Geo-Engineering Modeling Studies, Phil Rasch, Jack Chen, John Latham


- Salter et al, *Sea-going hardware for the cloud albedo method of reversing global warming* 2008, special issue on geoengineering, Phil. Trans. A.,

Thanks to A. Gettelman, H. Morrison
Model Setup

- Community Atmosphere Model version 3.5+
  - Revised convection
  - Cloud microphysics tweaks,
    - Drop Activation tweaked between sfc and 850mb (assume perfect control of cloud drop nucleation)
    - Morrison, Gettelman, Ghan (2007a, b; internally consistent 2 moment scheme predicting mass and number of cloud drops)

- 2x2.5°, 26 layers

- 2 Ocean Models
  - SOM/Thermodynamic Sea-Ice Model
    (ocean currents, and vertical mixing are prescribed, sea ice grows and decays solely based on ocean surface temperature)
  - Full ocean model, Full Sea-Ice Model
    (ocean currents change, depth of mixing changes, ice dynamics much more realistic)
Cloud forcing as a function of areal extent (most susceptible clouds seeded first)
Optimizing cloud seeding
(Sampling over a 5 year simulation)
Results are very preliminary!
Proceed with caution
Changes in cloud drop number propagate.

- Changes to Liquid Water Path
SST cooling from geoengineering by boundary layer cloud seeding
Decreasing Summer Sea Ice due to 2xCO2
Replenishment of Sea Ice due to Geoengineering
Precip Changes from 2xCO2
Precip Changes due to geoengineering

ccsm_seedling20_200 (yrs 2000-2019)

Precipitation rate: mean = 2.87 mm/day

ccsm_control (yrs 2000-2049)

Precipitation rate: mean = 2.98 mm/day

ccsm_seedling20_200 - ccsm_control

Precipitation rate: mean = -0.11 mm/day, rmse = 0.56

JJA

Min = 0.00, Max = 28.93

Min = 0.01, Max = 33.12

Min = -4.19, Max = 5.29

Min = -5.34, Max = 2.92

DJF

Min = 0.00, Max = 13.89

Min = 0.00, Max = 15.56

Min = 0.00, Max = 33.12

Min = -5.34, Max = 2.92
Changes in Cloud Cover

**ccsm_seeding20_200 (yrs 2000-2019)**

Low-level cloud mean = 38.17

**ccsm_control (yrs 2000-2049)**

Low-level cloud mean = 38.19

**ccsm_seeding20_200 - ccscontrol**

mean = -0.03 rmse = 2.53
Summary

- Aerosol cloud interactions are extremely complex (e.g. IPCC AR4)
- Nevertheless: The short lifetime of aerosols, the short response time of clouds to aerosol perturbations, the fact that the perturbation is to existing components of the natural system, the strong influence on climate, cost --> make cloud seeding interesting to consider as a means to geo-engineering
- Assuming that this model provides insight into forcing of the climate system:
  - Extra-tropical clouds might play a role in the geo-engineering
  - Response will be non-local
  - Feedbacks are very important
  - Pristine clouds more susceptible --> Southern Hemisphere easier to brighten
  - Changing CDNC at higher altitudes could also play a role in forcing
  - Study suggests that seeding perhaps 25% of the globe would counteract much of the forcing associated with a doubling of CO2 --> quite strong local radiative forcing
  - Response of coupled system important to explore (feedbacks, ocean circulations, ocean ecosystems, land/ocean precipitation redistribution, ?)
Next Steps

► Global model
  ■ Extending simulations
  ■ Ensembles

► Smaller Scale Models
  ■ Large Eddy Simulations
  ■ Cloud resolving models

► Exploration of Practical Issues
  ■ Production of CCN
  ■ Detection of effects
  ■ How would one design a Field Experiment?
Geoengineering by boundary layer cloud seeding

- Deliberate introduction of CCN to enhance the Droplet Concentration in Low-level clouds increasing Cloud Albedo & Longevity - i.e. a cooling effect.

- This geo-engineering approach may be considered an analogue to Natural droplet creation at ocean surface
  - Bubble-bursting, white-capping
  - NaCl droplets effective CCN

- Ship tracks, fires, industrial pollution sources

- (Idea based on: -**Twomey** (1977), **Charlson** et al. (1987), **Wigley** (1989), **Slingo** (1990))

- CO2 doubling compensated by (Slingo, 1990):
  - 120% increase in droplet concentrations
  - 40% decrease in effective radius
  - 12% increase in oceanic cloud cover

- Follow up to studies of Latham, 1990, 2000, Bower et al., 2006
The cloud seeding paradigm

- Natural sea salt is estimated to be ~10% of CCN over the ocean. If one increased sea salt mass but maintained the same naturally broad size distribution, then a 10x increase in seasalt particles might double CCN, but might also produce more giant nuclei, increasing precipitation, and decreasing cloud.

- Instead, assume is that the particle size distribution of a geoengineered aerosol could be optimized (e.g. monodisperse, initial droplet size of 0.8 micron)

- These CCN activate preferentially over naturally occurring aerosol. Doubling of droplet number N could be ensured by adding 2N seawater CCN.
Geoengineering and the Earth System
Closing thoughts

► If one thinks of an Earth System Model as a model that includes the physical, biological, and social components, then geoengineering provides a fascinating context in which to explore interactions between components.

► Even our crude initial exploration provides surprises and reminds us of how complex the system is.

► We are already engineering the planet, but doing it inadvertently. Considering a deliberate engineering confronts us with all the same issues that we encounter in any climate change problem, ranging from the moral, and ethical to the scientific.
Raupach et al., 2007, Global and regional drivers of accelerating CO2 emissions, PNAS
Preliminaries

Geoengineering: The intentional large-scale manipulation of the global environment. The term is usually applied to proposals to manipulate the climate with the primary intention of reducing undesired climatic change caused by human influences.
SMOKING DOES NOT CAUSE CANCER.

OKAY, IT DOES, BUT I'M ADDICTED.

I'M ADDICTED BUT I KNOW I'M GOING TO HAVE TO QUIT.

I HAVEN'T QUIT YET, BUT I'M CUTTING BACK.

I DIDN'T CUT BACK VERY MUCH, SO NOW I'M GOING TO QUIT.

I SHOULD HAVE QUIT WHEN I SAID I WOULD, BUT NOW IT'S TOO LATE.

FOSSIL FUELS DO NOT CAUSE GLOBAL WARMING.

OKAY, THEY DO, BUT I'M ADDICTED...

LIVE AND LEARN, OR VICE VERSA.
Cloud Seeding feedbacks

**Fixed SST**

Nc=375 (yrs 1979-1983)

TOM SW cloud forcing mean = -57.54 W/m²

JJA

Min = -211.00 Max = 0.00

control (yrs 1979-1983)

TOM SW cloud forcing mean = -54.00 W/m²

Min = 192.41 Max = 0.00

Nc=375 - control

mean = -3.48 rmse = 8.29 W/m²

Min = -46.52 Max = 31.18

seeding 20% (yrs 1979-1988)

TOM SW cloud forcing mean = -70.54 W/m²

Ann

Min = -209.58 Max = -0.38

control (yrs 1979-1988)

TOM SW cloud forcing mean = -52.35 W/m²

Min = -137.99 Max = -0.56

seeding 20% - control

mean = -18.19 rmse = 44.62 W/m²

Min = -185.71 Max = 99.67
Experimental setup

Simulations performed

- Fixed aerosol and greenhouse forcing at present day values (Control)
- Doubled CO2 (2XCO2)
- Injection of SO2 at 25km, 10N - 10S
  - Pinatubo thought to inject 10-30 Tg S (over a few days)
  - 1 Tg S/yr assuming a small (or background) aerosol size distribution forms
  - 2 Tg S/yr small particles
  - 2 Tg S/yr as large (or volcanic) aerosol forms
- Doubled CO2 + the above permutations of emission amount and aerosol size
Annual Averages of Short Wave Cloud Forcing

Control SWCF

$\Delta$ SWCF from increment $\rightarrow 375/cm^3$

$\Delta$ SWCF from increment $\rightarrow 1000/cm^3$
"A reasonable man adapts himself to suit his environment. An unreasonable man persists in attempting to adapt his environment to suit himself. Therefore, all progress depends on the unreasonable man."

"People are always blaming their circumstances for what they are. I don't believe in circumstances. The people who get on in this world are the people who get up and look for the circumstances they want, and if they can't find them, make them."

"A life spent making mistakes is not only more honorable but more useful than a life spent doing nothing."

“It is dangerous to be sincere unless you are also stupid.”

Was GBS a “geoengineer before his time”??