

Overview of Climate Intervention Options and Technologies

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Climate Intervention Technologies

- Climate Intervention is

the deliberate large-scale manipulation of the planetary environment to counteract anthropogenic climate change

- Also called climate engineering or geoengineering.
- Treated as a fringe subject for decades, and still controversial
- Critical distinction – ***solar radiation management*** vs ***carbon dioxide removal***.

Carbon Removal and the Governance Divide

“This divergence of costs and risks means that the challenges of solar geoengineering and carbon removal raise for policy and governance are almost wholly different. Carbon removal is like mitigation....

Because solar geoengineering and carbon removal have little in common, we will have a better chance to craft sensible policy if we treat them separately.”

D. Keith, A Case for Climate Engineering at p. xxi (2013)



How Many Gigatons of Carbon Dioxide...?

have we released
to date?



more can we
"safely" release*?



are left to release?



what's in the ground: 2755

CURRENT ANNUAL
FOSSIL FUEL EMISSIONS

36 gigatons

TIME BEFORE WE BREAK
OUR 'CARBON BUDGET'



8 YEARS

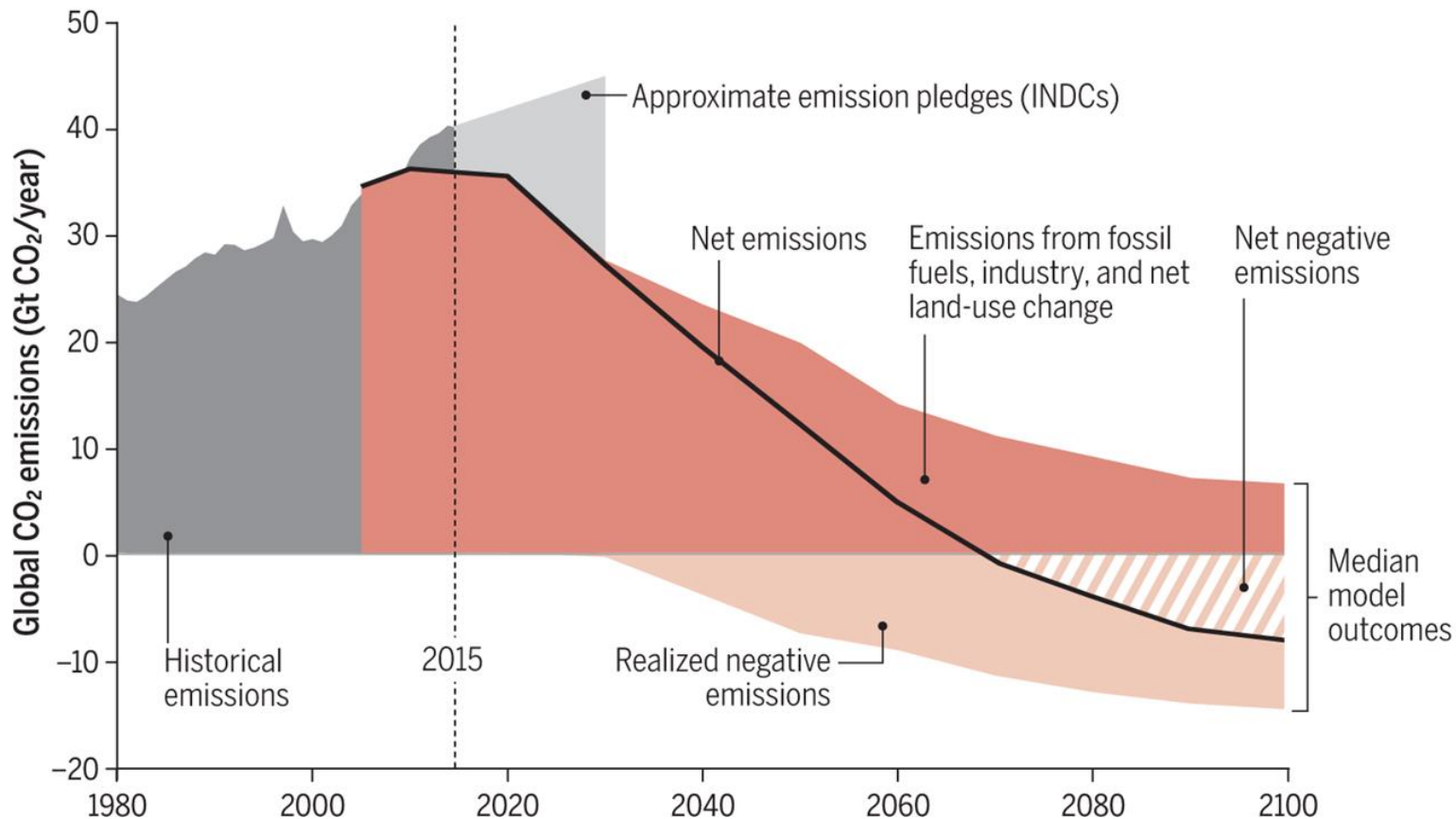
if emissions continue to increase at 2.5% per year

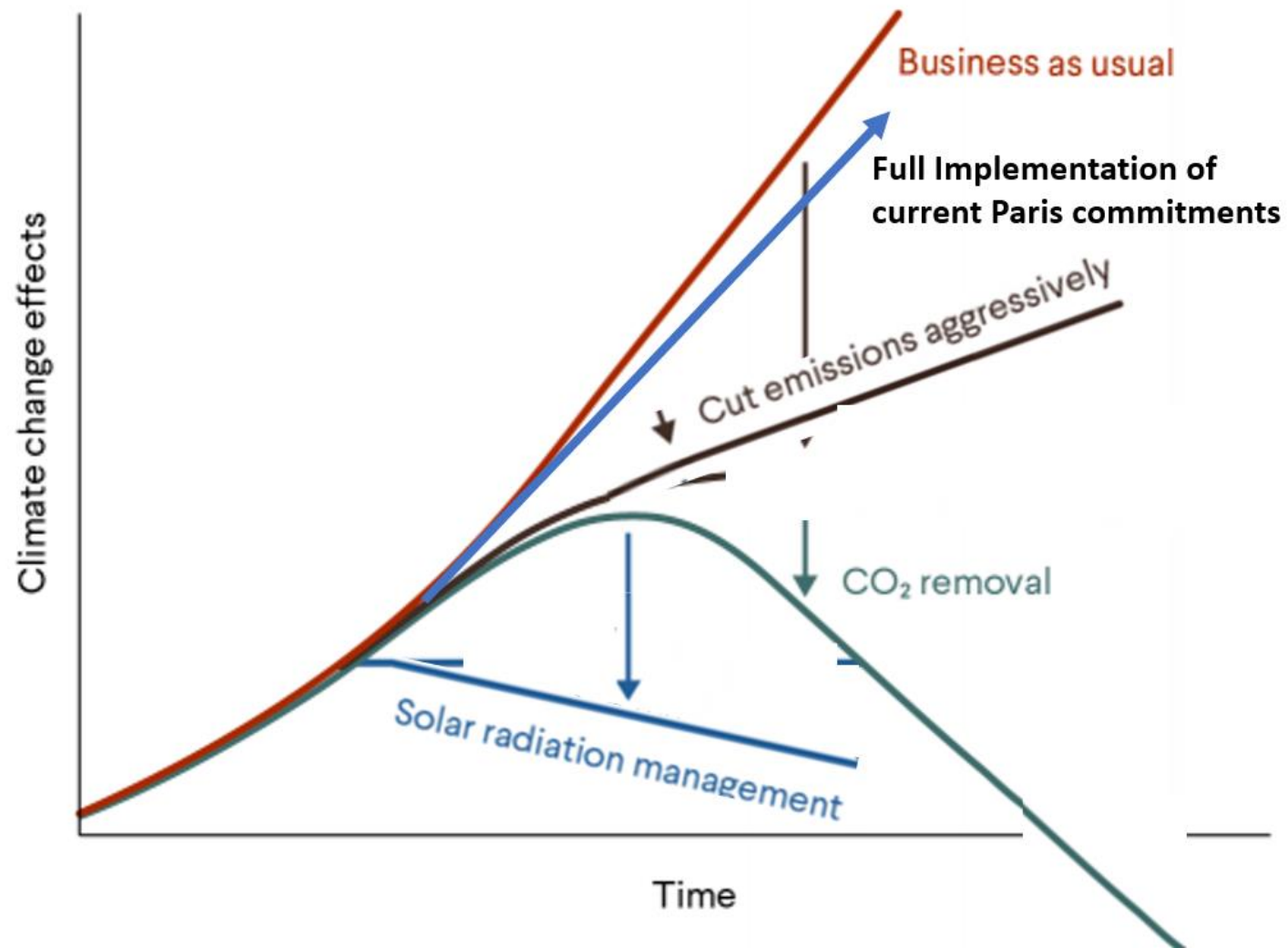
* before 2050 and still have an 80% chance
of staying below 2°C warming

The Need for NET

No quick fixes

Modelers generally report net carbon emissions, unintentionally hiding the scale of negative emissions. Separating out the positive CO₂ emissions from fossil fuel combustion, industry, and land-use change reveals the scale of negative CO₂ emissions in the model scenarios (16). INDCs, Intended Nationally Determined Contributions.





In the news...



Climate Intervention: Reflecting Sunlight to Cool Earth

Committee on Geoengineering Climate:
Technical Evaluation and Discussion of Impacts

Board on Atmospheric Sciences and Climate

Ocean Studies Board

Division on Earth and Life Studies

H. R. 4586

To provide for the National Academies to study and report on a research agenda to advance the understanding of albedo modification strategies, and for other purposes.

IN THE HOUSE OF REPRESENTATIVES

DECEMBER 7, 2017

Mr. MCNERNEY (for himself and Ms. EDDIE BERNICE JOHNSON of Texas) introduced the following bill; which was referred to the Committee on Science, Space, and Technology

A BILL

To provide for the National Academies to study and report on a research agenda to advance the understanding of albedo modification strategies, and for other purposes.

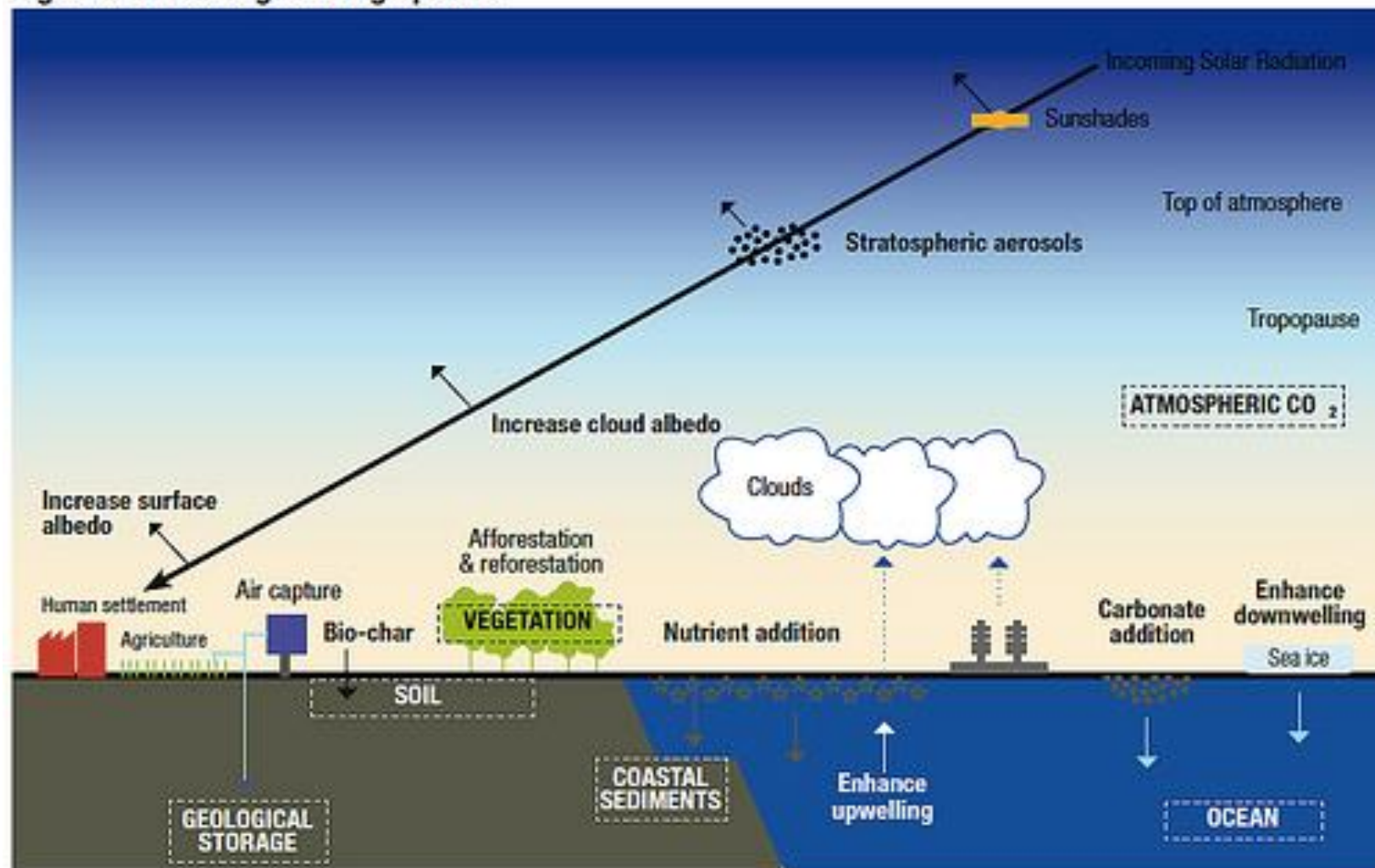
1 *Be it enacted by the Senate and House of Representa-*
2 *tives of the United States of America in Congress assembled,*

3 **SECTION 1. SHORT TITLE.**

4 This Act may be cited as the “Geoengineering Re-
5 search Evaluation Act of 2017”.

6 **SEC. 2. FINDINGS.**

Figure 5.4: Geoengineering options





Solar Radiation Management



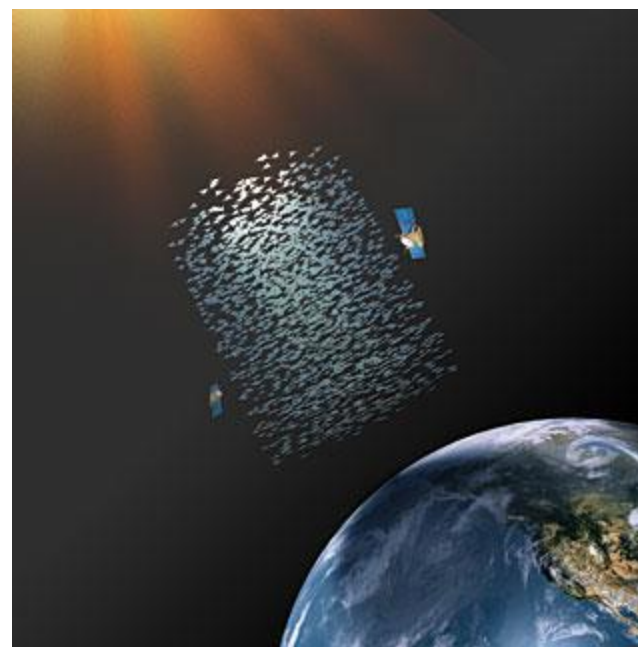
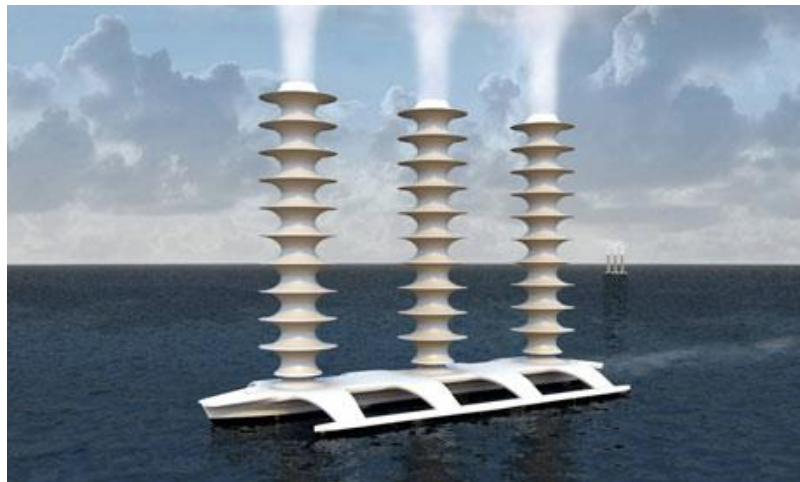
- Focuses on reducing the amount of solar energy reaching the Earth's surface
- Key examples
 - Stratospheric aerosol releases
 - Cloud whitening or stripping
 - Surface albedo enhancement
 - Satellite reflectors

Solar Radiation Management Through Stratospheric Aerosol Releases



- Mimics global cooling caused by volcanic eruptions
- Effectiveness: half-ounce of SO_2 offsets one ton of CO_2
global temperatures reduced by 2 degrees C
- Requirements: 5 million tons of SO_2 annually
\$1 billion to \$50 billion annually

Other Solar Radiation Management Options



Hard lessons of experience for future SRM field research

Geoengineering trials get under way

Updated 17:10 14 September 2011 by [Michael Marshall](#)

Magazine issue [2829](#).



Volcanic ash inspires sunshade (Image: Arctic Images/Corbis)

- **Update 14 September 2011:** *The field test will be conducted at an abandoned airfield in Sculthorpe, UK. Matthew Watson of the University of Bristol, UK, presented details of the project at the [British Science Festival](#) in Bradford, UK.*

Field trials for experiments to engineer the climate have begun. Next month a team of UK researchers will hoist one end of a 1-kilometre-long hose aloft using a balloon, then attempt to pump water up it and spray it into the atmosphere.

ScopeX

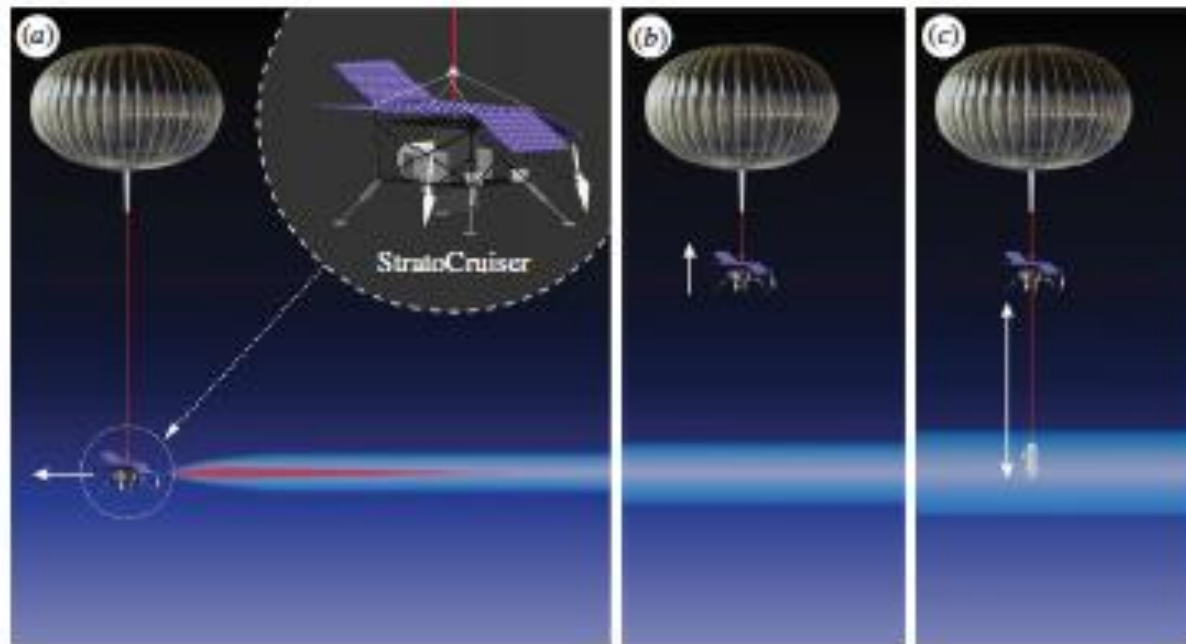
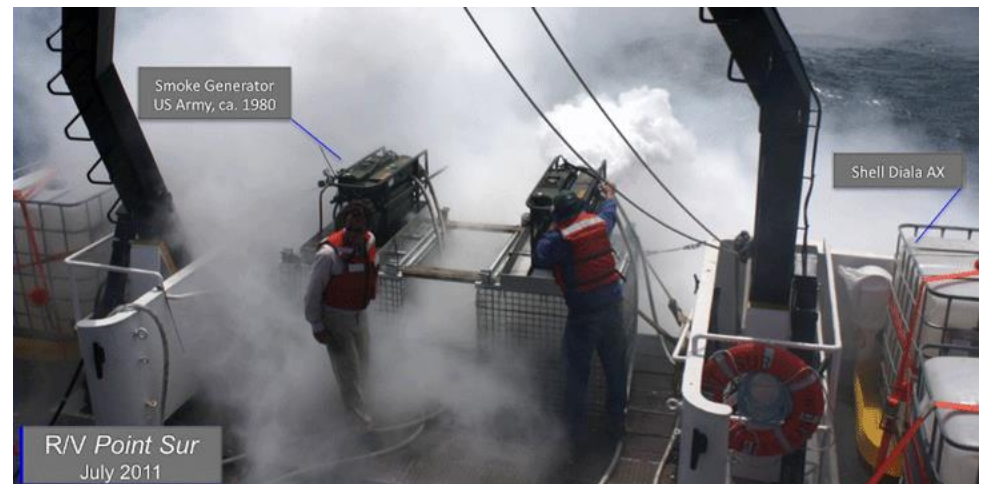
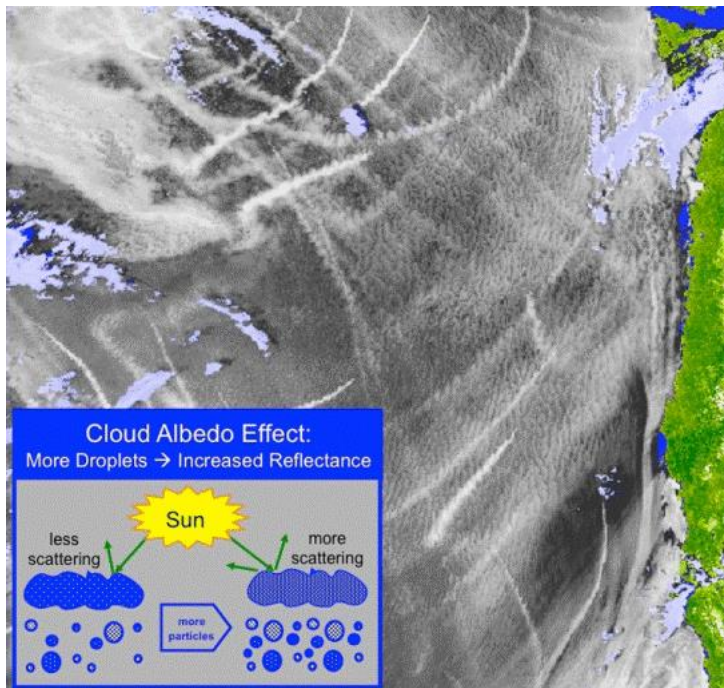


Figure 4. The concept of operations for the proposed experiment is initiated by seeding a 1 km length of stratospheric air with a combination of water vapour and sulfate aerosol using the propulsive capability of the StratoCruiser (a). Using a combination of its altitude and propulsive capabilities, the StratoCruiser manoeuvres past and above the seeded volume, which continues to expand owing to the turbulent wake generated by the propellers. The suspended instrument payload is reeled through the seeded volume to measure aerosols, water vapour and chemical species including HCl and ClO (b). The propulsion capability together with the LIDAR surveillance is used to track the seeded volume as it drifts with ambient wind and to make repeated measurements with the suspended payload, resolving the chemical evolution within the seeded volume as a function of time (c).

E-PEACE (2011) - Marine Cloud Brightening

- Eastern Pacific Emitted Aerosol Cloud Experiment (EPEACE) investigated physics of cloud formation
- Data also showed proof of concept, but concerns remain on possible environmental and health impacts



Weakening of hurricanes via marine cloud brightening (MCB)

John Latham,^{1,2} Ben Parkes,³ Alan Gadian^{3*} and Stephen Salter⁴

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²SEAS, University of Manchester, UK

³NCAS, SEE, University of Leeds, UK

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Abstract

This paper examines the potential to cool ocean surface waters in regions of hurricane genesis and early development. This would be achieved by seeding, with copious quantities of seawater cloud condensation nuclei (CCN), low-level maritime stratocumulus clouds covering these regions or those at the source of incoming currents. Higher cloud droplet density would increase these clouds' reflectivity to incoming sunlight, and possibly their longevity. This approach is therefore a more localized application of the marine cloud brightening (MCB) geoengineering technique promoting global cooling. By utilizing a climate ocean/atmosphere coupled model, HadGEM1, we demonstrate that – subject to the satisfactory resolution of defined but unresolved issues – judicious seeding of maritime stratocumulus clouds might significantly reduce sea surface temperatures (SSTs) in regions where hurricanes develop. Thus artificial seeding may reduce hurricane intensity; but how well the magnitude of this effect could be controlled is yet to be determined.

We also address the important question as to how MCB seeding may influence precipitation. GCM modelling indicates that the influence of seeding on undesirable rainfall reductions depends on its location and magnitude. Much more work on this topic is required. Copyright © 2012 Royal Meteorological Society

Keywords: hurricanes; marine cloud brightening; sea surface temperature; cloud seeding; global climate modelling

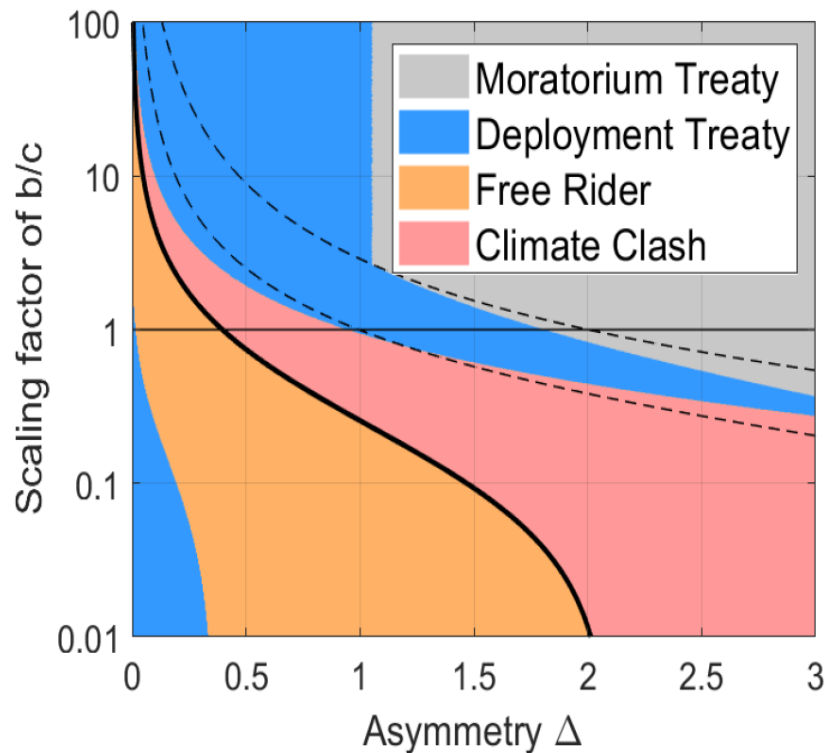
Received: 24 June 2011

Revised: 10 July 2012

Accepted: 10 July 2012



Emerging Issues on SRM Implementation



- Free Rider vs Free Driver
- Technical feasibility of Rogue Climate Interventions
- Detection Technologies
- Counter-SRM

An alternative concern – regional climate SRM in response to emergencies

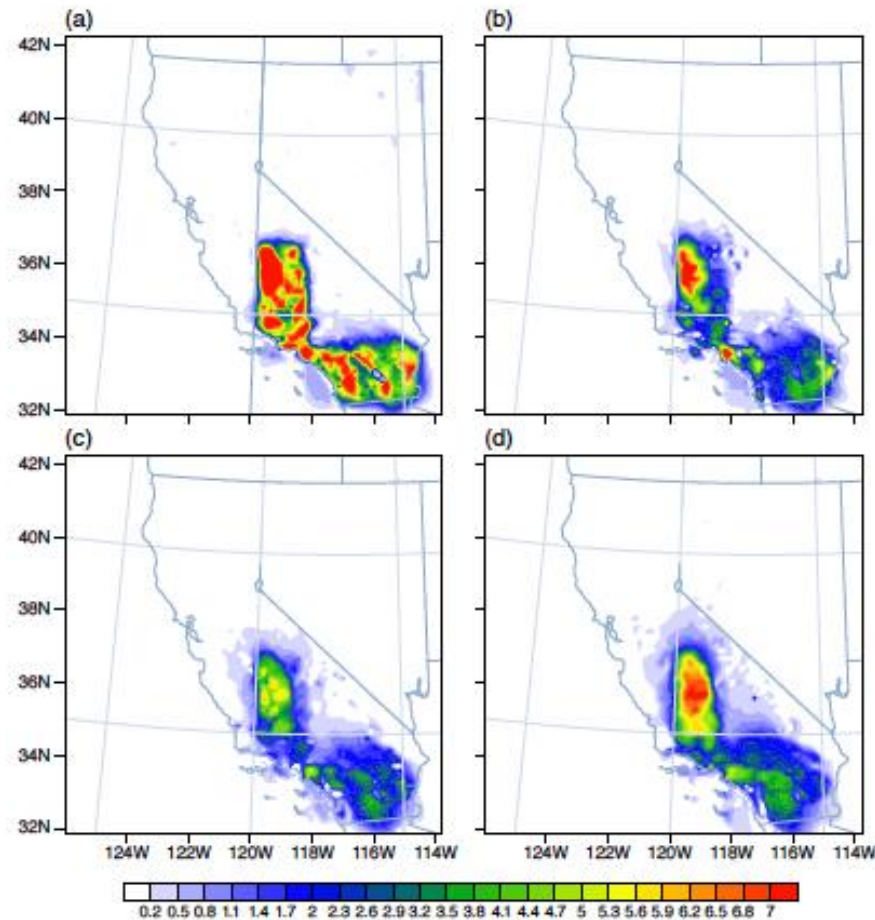


Fig. 12. Surface air temperature differences [°C] on 22 July at hours (a) 10:00 LT, (b) 12:00 LT, (c) 14:00 LT, and (d) 16:00 LT for the smaller-scale injection experiments.

Regional climate engineering to preserve coral reefs



- Marine cloud brightening options for Great Barrier Reef
- Local pH modification as well
- MCB for coastal forests

AUSTRALIA

Sweltering state to pump oxygen into rivers as fish die

Published: Wednesday, January 16, 2019

An Australian state government yesterday announced plans to mechanically pump oxygen into lakes and rivers after hundreds of thousands of fish have died in heat wave conditions.

Up to a million dead fish were found floating last week in the Darling River in western New South Wales state, and the state government announced that 1,800 more rotting fish had since been found in Lake Hume in the state's south.

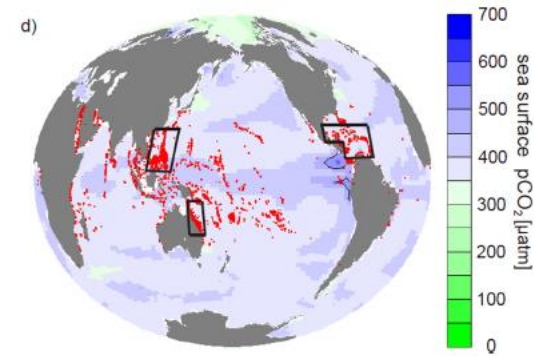
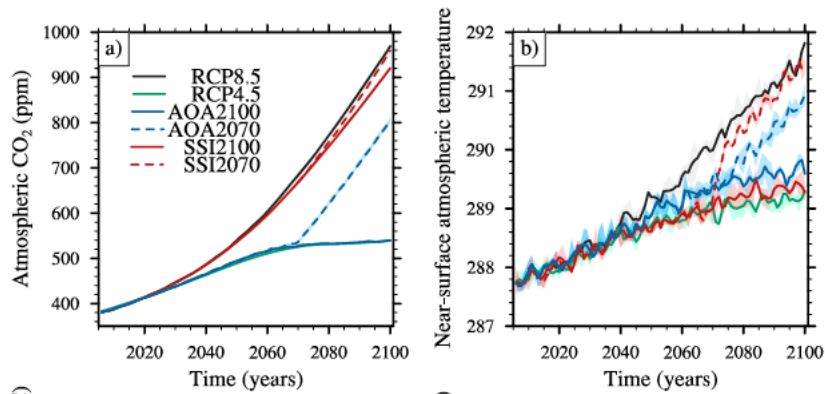
Minister for Regional Water Niall Blair said 16 battery-powered aerators had been bought and would be placed in various drought-affected waterways after they are delivered by today.

"They are a Band-Aid solution; we admit that," Blair told reporters.

"Nothing will stop this fish kill unless we get proper river flows and water levels in our dams back up to normal. We are doing everything we can to try and limit the damage," he added.

Experts blame heat wave conditions across much of Australia, drought and algal blooms for starving waterways of oxygen.

Localized ocean alkalization



Gonzalez et al, Artificial Ocean Alkalinization Termination,
[10.1029/2018GL077847](https://doi.org/10.1029/2018GL077847)

Environ. Res. Lett. **11** (2016) 074008



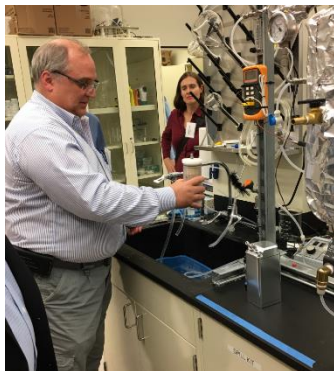
Kelp demonstration site at Hood Head. Kelp may act as a buffer to acidifying conditions, and could be an important adaptation tool.
 Photo credit: John Mickett



The Other Path: Carbon Dioxide Management

- Dispute over whether to include CDM as climate engineering at all
- Mechanism: enhance or directly engineer absorption of carbon dioxide and other greenhouse gases from ambient atmosphere
- Techniques:
 - Afforestation
 - Ocean fertilization
 - Mechanical removal of CO₂
 - Biochar

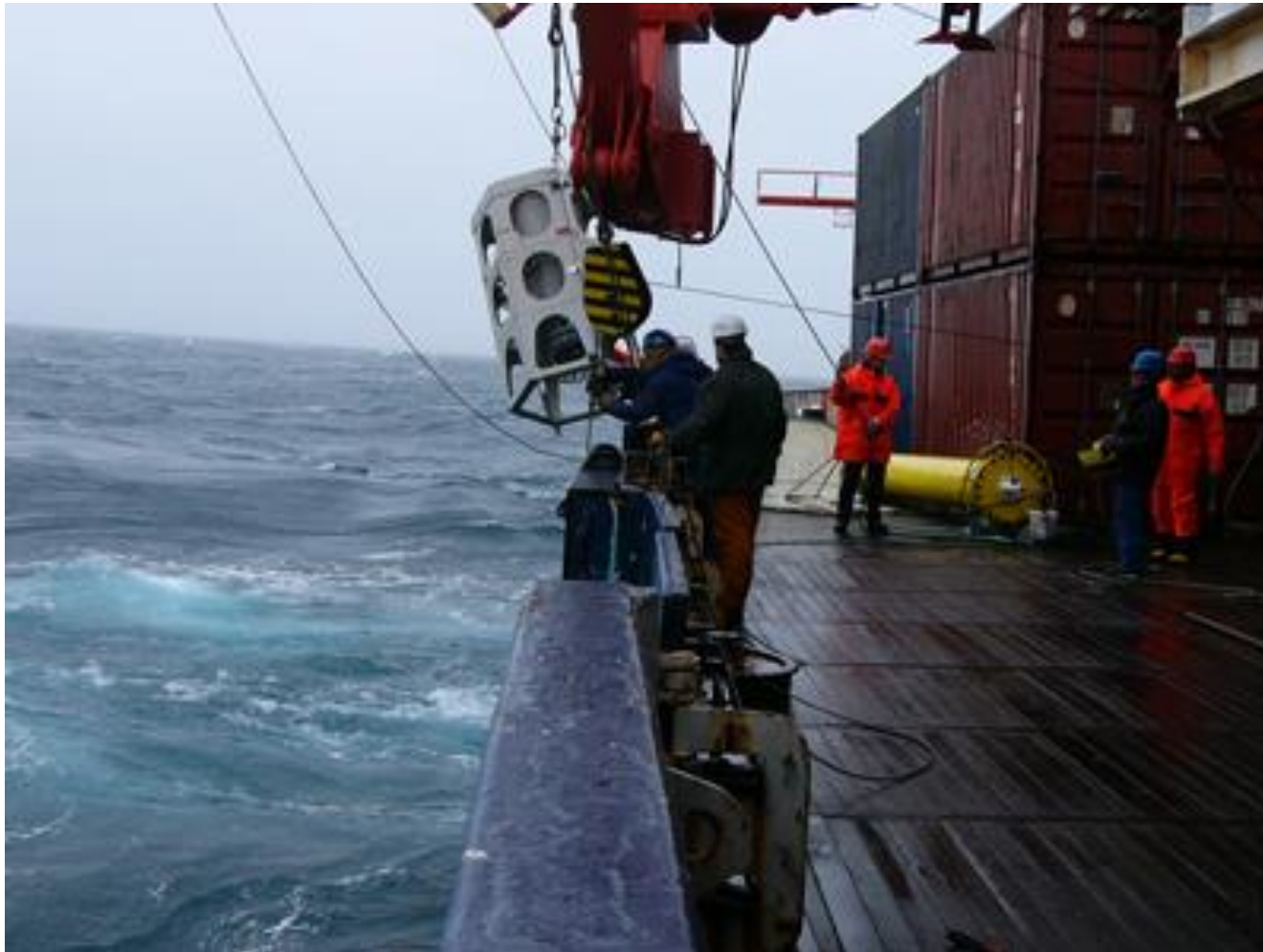
The Varieties of Direct Air Capture



- Mechanical Direct Air Capture
- Carbon Capture & Storage (CCS)
- Biological Energy + CCS (BECCS)
- Ocean Iron Fertilization
- Biochar + Soil enhancement
- Ocean CO₂ entrainment
- Afforestation
- Air Fuel Capture



A Controversial Example of Carbon Dioxide Removal: Ocean Iron Fertilization



Haida Ocean Fertilization



100 tons of iron sulfate

Dispersed into coastal waters off British Columbia in July 2012

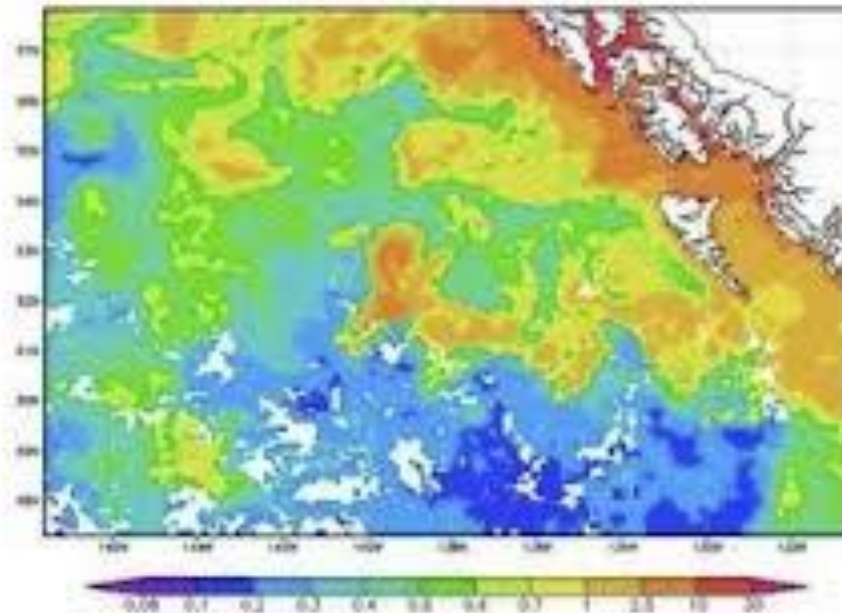
Plankton bloom and salmon runs

By Haida Salmon Restoration Corp.



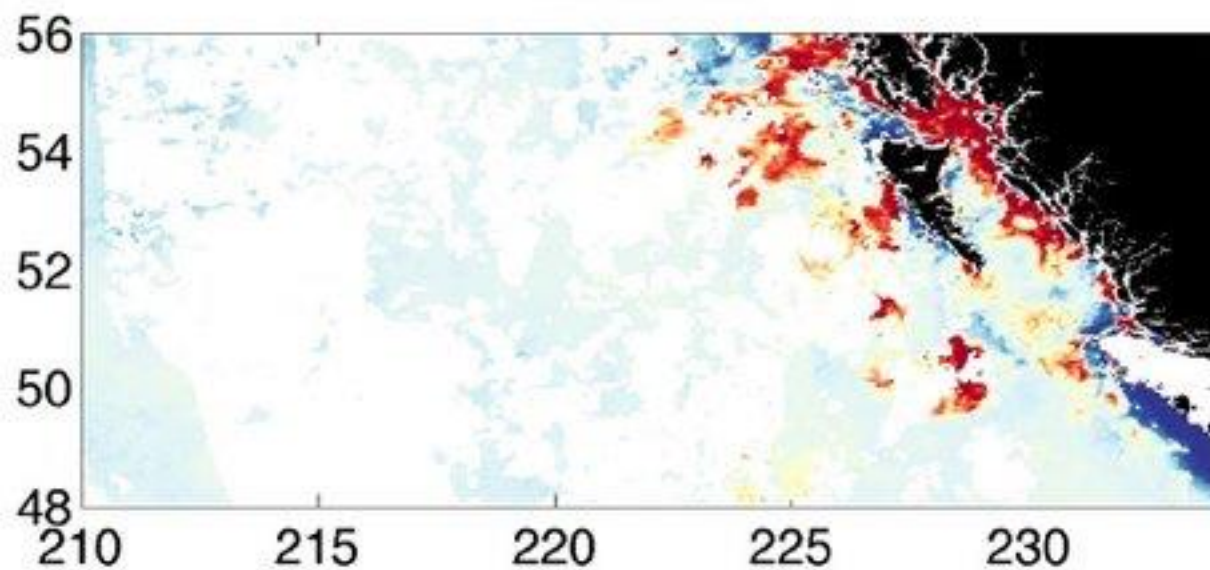
Search warrants
executed by Canada
Environment

Chlorophyll during August 2012 during Russ George
iron fertilization experiment

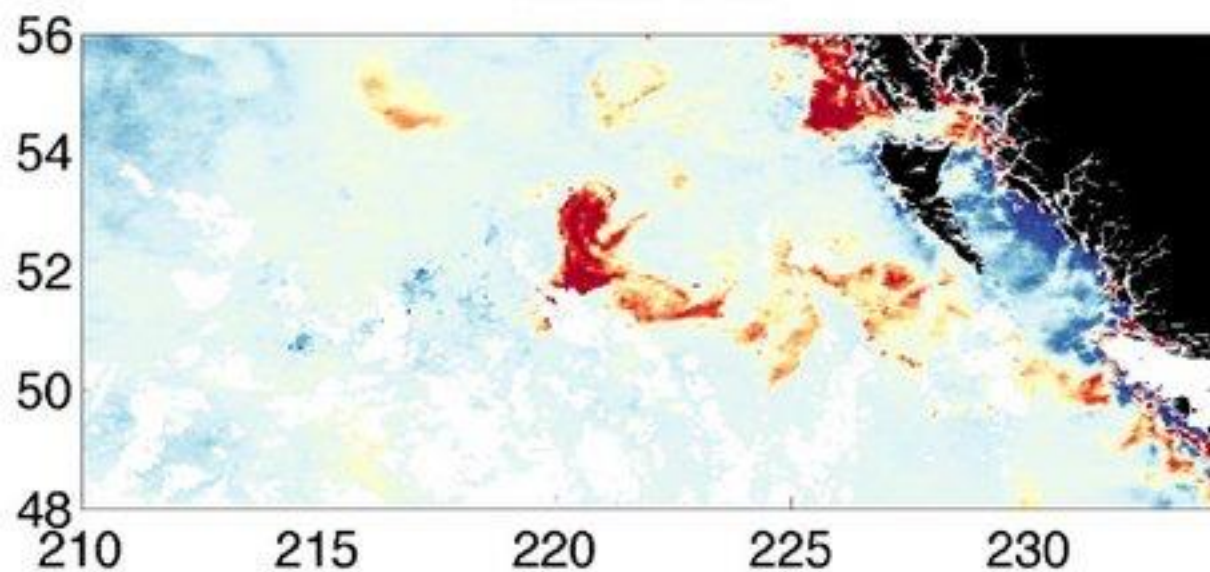


Originally planned to
renew iron fertilization in
2013; now halted

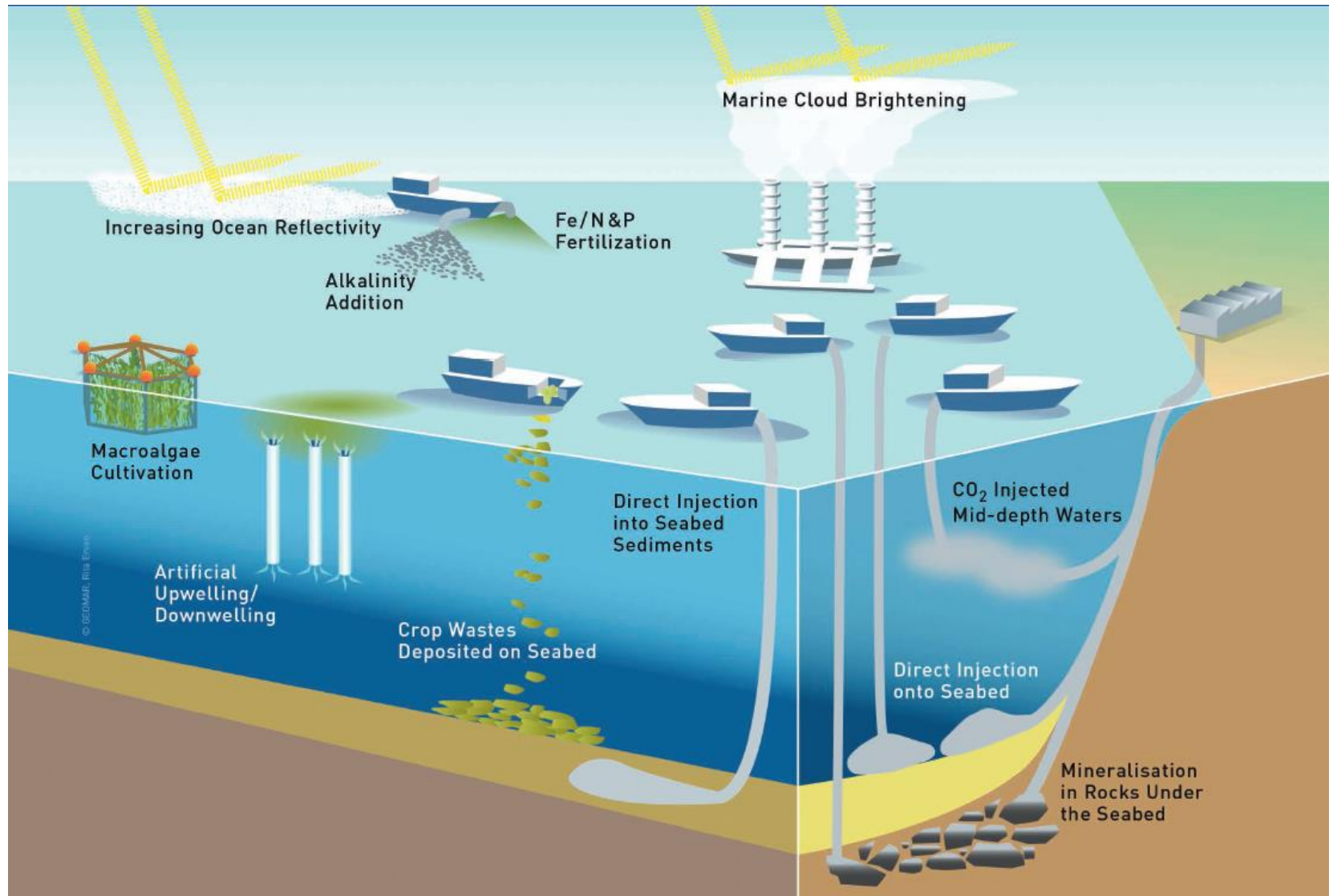
2012/JUL



2012/AUG



There's Always Many Possible Paths...



Environmental Laws and Direct Air Capture

- Legal Advantages of DAC

- Slow Pace
- Reversibility
- Familiarity



- Likely focus of initial legal hurdles

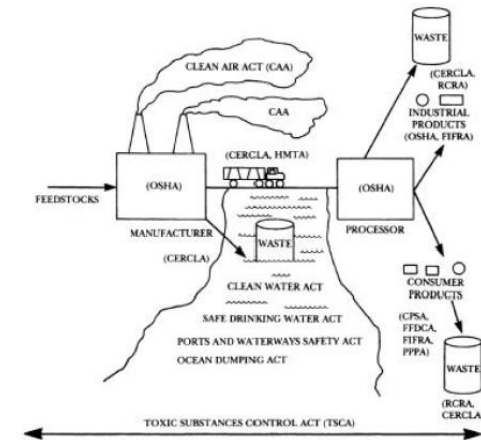
- Permits and approvals for environmental side effects of the capture process
- Management of captured CO2
- Legal status of products or materials generated from captured CO2

Thought Experiment



Default governance pathway: regulation by surrogate

- Note that all of these regulatory options focus on regulating DAC through its environmental side effects.
- So focus on the hard case – how (or should) we regulate a DAC process that does not pose any obvious environmental side-effects
- Consequence of the black box model to U.S. environmental regulation, which consciously seeks not to regulate the production process itself
 - Clean Air Act (BACT, MACT, LAER)
 - Pollution Prevention Act of 1990
 - Toxic Substances Control Act



CERCLA: Comprehensive Environmental Response, Compensation, and Liability Act
FFDCA: Federal Food, Drug, and Cosmetic Act
RCRA: Resource Conservation and Recovery Act
FIFRA: Federal Insecticide, Fungicide, and Rodenticide Act
CPSA: Consumer Product Safety Act
OSHA: Occupational Safety and Health Act
HMTA: Hazardous Materials Transportation Act
PPPA: Poison Prevention Packaging Act



Governance by Environmental Surrogate

Kamala D. Harris
Attorney General of the State of California
Office of the Attorney General
1300 "I" Street
Sacramento, CA 95814-2919

To the Proposed Defendants:

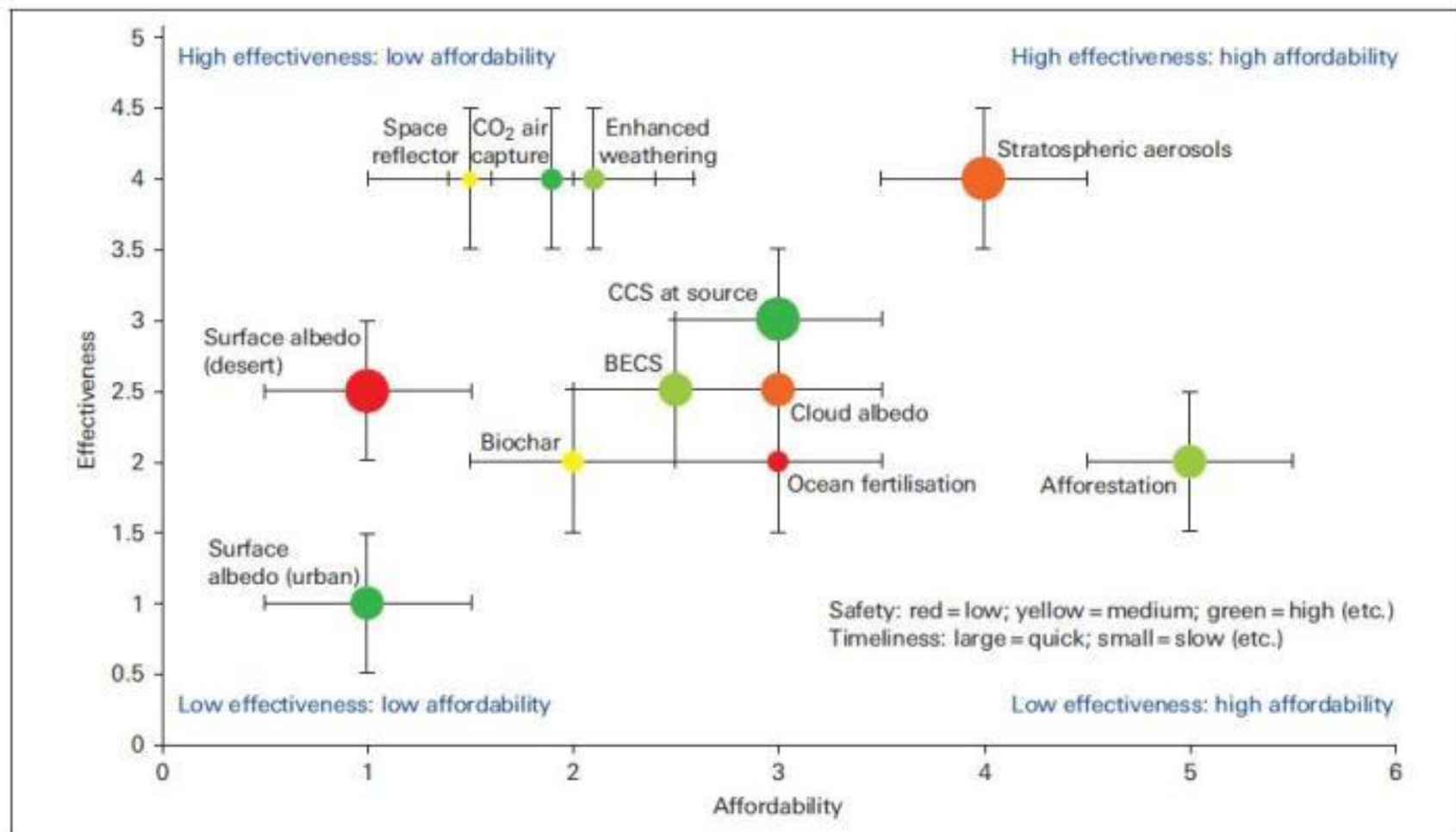
The undersigned attorneys represent Proposed Plaintiffs (listed below) and complain under the statutory “citizens’ suit” provisions of the federal Clean Water Act, §505(a), 33 U.S.C. §1365(a) *et seq.* (CWA), and Safe Drinking Water Act, §1449(a)(1), 42 U.S.C. 300f *et seq.* (SDWA) (collectively, as amended, the “Statutes”) of past and continuing violations of the Statutes by Proposed Defendants (listed below) in the State of California, including, without limitation, Shasta, Placer, Siskiyou and Santa Cruz Counties. Upon the expiration of the 60-day statutory waiting period required under both Statutes, and in the absence of adequate remedial effort by Proposed Defendants, Proposed Plaintiffs will file one or more citizens’ suits in the United States District Court for the State of California under the applicable provisions of the Statutes, as follows:

A. PRELIMINARY STATEMENT





Comparison of Climate Engineering Options and Risks





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