Assessing Marine Cloud Brightening as a Mechanism for Reducing Climate Risk

MARINECLOUD
— BRIGHTENING PROJECT —

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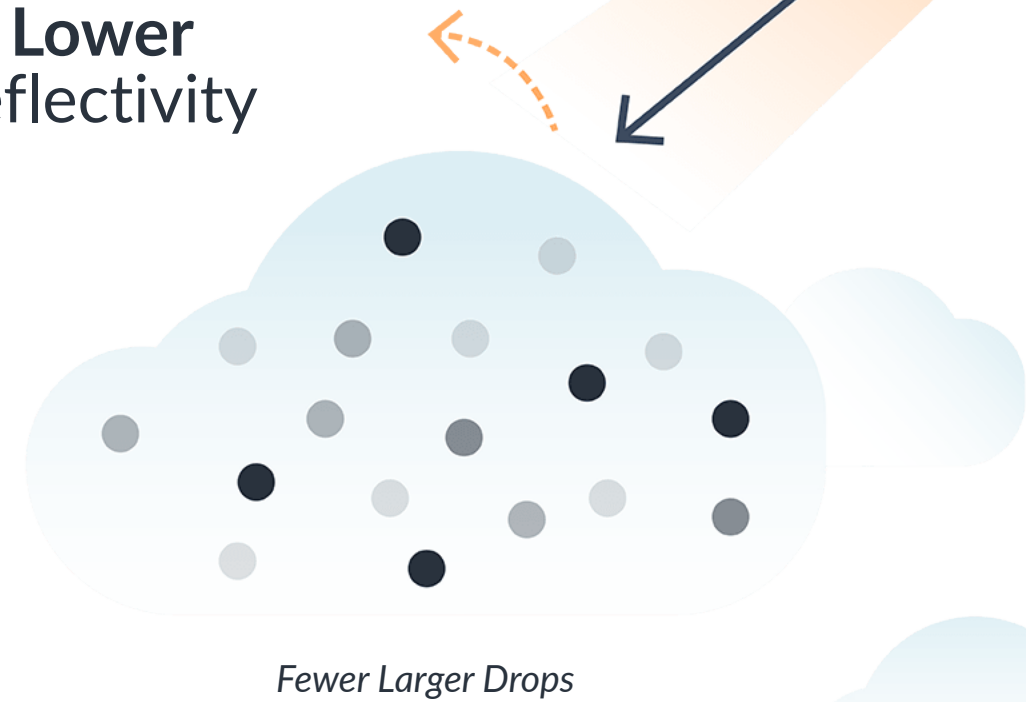
The Marine Cloud Brightening Project is a collaboration of >35 researchers across 5 institutions

UNIVERSITY of WASHINGTON
parc
University of Victoria
Pacific Northwest NATIONAL LABORATORY
OLD SALTS
SILVER LINING

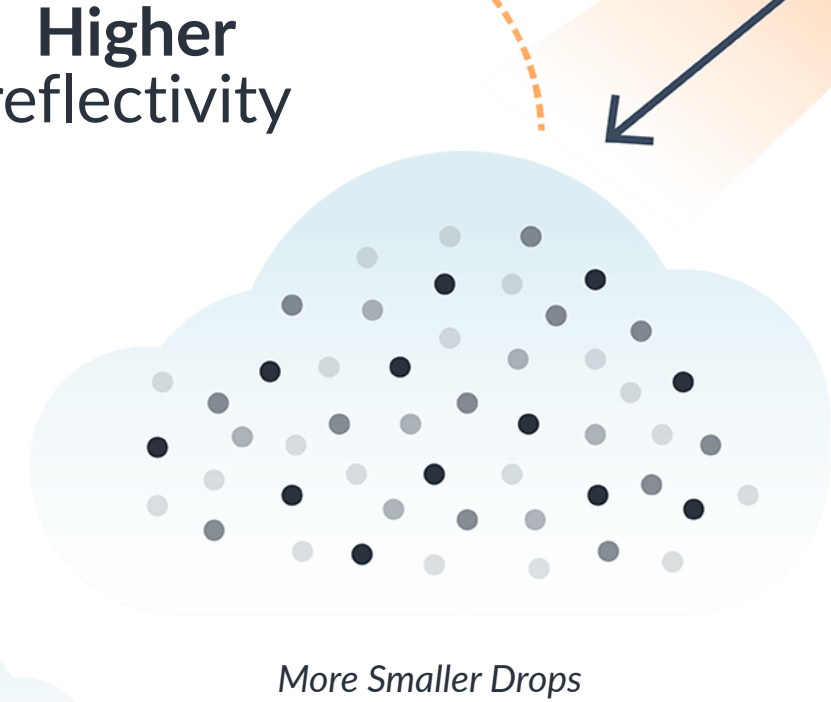
BASIC PRINCIPLE BEHIND MARINE CLOUD BRIGHTENING

Lower reflectivity



Fewer Larger Drops

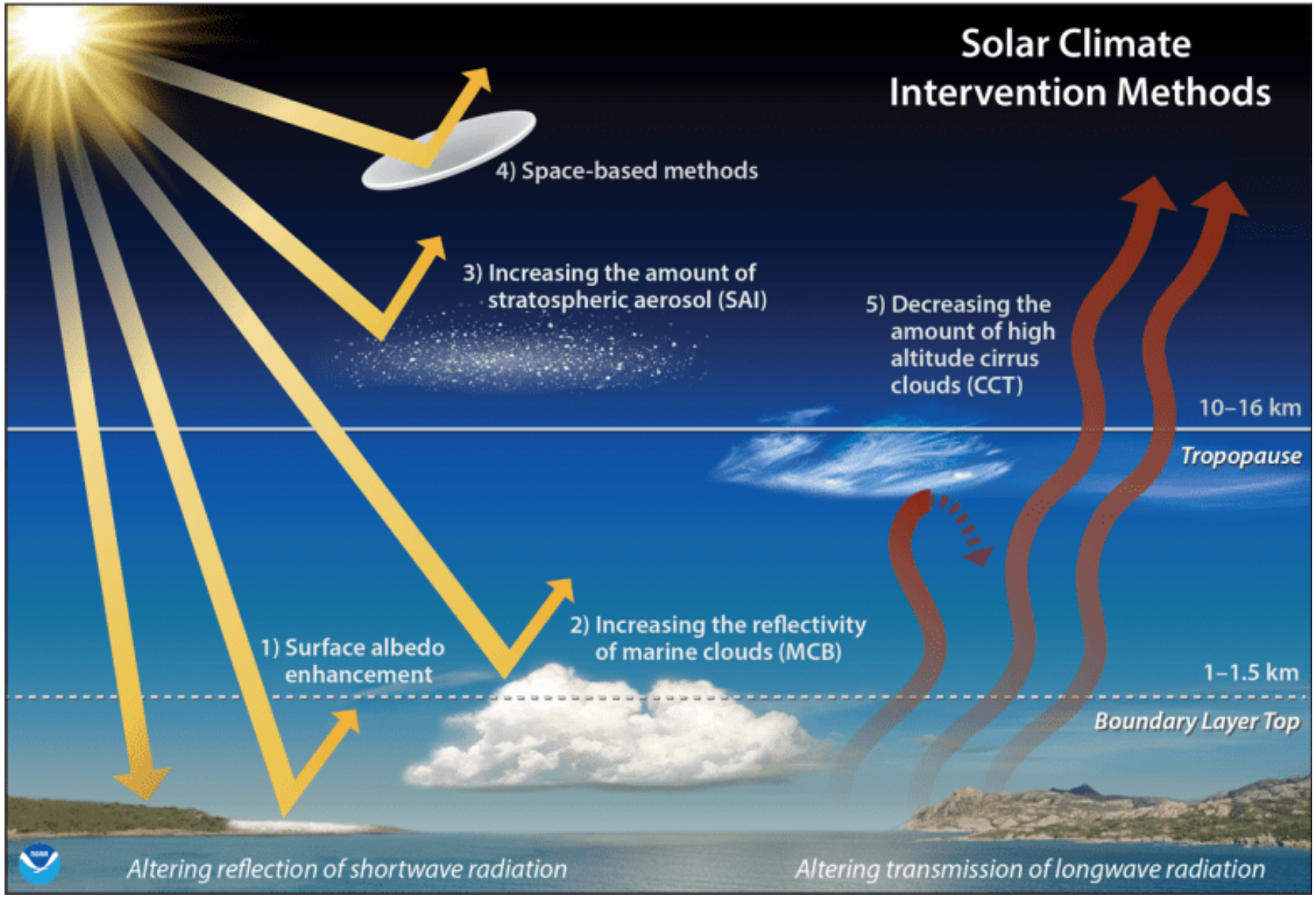
Higher reflectivity



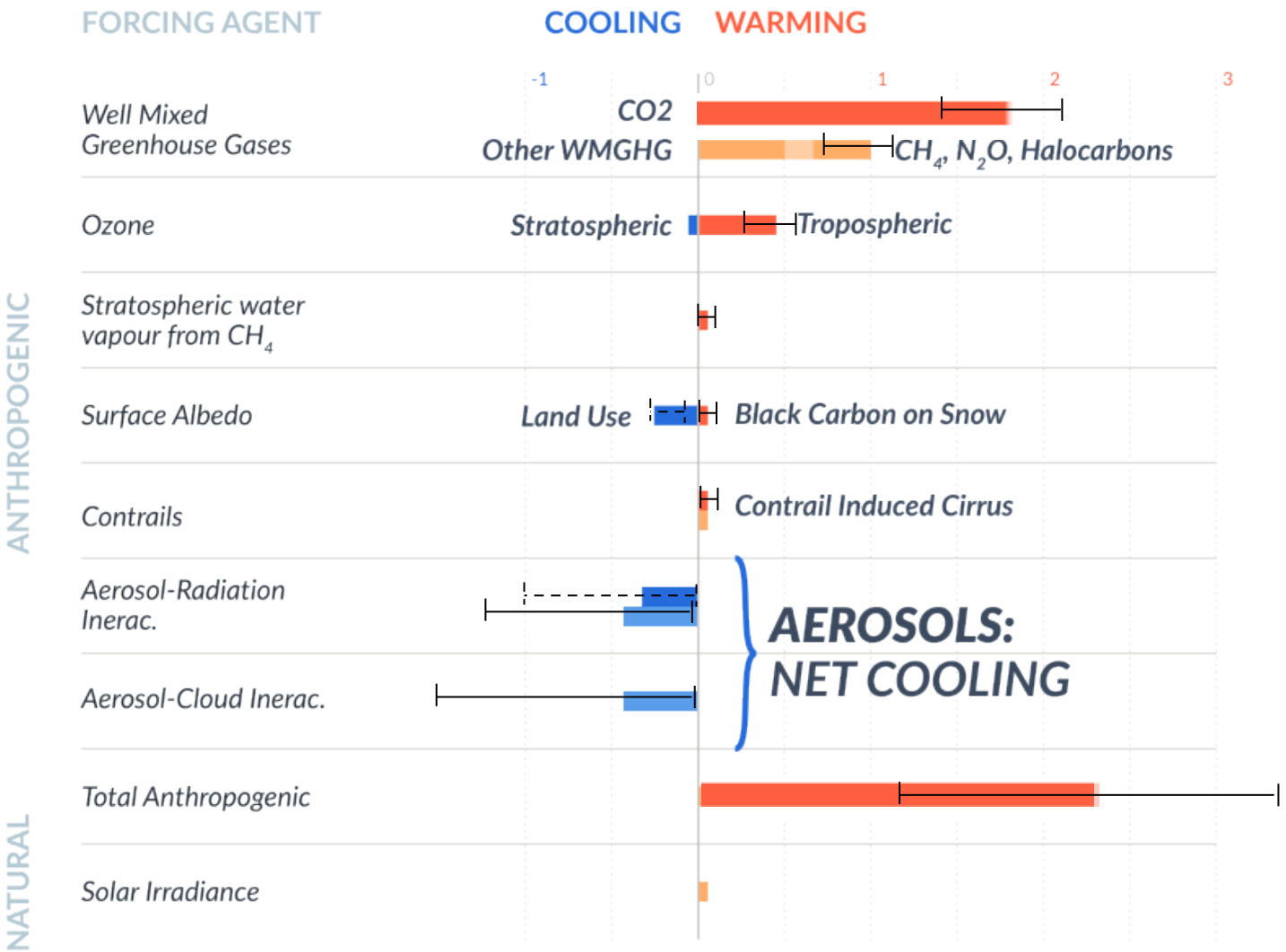
More Smaller Drops

Source: [1]*Ship tracks over the Northern Pacific, March 4, 2009;*
[2]*Wikipedia Commons.*

MARINE CLOUD BRIGHTENING IS ONE OF A NUMBER OF DIFFERENT PROPOSED SOLAR CLIMATE INTERVENTION METHODS



RADIATIVE FORCING *1750-2011*



"Aerosols and their interactions with clouds ..continue to contribute the largest uncertainty to the total ***[Radiative Forcing]*** *estimate."*

IPCC 5th Assessment, 2013, Summary for Policymakers p. 13-14.

IDEA:

BRIGHTEN CLOUDS WITH SEA-SALT SPRAY FROM SHIPS

Estimate:

- Several thousand ships,
  each spraying **~10^{16}** particles/second
- Particles are **~100 nm** diameter sea salt
- Injected into regions of marine clouds,
  could offset a significant fraction of the warming
  from increasing greenhouse gases

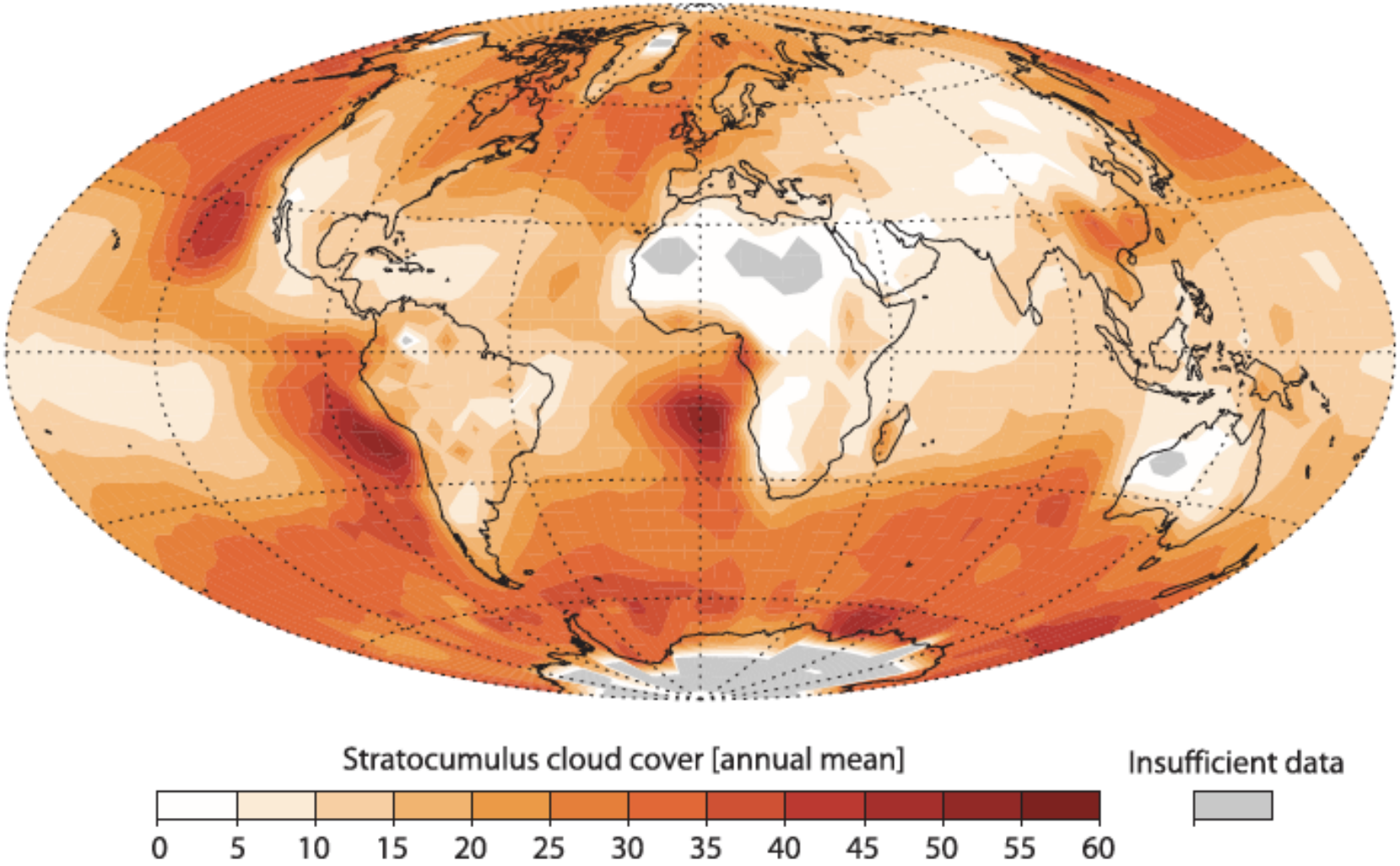
Source: [1]*Salter et al., Phil. Trans. R. Soc. A (2008), 366, 3989–4006;*
[2] *Wood, R. Atmos. Chem. Phys. (2021), 19, 14507-14533*

TARGET: LOW MARINE CLOUDS

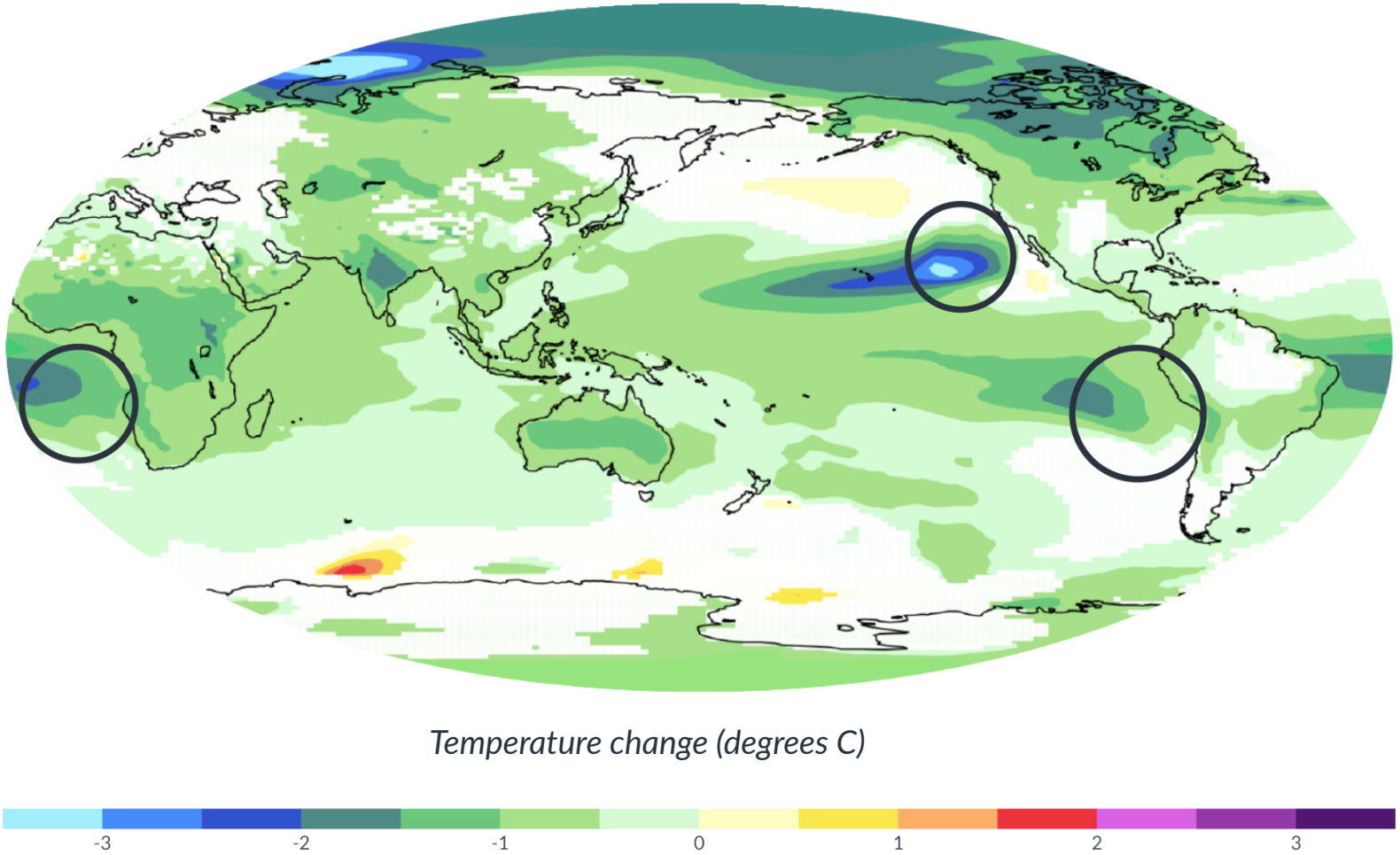
Oceans

Stratocumulus coverage: ***22%***

Cumulus coverage: ***13%***



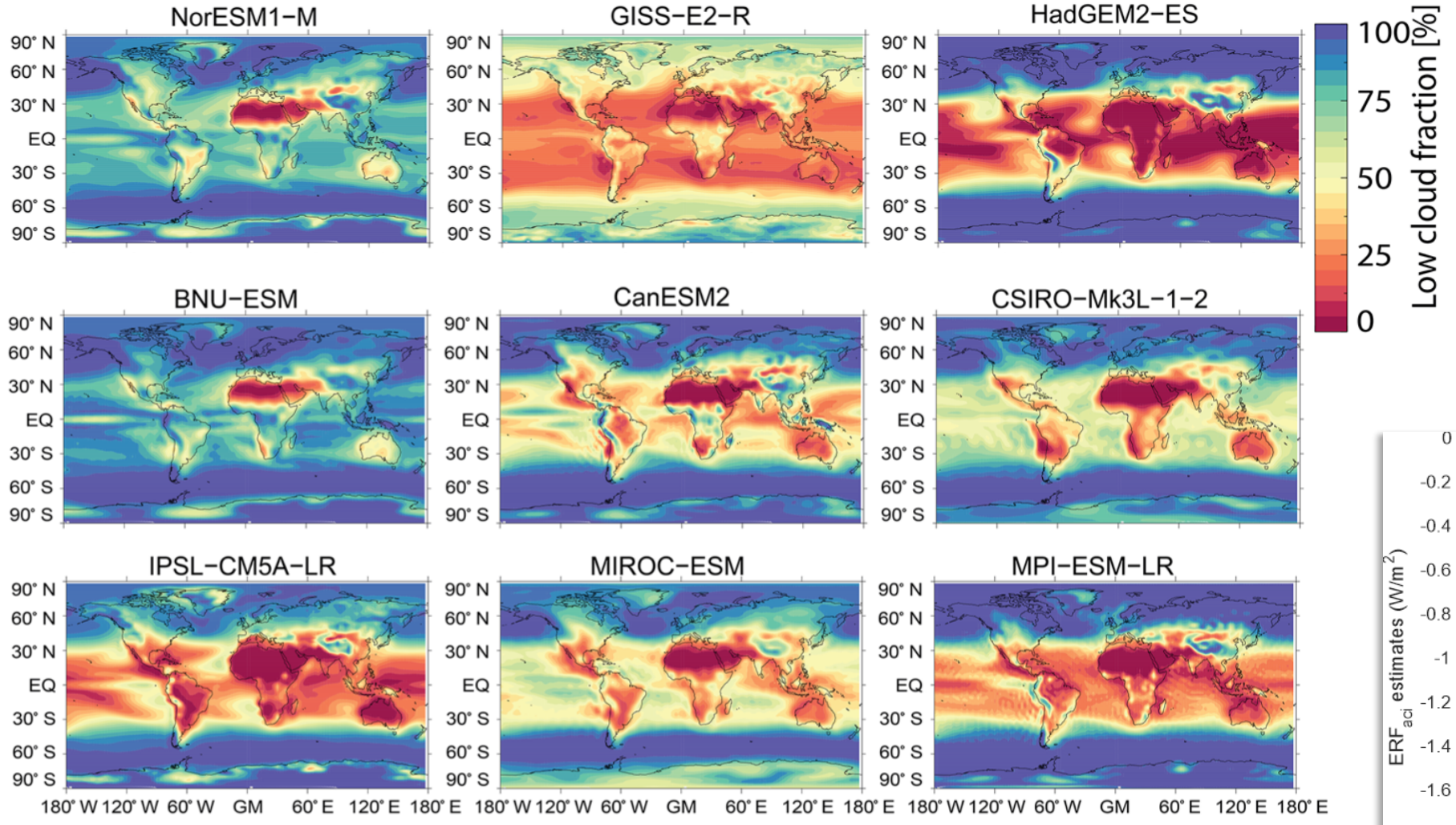
GLOBAL COOLING WITH REGIONAL MCB IMPLEMENTATION



Source: *Data by Jones et al., 2009.*

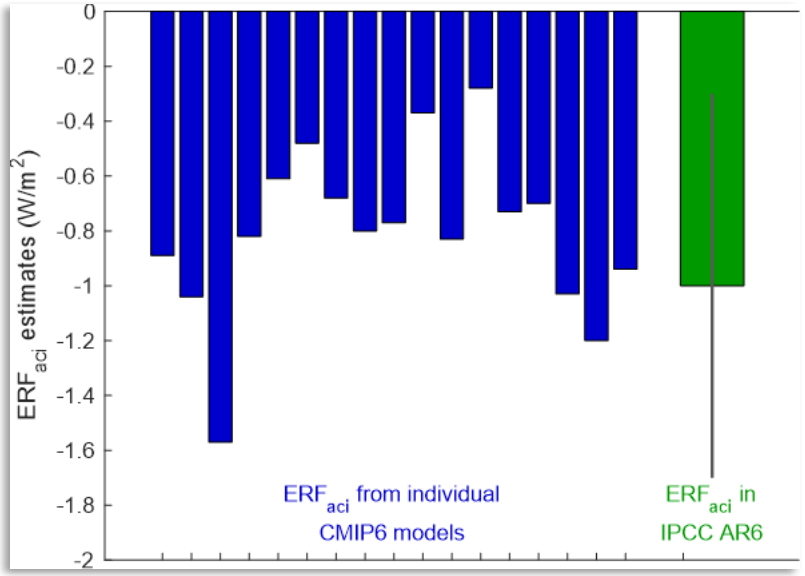
GLOBAL MODELING OF CLIMATE IMPACTS OF MCB

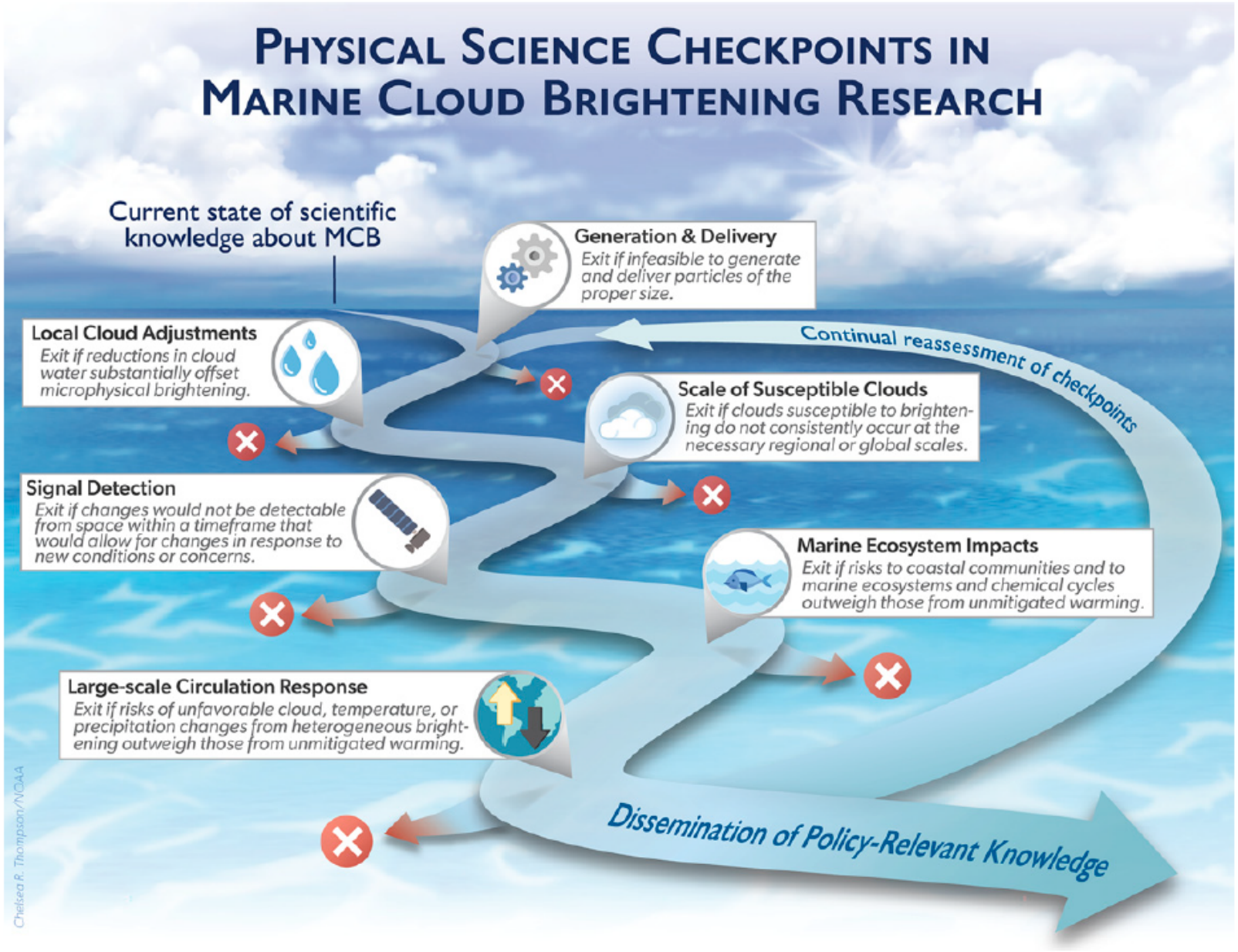
An issue: Poor representation of low clouds in global models



Source: *Stjern et al., 2018*

Global models also have large variability in climate forcing from aerosol-cloud interactions (ERFaci)





Can we generate the right aerosols at the required scale?

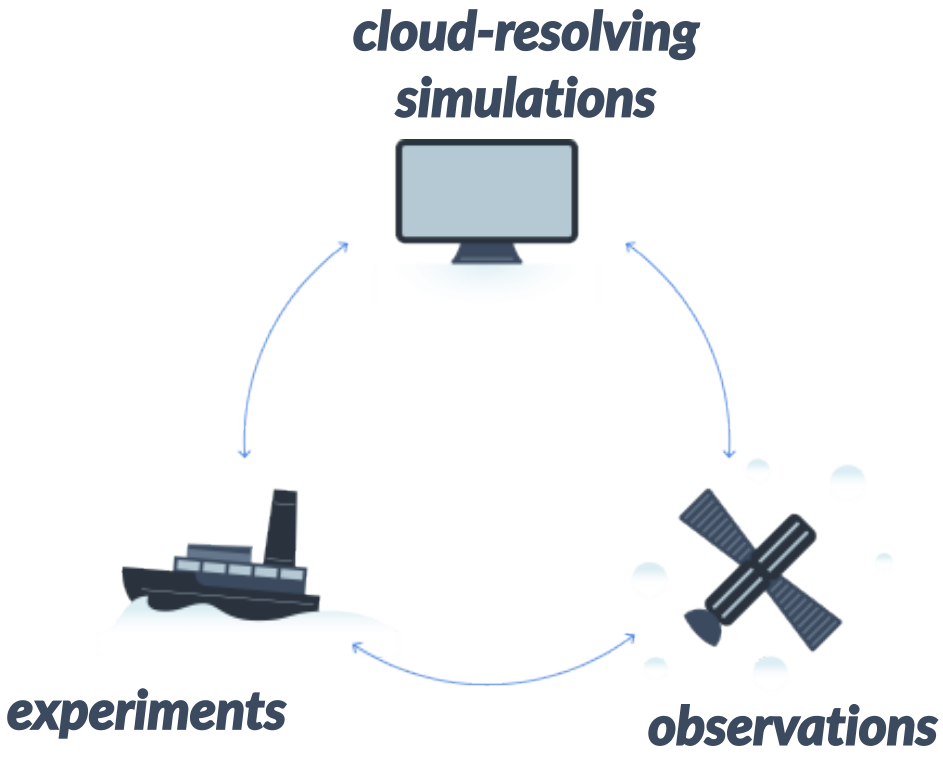
What is the effect on marine clouds under various conditions?

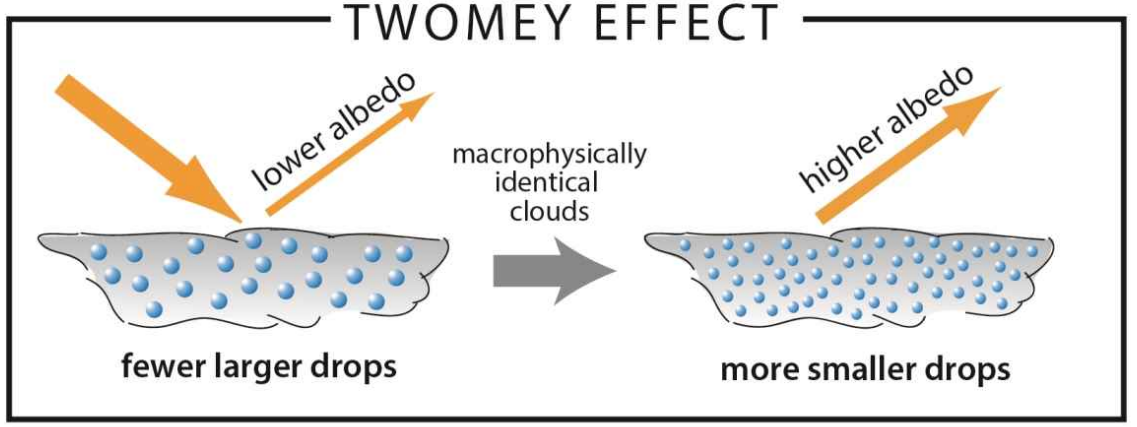
How much cooling could be achieved with MCB?

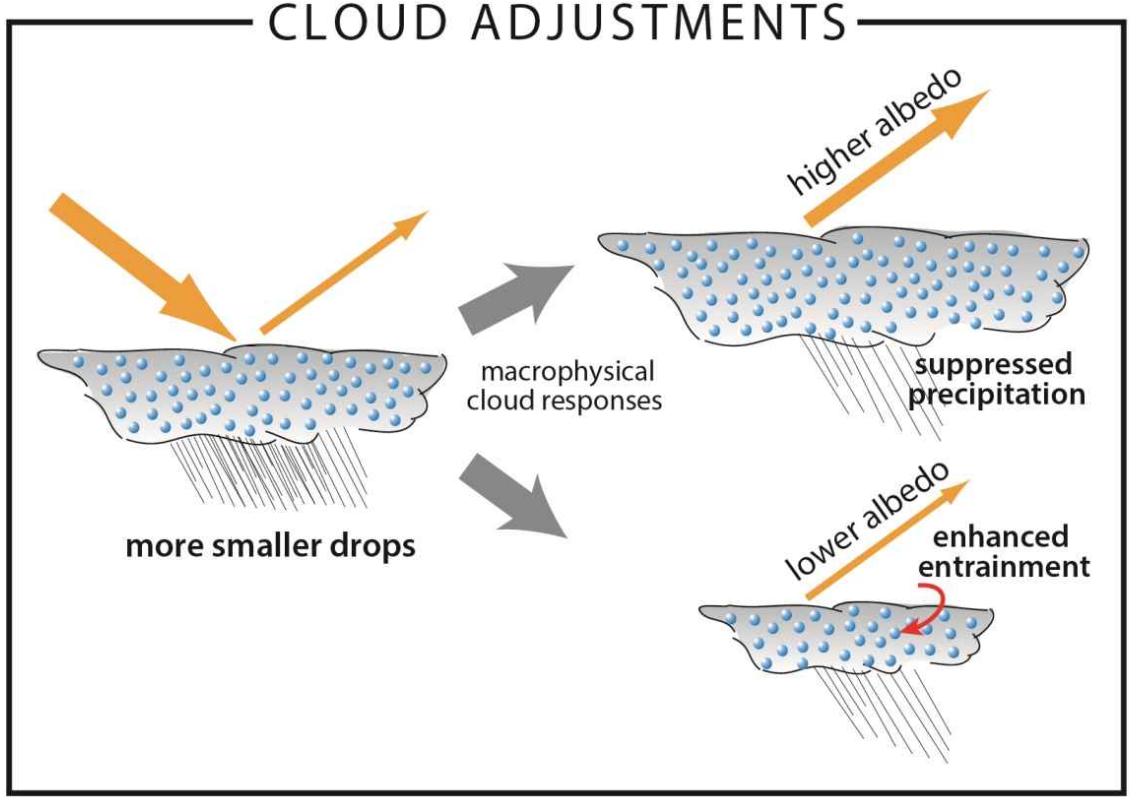
What are the global effects and regional impacts?

Diamond et al, (2022). **Opinion: To assess marine cloud brightening's technical feasibility, we need to know what to study—and when to stop.** *Proceedings of the National Academy of Sciences*, **119**. https://doi.org/10.1073/pnas.2118379119

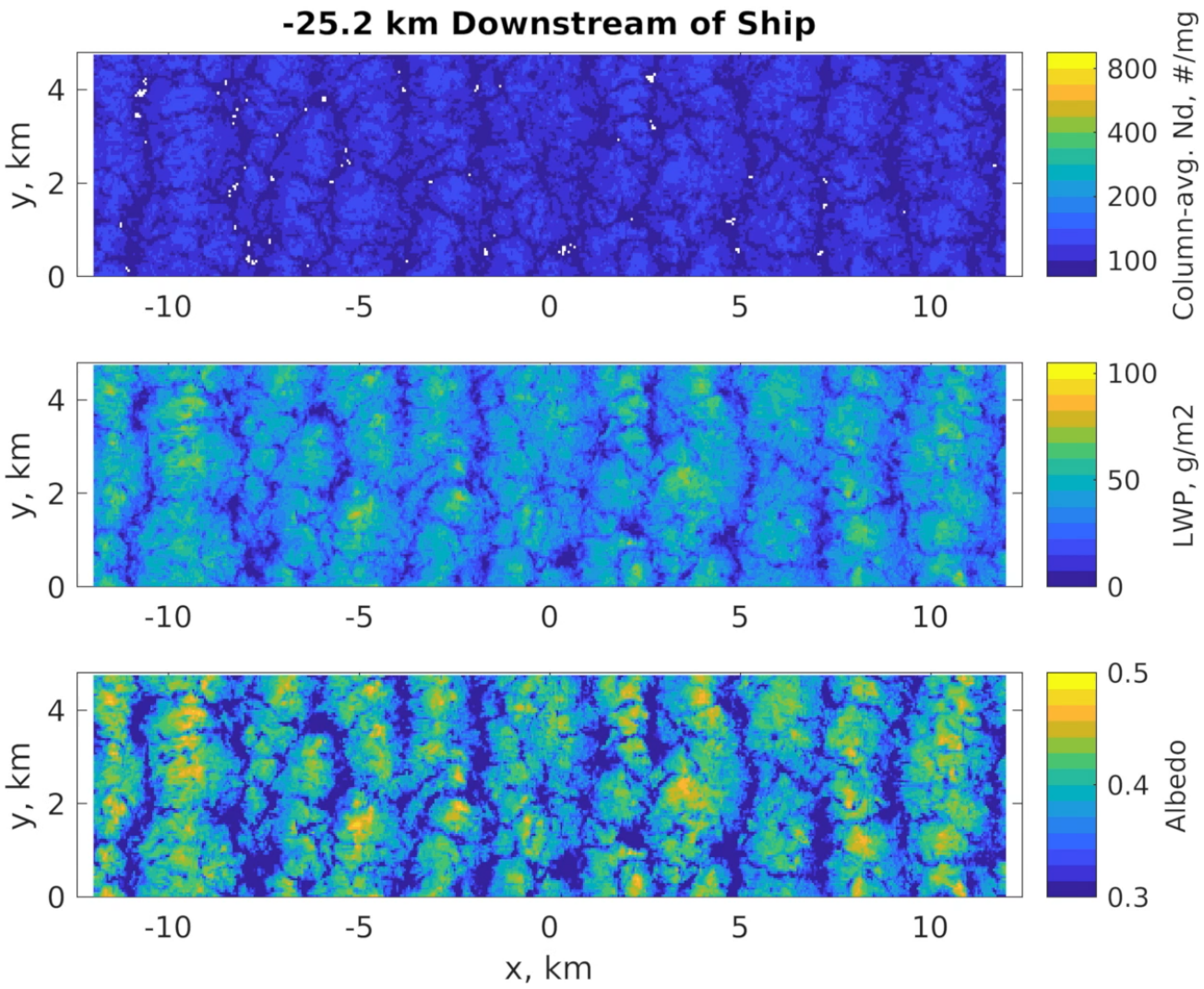
QUANTIFYING CLOUD RESPONSES







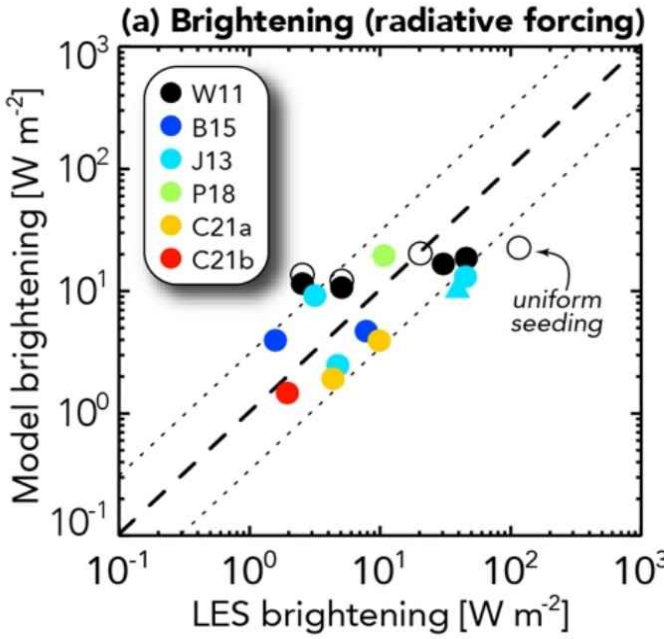
QUANTIFYING CLOUD RESPONSES: HIGH-RESOLUTION MODELING



DROPLET DENSITY

LIQUID WATER AMOUNT

REFLECTIVITY



Wood, R. (2021). **Assessing the potential efficacy of marine cloud brightening for cooling Earth using a simple heuristic model.** *Atmos. Chem. Phys.*, *21*, 14507–14533.

Chun, J.-Y., Wood, R., Blossey, P., & Doherty, S. J. (2023). **Microphysical, macrophysical, and radiative responses of subtropical marine clouds to aerosol injections.** Atmos. Chem. Phys, 23, 1345–1368.

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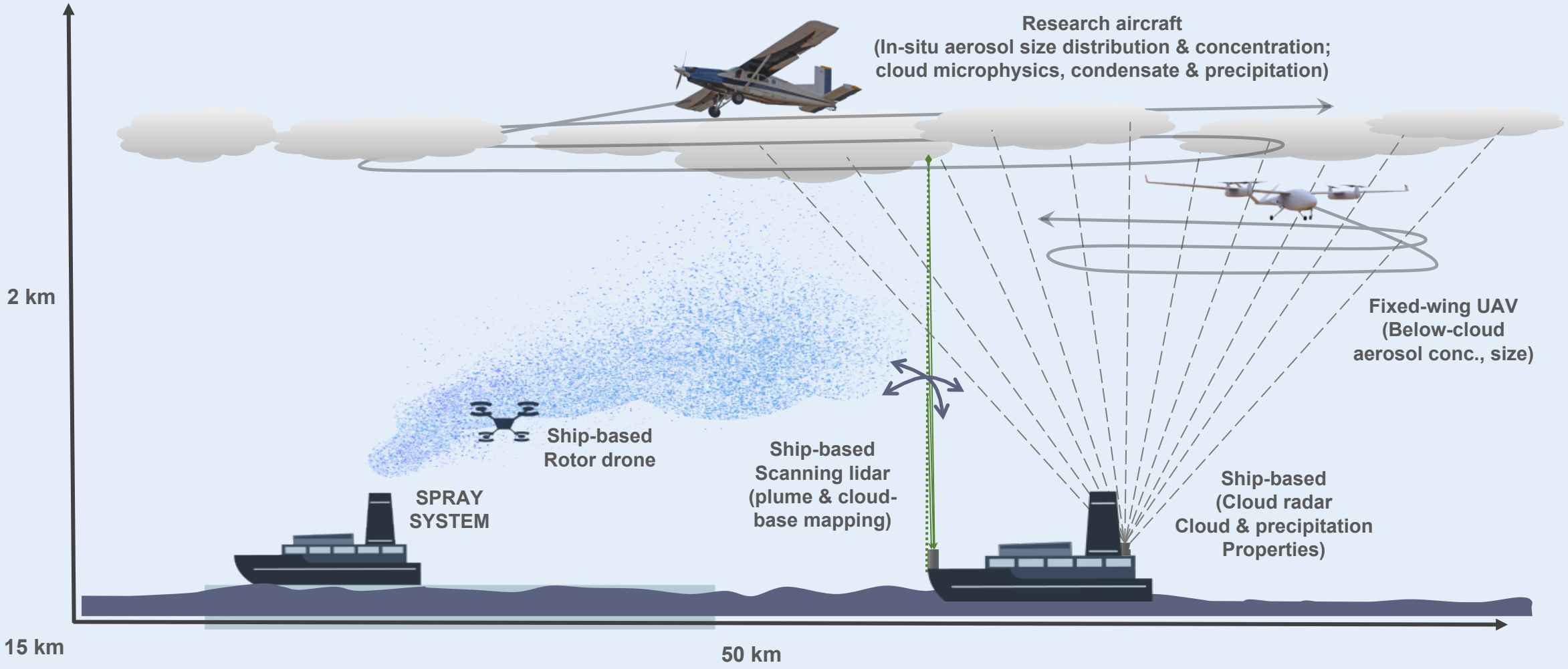
MARINE CLOUD BRIGHTENING PLUME STUDIES

Characterizes particle releases in the atmosphere to inform models of effects at larger scales.
The study design is based on the approach used for study of ship plumes and other pollution emissions.



Summary

- Marine Cloud Brightening has potential to cool Earth but much remains uncertain in terms of aerosol injection and delivery, local cloud adjustments and our understanding of cloud responses on regional scales
- Some conclusions
  - Salt particles <100 nm in diameter are most efficient in terms of maximizing forcing per mass sprayed.
  - Cloud macrophysical responses (adjustments of cloud cover and/or liquid water) remain poorly understood but LES models and field experiments can constrain these
- Field experiments using a spray system delivering ~10^{16} particles per second would provide critical tests of cloud-resolving and climate models for understanding MCB and aerosol-cloud interactions in general.

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— BRIGHTENING PROJECT —

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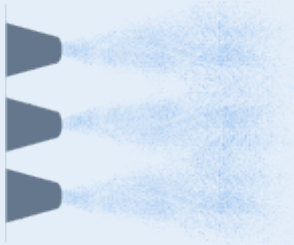
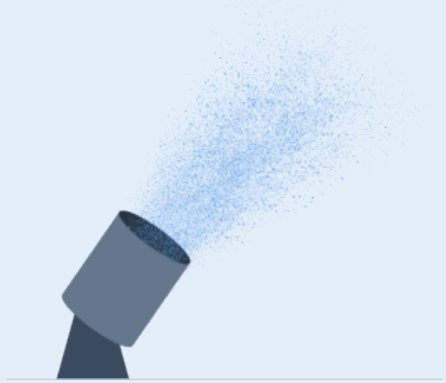
MARINE CLOUD BRIGHTENING RESEARCH PROGRAM: OVERVIEW

Program to reduce uncertainty in projections of the effects of marine cloud brightening and anthropogenic aerosols on clouds and climate

Phase 1: Indoor →



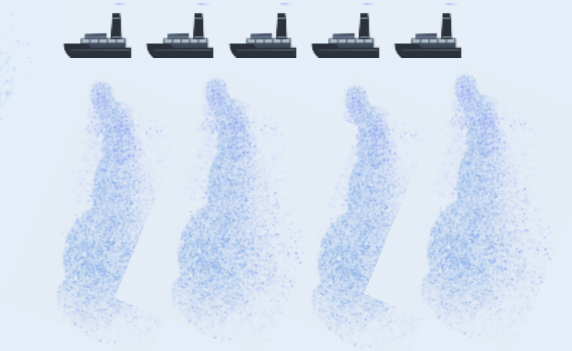
Aerosol generation and characterization (lab/benchtop studies)



Aerosol generation and characterization (full spray system indoor testing and scientific studies)

Phase 2: Field →

Single plume studies in the marine environment



Limited Area Field Experiment (LAFE) multiple ships/plumes over an area sufficient for studying brightening

Scientific data and modeling studies ----------→

CLIMATE MODELING AND IMPACTS ASSESSMENT

- **Global cooling**
- **Impacts**
  - Regional temperature, precipitation
  - Ocean surface temperature & biological impacts
- **Localized MCB**
  - Coral reef protection
  - Reducing hurricane intensity

Learning from MCB research

- *Improved aerosol cloud interactions*
- *Improved climate models*

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MARINE CLOUD BRIGHTENING RESEARCH PROGRAM: OVERVIEW

Program to reduce uncertainty in projections of the effects of marine cloud brightening and anthropogenic aerosols on clouds and climate

parc & OLD SALTS

Private Research & Innovation Lab: spray system development & testing for aerosol-cloud perturbation experiments

Pacific Northwest NATIONAL LABORATORY

DOE National Lab: spray system development; aerosol transport modeling; aerosol-cloud interaction modeling studies

SILVER LINING
ENSURING A SAFE CLIMATE

Focused Research Organization (NGO): fundraising; communications; government interface; coordinated research effort

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MCB RESEARCH PROGRAM: TEAM

Leading experts from atmospheric science, climate research and aerosol engineering.

Principals:

University of Washington

- Prof. Prof. Robert Wood, MCB Program Lead, Atmospheric Sciences
- Dr. Sarah Doherty, MCB Program Manager, CICOES
- Dr. Philip Rasch, Regional/Global Modeling Lead, UW, formerly DOE Pacific Northwest National Lab

PARC

- Dr. Sean Garner, Technology Development Lead, PARC
- Dr. Jessica Medrado, PARC
- Armand Neukermans, "Old Salts" Lead, Engineer, retired

SilverLining

- Kelly Wanser, Program Development, Policy and Communications Advisor, SilverLining

Univ. of Washington Team:

- Thomas Ackerman, Emeritus Faculty, Atmospheric Sciences
- Dr. Peter Blossey, Research Scientist, Atmospheric Sciences
- Dr. Matthew Wyant, Research Scientist, Atmospheric Sciences
- Ehsan Erfani (now Assistant Research Professor, Desert Research Institute)
- Kyoungock Choi, Postdoctoral Fellow, Atmospheric Sciences
- Je-Yun Chun, Graduate Student, Atmospheric Sciences
- Celeste Tong, Graduate Student, Atmospheric Sciences
- Emily Norton, Research Staff, CICOES
- Lucas McMichael, Postdoctoral Fellow, Atmospheric Sciences

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RELATED US FEDERAL AND AGENCY PROGRAMS

The MCB research effort is integrated with federal agency science and seeks to leverage agency capabilities for research and observation coverage over time.

Current collaborations

NOAA Earth's Radiation Budget Program: *current grant recipient*

DOE Atmospheric System Research program: *current grant recipient*

NCAR et al (and SilverLining) ARISE: *global climate modeling for MCB*

Amazon computing credits for global modeling

Likely collaborators on future field work

NOAA observing platforms: autonomous aerial platform, aircraft

DOE observing programs: aircraft and ARM programs

State: scientific cooperation and UN scientific assessment programs