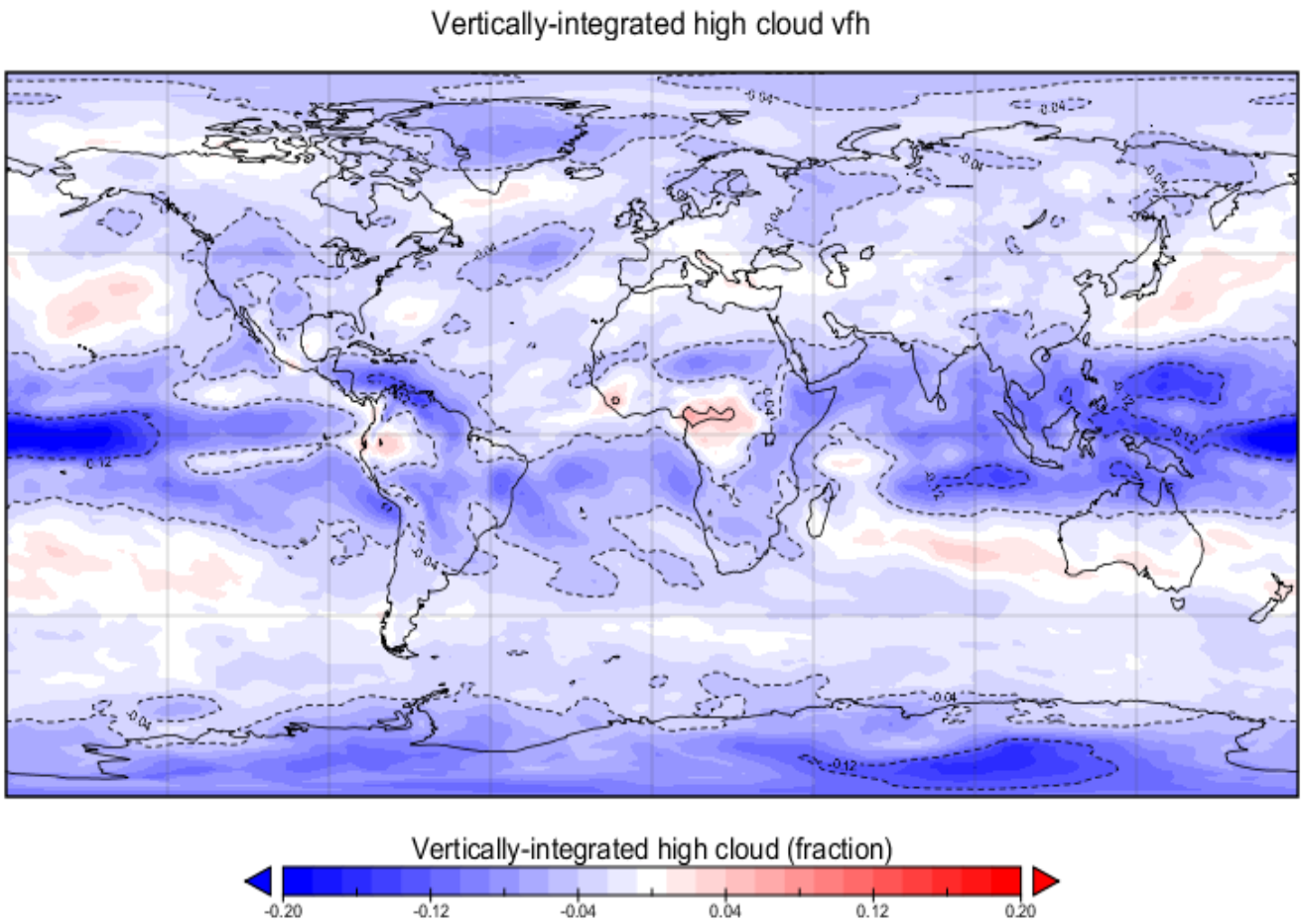
- CESM1_0_3:
  - CAM5 coupled to slab ocean, with CLM4 land model and CICE sea ice model.
  - 0.9 x 1.25º lat x lon resolution.
  - 30 vertical levels, 20 minutes time step.
  - Liu & Penner ice parameterisation.
- Year 2000 time slice
- Ice fall speed perturbation as analogy to seeding.
  - Ice fall speed doubled as a sensitivity test.
  - v=aD^b

Cloud ice



High cloud ice fall out.
Aggregation leads to more snow flakes lower down.

High cloud amount



Reduction in high clouds

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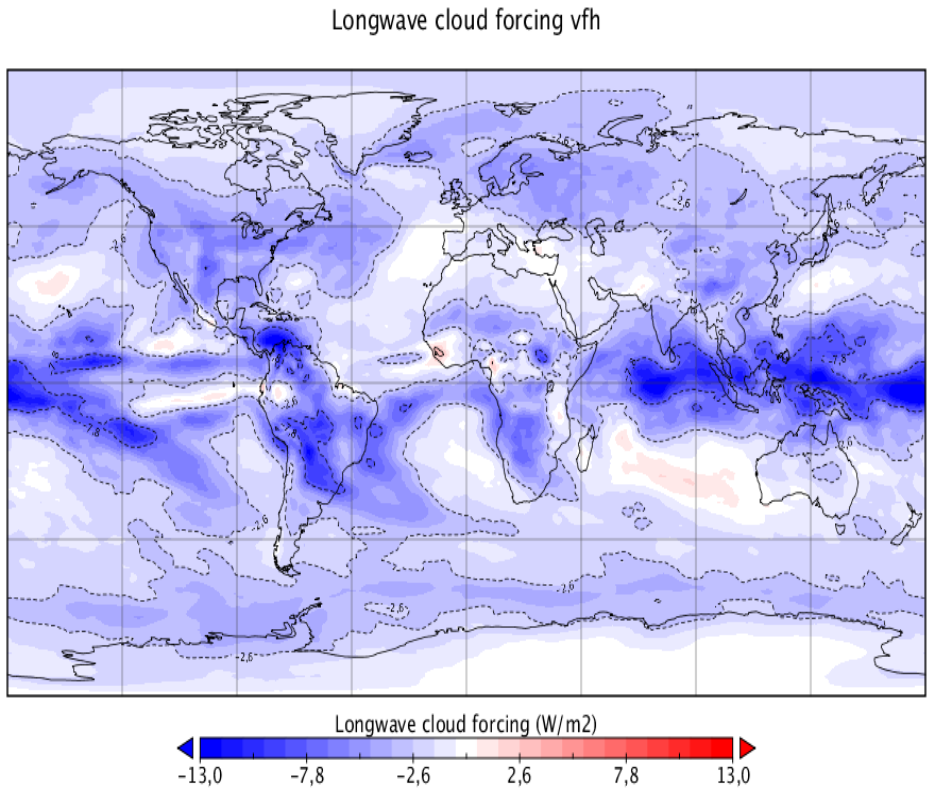
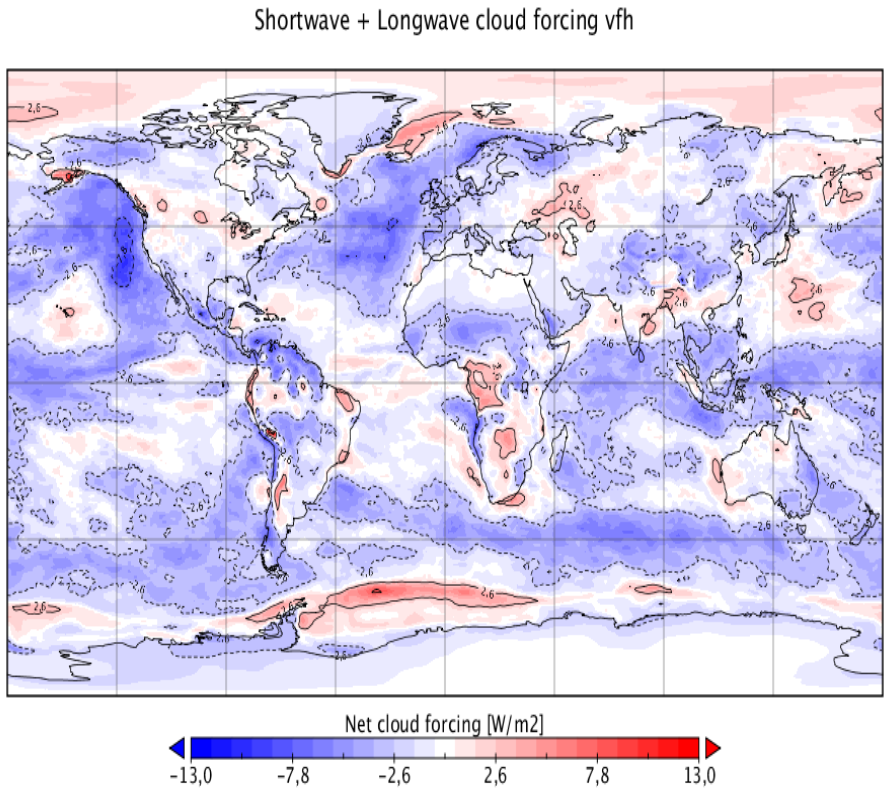
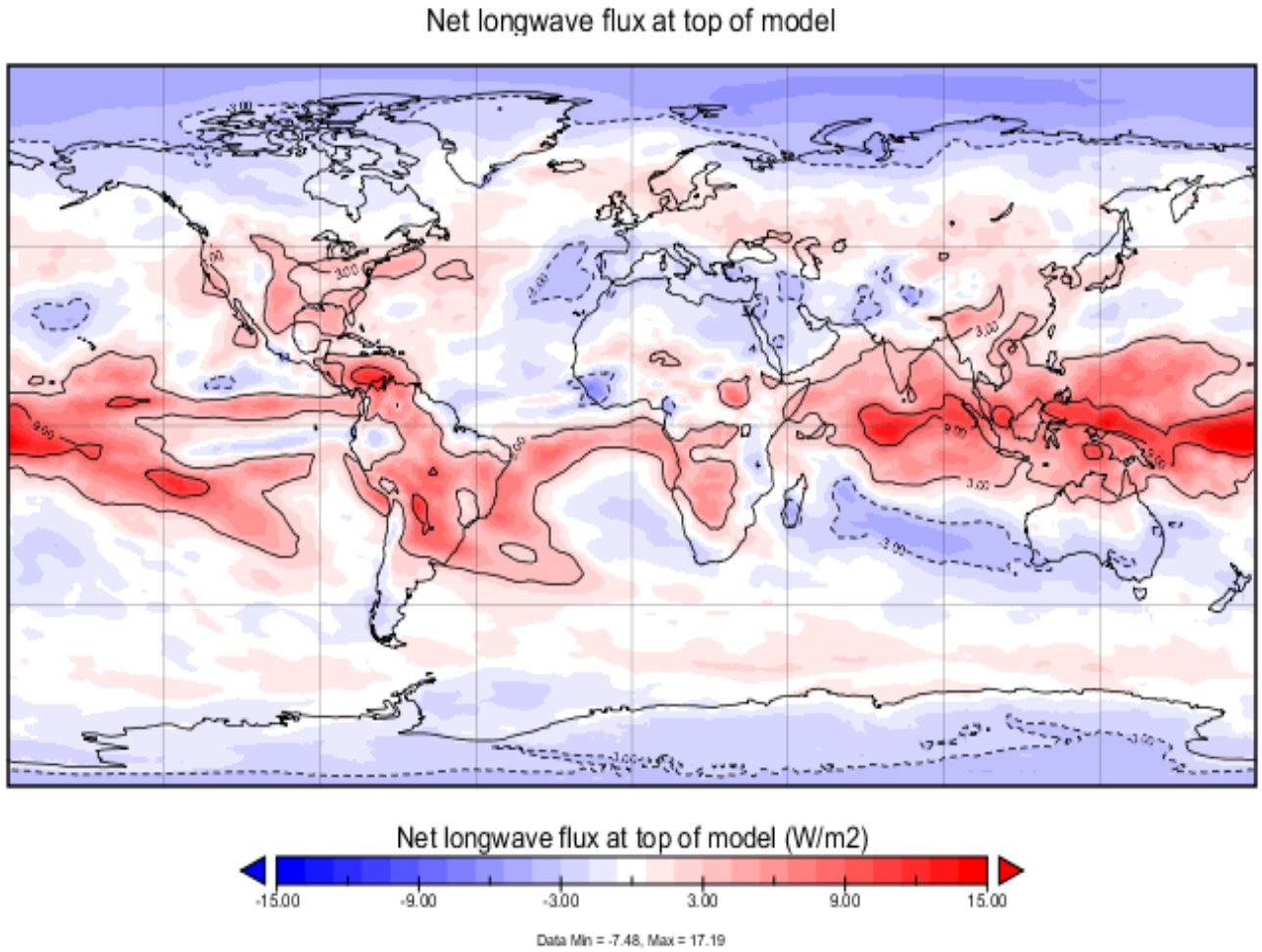
Cloud forcing





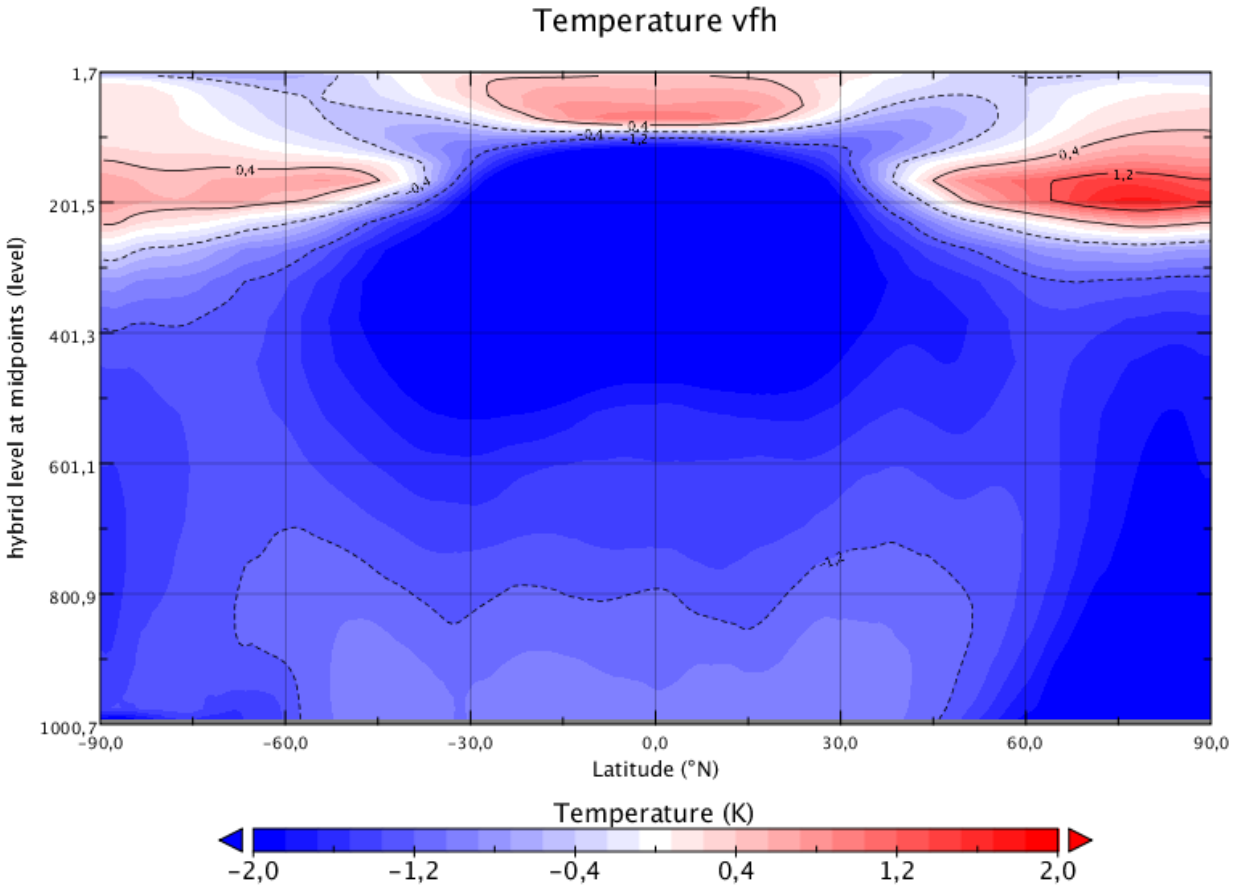
Reduced longwave cloud forcing (-3.3Wm^{-2}). Dominates the net cloud forcing.

TOA LW flux



Increase in OLR

Temperature



Tropospheric cooling.

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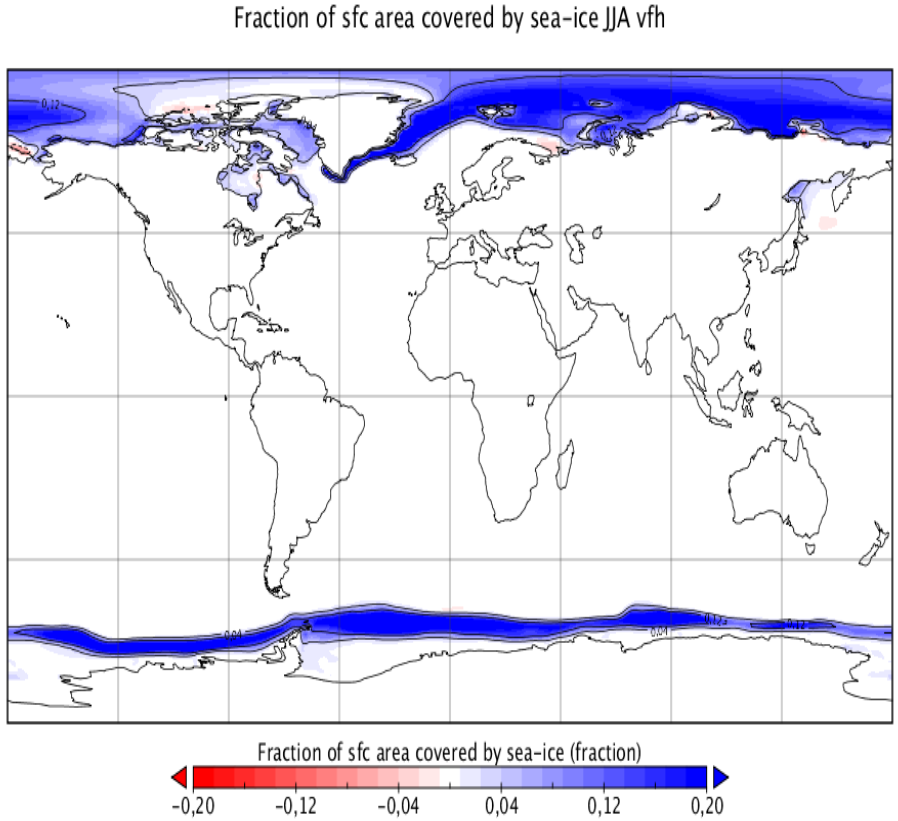
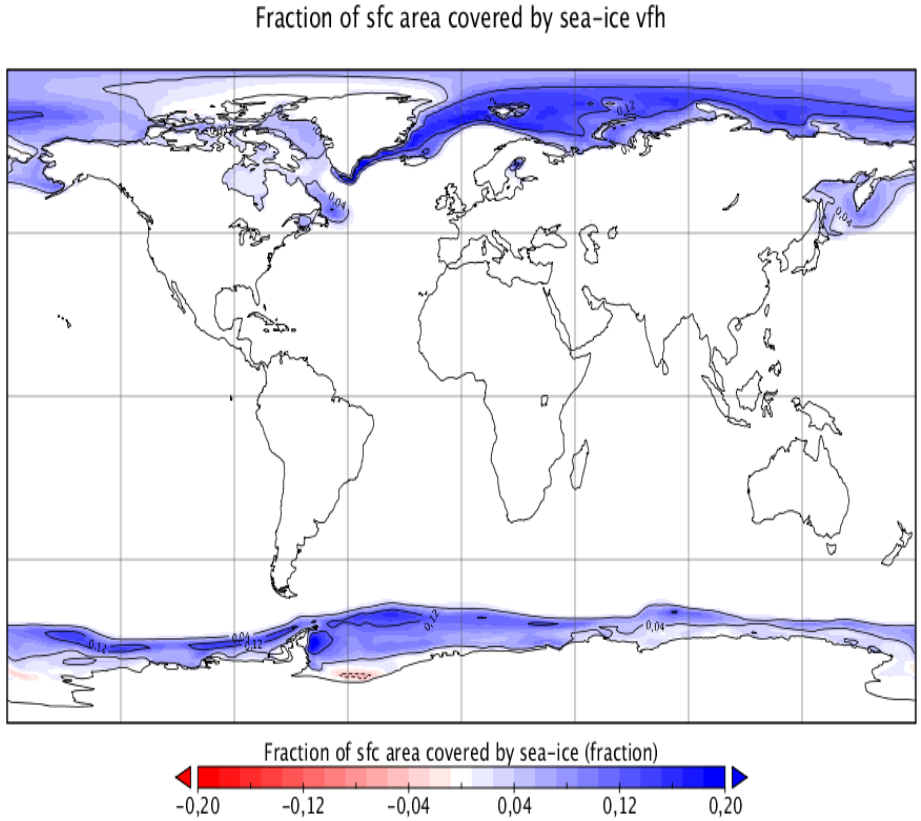
Sea ice fraction

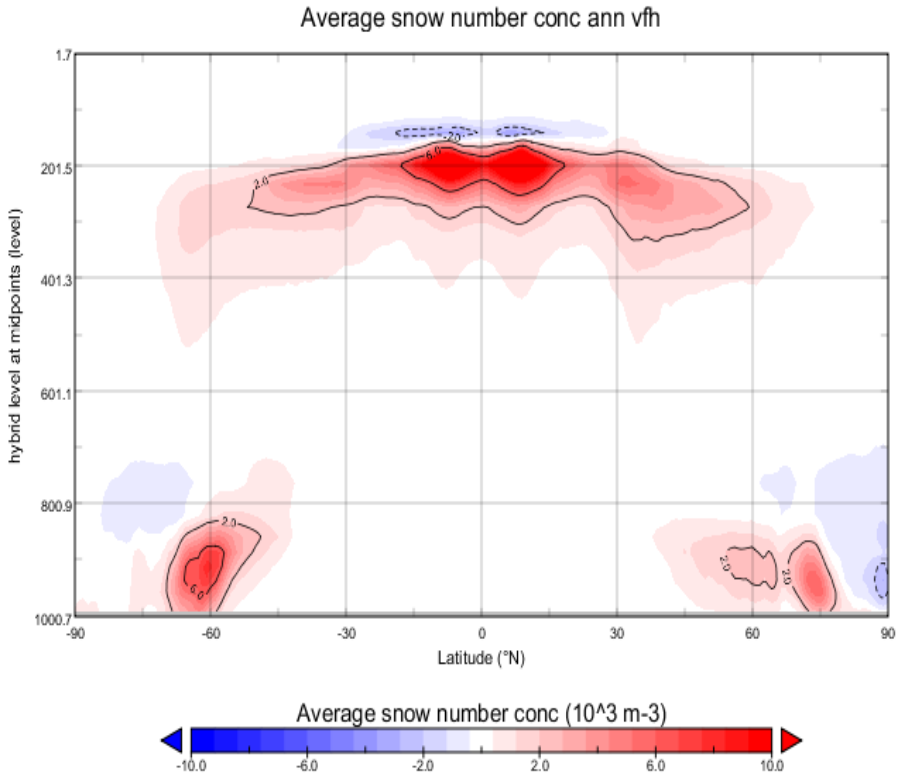




JJA and annual mean sea ice recovery.

Last words

- Simple sensitivity tests show that cirrus seeding should be considered alongside the other options.
- Could have potential to cool atmospheric temperatures and relieve the Arctic sea ice conditions.
- Geoengineering needs to be tested thoroughly in theory before practice.


Average snow number conc ann vfh
hybrid level at midpoints (level)
1.7
201.5
401.3
601.1
800.9
1000.7
-90
-60
-30
0
30
60
90
Latitude (°N)
Average snow number conc (10^3 m-3)
-10.0
-6.0
-2.0
2.0
6.0
10.0