Global Temperature Stabilisation via Cloud Albedo Enhancement

Geoengineering Options to Respond to Climate Change

(Response to National Academy Call)

Philip Rasch[1], C-C (Jack) Chen[2] & John Latham [3]

[1]Pacific Northwest National Laboratory, 902 Battelle Boulevard, P. O. Box 999,
MSIN K9-34, Richland, WA, 99352 (philip.rasch@pnl.gov)
[2]CGD Division, NCAR, Boulder, P.O. Box 3000, Boulder, CO., 80307-3000, USA (cchen@ucar.edu)
[3]MMM Division, NCAR, Boulder, P.O. Box 3000, Boulder, CO., 80307-3000, USA
SEAES, University of Manchester, PO Box 88, Manchester M60 1QD, UK (latham@ucar.edu)

Summary

The geo-engineering idea we are investigating is to increase, in a controlled way, the albedos of shallow oceanic clouds, by seeding them with seawater aerosol to increase their droplet number concentration: thereby producing a cooling sufficient to balance global warming. This technique, together with assessments of it from modelling and (to a lesser extent) observational work are summarised below. The provisional conclusion – subject to resolution of specific problems – is that it could hold the Earth's temperature constant as the atmospheric CO2 concentration continues to rise to at least twice the current value. Preliminary results from computations involving a fully-coupled atmosphere/ocean GCM are that maintenance of current values of Arctic ice cover is achievable. The ramifications of possible deployment of this technique are also under examination.

1. The Cloud Albedo Enhancement Geoengineering Scheme

Atmospheric clouds exercise a significant influence on climate. They can inhibit the passage through the atmosphere of both incoming, short-wave, solar radiation, some of which is reflected back into space from cloud-tops, and they intercept long-wave radiation flowing outwards from the Earth's surface: a global cooling, and warming respectively. On balance, clouds produce a cooling effect, which we propose (Latham, 1990, 2000: Bower et al. 2006, Latham et al. 2008) to accentuate by increasing the reflectivity of the marine stratocumulus clouds that cover about a quarter of the oceanic surface. These clouds characteristically reflect between 30% and 70% of the sunlight that falls upon them. They therefore produce significant global cooling. A further 10% increase in reflectivity – which we hope to achieve via cloud seeding - would produce an additional cooling to roughly balance the warming resulting from atmospheric CO2 doubling.

The reflectivity increase could be achieved by seeding these clouds with seawater particles sprayed from unmanned, wind-powered, satellite-guided Flettner-rotor vessels (Salter et al. 2008) sailing underneath the clouds. These particles would be about one micrometer in diameter at creation and would shrink through evaporation as about half of them are carried by turbulence up into the clouds, where they act as centres for new droplet formation, thereby increasing the cloud droplet number concentration and thus the cloud reflectivity (and possibly longevity). In this way the clouds would reflect more sunlight back into space, possibly for a longer time, and so planetary cooling occurs. The global seawater volumetric spray-rate required to produce a cooling sufficient to balance the warming associated with CO2-doubling is estimated to be around 50 cubic metres per second. More information on technological aspects of this idea is provided in the Royal Society submission from Professor Salter.

Ship-tracks can be adduced as evidence showing that the seeding of marine stratocumulus clouds can enhance their reflectivity. More quantitative support is provided by three experimental studies (outlined in Latham et al. (2008)), two involving satellite measurements, the other, flights through and around clouds by instrumented aircraft.

Latham et al. (2008) describe atmosphere-only GCM studies of this global temperature stabilisation scheme conducted using two high-level models, the Meteorological Office HadGAM numerical model, and a version of the NCAR Community Atmosphere Model (CAM). Both models reveal that a technologically feasible imposed increase in cloud droplet number concentration resulting from seeding can cause an overall significant global cooling, sufficient to balance the warming resulting from CO2-doubling. The computations showed strong seasonal variations in the global distribution of cooling, with a maximum in the Southern Hemisphere summer.

2. Recent computations using a fully-coupled ocean/atmosphere GCM

The published GCM studies cited above used “atmosphere only” simulations (with ocean temperatures prescribed to climatological values) to assess the possible forcing associated with seeding. The continuing studies outlined in this section have not been published, and results should be viewed as preliminary. We have extended the simulations to a fully coupled climate model, the CCSM3.5 model described in Neale et al (2008). This model is an experimental version of CCSM, similar in many respects to CCSM3 (Collins et al, 2006) except that some components of the ocean and atmosphere have been improved. Of particular importance is the change to the cloud microphysical formulation which now provides an improved formulation for drop activation, condensation and coalescence processes (Morrison and Gettelman 2008, Gettelman and Morrison 2008) and predicts cloud drop number, the quantity that we influence through our geoengineering strategy.

We show two figures indicating the potential of this geoengineering strategy. Each figure compares two simulations averaged over the first 20 years of the simulations started from initial conditions at equilibrium for present day greenhouse gas concentrations. One simulation employed a doubling of CO2 concentration. The other included the doubling of CO2 but also included geoengineering. Our geoengineering strategy was to assume that we could produce perfect cloud condensation nuclei and control them to the point that all cloud between the surface and 850 hPa would attain a cloud drop number of 1000/cm3. This strategy differs substantially from the one employed in a recent UKMO study that used a “slab ocean” framework, and seeded only in small areas of the ocean, so our results will not necessarily be consistent with that study. Our seeding strategy is obviously very artificial, and more exploration of the appropriate choice of area, and amount will be needed to balance a particular warming scenario optimally. Also, the production of CCN and the influence on boundary layer clouds is in itself a formidable task (not dealt with in this study), and our seeding strategy is designed to produce a very strong signal, exceeding that required to compensate for a warming associated with a doubling of CO2. The solutions are not at an equilibrium, but signals in many features are evident. We wish to emphasize that these simulations are not designed to precisely compensate for the CO2 warming, but rather to identify the primary signals seen with geoengineering using this strategy.

Figure 1 shows the annually averaged change in sea ice extent in the northern hemisphere. The geoengineering has compensated for the loss in sea ice associated with the greenhouse warming by increasing the sea ice extent by 2% of the surface area of the northern hemisphere during the first 20 years of the simulation compared to the warming scenario.

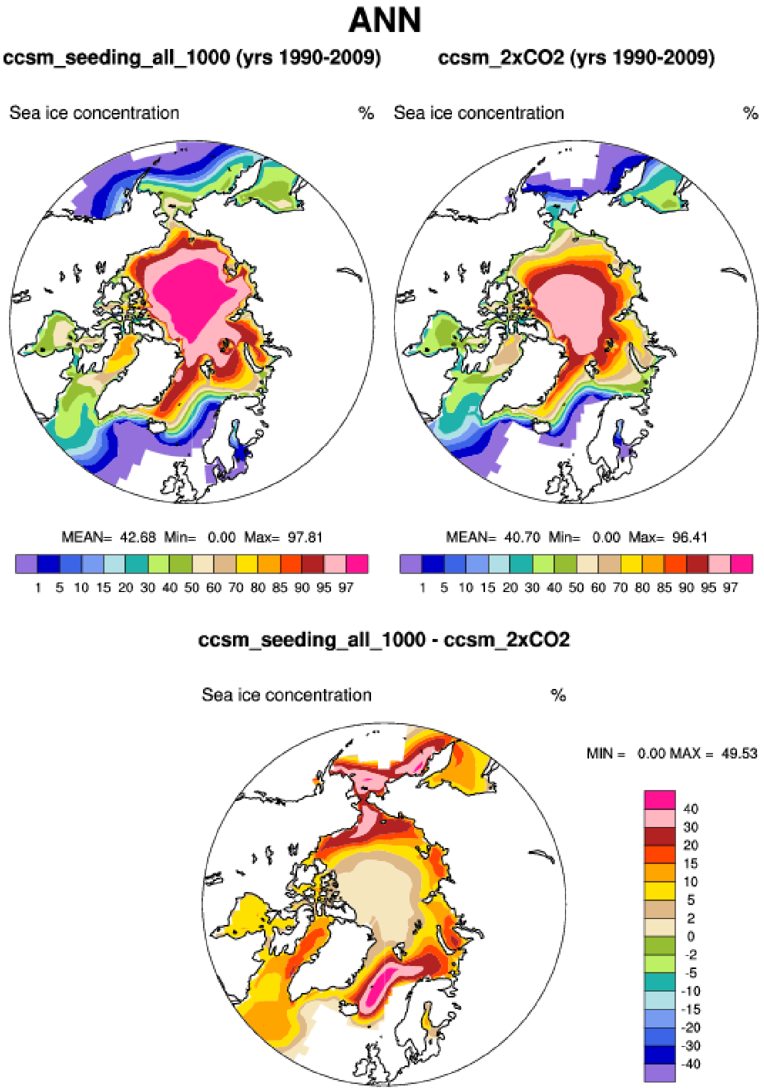

Figure 1: Annually averaged sea ice extent. Top left panel shows the simulation for a 2xCO2 enhanced simulation with geoengineering simulation; Top Right the simulation with 2xCO2 but without geoengineering. Bottom Panel shows the difference

Figure 2 shows the corresponding surface temperature changes over the globe. The model is about 1.8K cooler in the geoengineered run over the first 20 years of the simulation (recall that these are not equilibrium values so these changes just provide hints as to the sign of the changes).

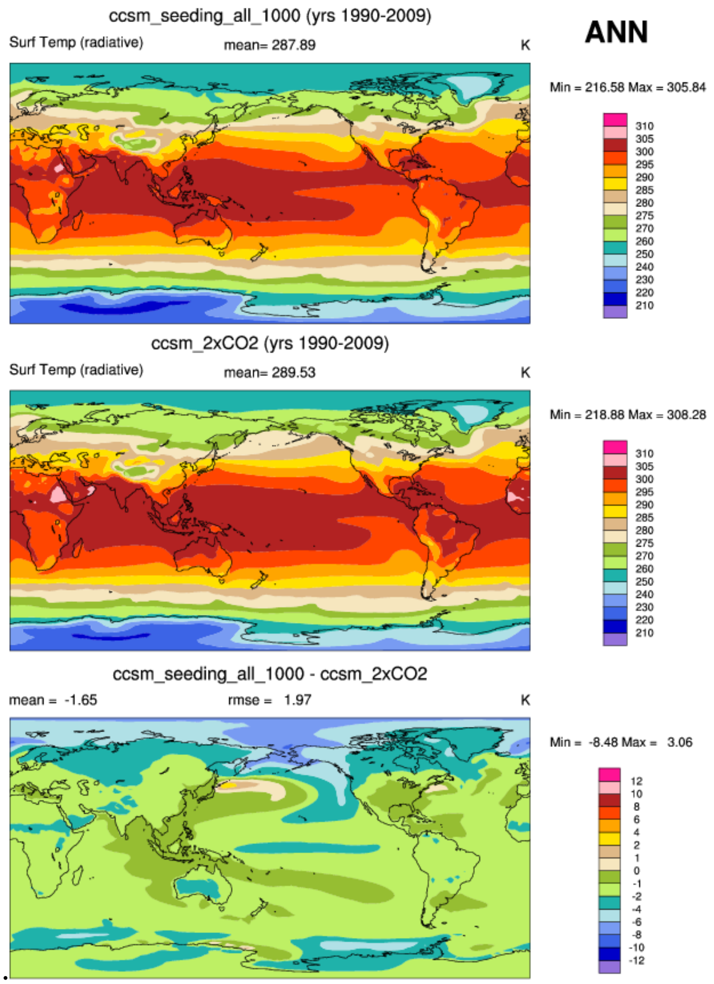

Figure 2: Annually averaged surface temperature. Top Panel: Simulation with 2xCO2 and geoengineering; Middle Panel: Simulation with 2xCO2. Bottom panel difference.

The geoengineering has clearly had a strong effect on the simulation, acting to cool the planet by about 1.7K over this 20 year period in the global average with the maximum signal in the northern arctic region compared to the warming scenario.

3. Discussion

Much more climate modelling work is required to understand the consequences of geoengineering using this method. Other seeding scenarios and effects on precipitation, ocean circulations, ecosystems, and many other issues remain to be explored. There are also many issues (Latham et al. 2008) associated with the technology needed to produce the CCN and deliver them, to model the real complexities of marine stratocumulus clouds, and to make a detailed assessment of ramifications associated with the possible deployment of our geo-engineering. We should also develop plans for executing a limited-area field experiment in which selected clouds are inoculated with seawater aerosol, and airborne, ship-borne and satellite measurements are made to establish, quantitatively, the concomitant microphysical and radiative differences between seeded and unseeded adjacent clouds: thus, hopefully, to determine whether or not this temperature-stabilization scheme is viable.

The scheme has a number of desirable attributes: (1) the amount of cooling might be controlled by measuring cloud reflectivity from satellites and turning disseminators on or off (or up and down) remotely as required: (2) if any unforeseen adverse effect occurred, the entire system could be switched off instantaneously, with cloud properties returning to normal within a few days: (3) the only raw materials are wind and seawater: (4) there exists flexibility to choose where local cooling occurs, since not all suitable clouds need be seeded. This flexibility might help subdue or eliminate adverse ramifications of the deployment of our scheme.

4. References

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