Marine Cloud Brightening: Science, Feasibility and a Plan for Research

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Marine Cloud Brightening proposes using sea-salt mist to brighten low clouds over the ocean.

- Adding salt particles increases cloud droplet nuclei number
- Makes smaller, more numerous droplets
- Makes cloud more reflective and more sustained

100 nanometer particles

10^{15} particles/second

Identify susceptible marine clouds

Infuse with mist delivered from ships

Ecologically benign material

Localized, temporary effects

Today, anthropogenic aerosol particles mix with clouds creating a cooling effect, estimated at between $0.5^\circ C$ and $1.5^\circ C$. Most particles cool by:
- Reflecting sunlight directly
- Affecting clouds in a way that increases the amount of sunlight they reflect ("cloud-aerosol effect")

Some particles (soot) warm.

The net effect is a cooling.

There is high confidence that aerosols and their interactions with clouds have offset a substantial portion of global mean forcing from well-mixed greenhouse gases. They continue to contribute the largest uncertainty to the total [Radiative Forcing] estimate. IPCC 5th Assessment 2013 Summary for Policymakers p 13-14
Applied to 10-50% of marine clouds, it might be possible to offset a significant fraction of CO₂ forcing globally with MCB.

Warming from CO₂ increases

Cooling from MCB covering 3% of Earth’s Surface Area

Jones et al. (2009), Stjern et al. (2017), inter alia.
Dual Purpose Research program aimed at major gap in climate science

**MCB Field Experiments**
- Provide scientific insight into cloud-aerosol interaction and test MCB effect on cloud microphysics
- Controlled, well-defined aerosol injected into marine boundary layer

**Cloud-aerosol models**
- Simulate plume releases at multiple scales
- Experiments test against model findings
- Improve cloud-aerosol representation in climate models
- Critical advances in climate science


Marine Cloud Brightening Experimental Research Program

1. Land-based testing in a coastal environment

2. Cloud-aerosol interaction single-plume experiments

3. Limited Area Field Experiment

Substantial technology development is required

Particle generation
Ecologically benign, nanoscale

- 100 nanometer particles
- Narrow size distribution
- Benign (but corrosive) material (salt)
- Method: Effervescent spray, Taylor-cones

Delivery systems
Cloud-scale, energy-efficient

- \(10^{15}\) particles/second
- 100-200 bar pressure, 200-300kW power
- Research: commercial snow-makers
- Deployment: power-efficient, tunable

Observation & analytics
Multi-platform, analysis-intensive

- Surface LIDAR/RADAR
- Aircraft/drone
- Satellite
- Post-measurement analytics
- Pre/post modeling

Hard problem: Silicon Valley aerosol experts took 6 years to solve
MCB may have local or regional applications to reduce climate impacts

- Reduce hurricane strength
- Prevent coral bleaching
- Change precipitation patterns to increase moisture

Weakening of hurricanes via marine cloud brightening (MCB), Latham, et al, Atmospheric Science Letters 23 August 2012

The Effects of Marine Cloud Brightening on Seasonal Polar Temperatures and the Meridional Heat Flux, Parkes et al. ISRN Geophysics 2012

(Photograph courtesy of Christopher Michel)
Summary

• Introducing additional salt particles into marine low clouds can increase their ability to reflect solar radiation
• Models suggest offsetting significant fraction of greenhouse gas warming is feasible, but representing aerosol-cloud interactions in climate models is a major challenge
• Dual purpose research program will provide important scientific insights into a major problem in climate research, and new constraints for models.
Additional slides
## Marine Cloud Brightening Experimental Research Plan

<table>
<thead>
<tr>
<th>Stage 1: Sprayer tests</th>
<th>Stage 2: Cloud-aerosol interaction tests: single plume</th>
<th>Stage 3: Limited Area Field Experiment (LAFE)</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Test [location]</strong></td>
<td><strong>Test [location, season]</strong></td>
<td><strong>Test [location, season]</strong></td>
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<tr>
<td>Indoor dispersion test [Ames Hangar]</td>
<td>Coastal cloud impacts [California coastal site, Spring/Summer]</td>
<td>Ground sites, Aircraft, Tethered Balloon [3-6 mo]</td>
</tr>
<tr>
<td>Duration</td>
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<tr>
<td>1-3 mo (repeats as needed)</td>
<td>1-2 mo</td>
<td>1-2 mo</td>
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<td><strong>Key Equipment [Analysis timescale]</strong></td>
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<tr>
<td>Particle size spectrometers [weeks]</td>
<td>Ground sites, Aircraft, Tethered Balloon</td>
<td>Cloud albedo responses to merged plume from 5-10 sprayers over 100x100 km region [NE Pacific ~500-1000 km offshore, Spring/Summer]</td>
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<td><strong>Test [location, season]</strong></td>
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<tr>
<td><strong>Outdoor dispersion test [Chico?]</strong></td>
<td>Single shiptrack [~100 km offshore, Spring/Summer]</td>
<td>Ship-ready sprayer, short range research aircraft (1-3), satellites, research vessel? [3-6 mo]</td>
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<td><strong>Duration</strong></td>
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<td>1 mo</td>
<td>2-3 mo</td>
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<td><strong>Key Equipment [Analysis timescale]</strong></td>
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<td><strong>Key Equipment [Analysis timescale]</strong></td>
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<tr>
<td>Scanning lidar [month]</td>
<td>Cloud albedo responses to merged plume from 5-10 sprayers over 100x100 km region [NE Pacific ~500-1000 km offshore, Spring/Summer]</td>
<td>Ship-ready sprayers, multiple deployment platforms, long range research aircraft (3), satellites, research vessel [1-2 yr]</td>
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<td><strong>Duration</strong></td>
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<tr>
<td>1 mo</td>
<td>2-3 mo</td>
<td>3-5 years, $30m+</td>
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<tr>
<td><strong>Key Equipment [Analysis timescale]</strong></td>
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<td><strong>Key Equipment [Analysis timescale]</strong></td>
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<tr>
<td>Aircraft instrumented with particle size spectrometers [2-4 months]</td>
<td>Arbitrary [6 months]</td>
<td>Ship-ready sprayers, multiple deployment platforms, long range research aircraft (3), satellites, research vessel [1-2 yr]</td>
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<td>1-2 mo</td>
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Source: Kelly Wanser, Marine Cloud Brightening Project
Simple model calculations of global forcing from Twomey effect

- Assume 50% of marine low clouds area is subject to spraying
- Estimate mass of salt sprayed and forcing as a function of number of ships spraying and mass sprayed per ship
Aerosol technology: Exploding Annular Flow Mode
6-years to develop
Lab spray nozzle: 1 trillion particles/sec
Effervescent ECS nozzle in operation

(Snow-making; NOT making small particles)
Our experience with field programs..

Numerous other cloud/climate experiments in ocean and land locations