Proposed $1B Marine Cloud Brightening Experimental Research Fund

By ChatGPT 5.6

August 10, 2026 | v1h |

Table of Contents

What is Marine Cloud Brightening (MCB)?

Prompt to AI: Summarize Marine Cloud Brightening (MCB) in roughly 300 words.

Response From AI:

Marine Cloud Brightening (MCB) is a proposed form of solar radiation modification intended to cool the climate by making selected low marine clouds reflect more sunlight back to space. The leading concept would use seawater as the feedstock. Shore-based systems, ships, or autonomous vessels would generate very large numbers of carefully sized sea-salt aerosol particles and release them into the marine boundary layer beneath or near susceptible clouds.

Some emitted particles could act as cloud-condensation nuclei. If the same amount of cloud water is divided among a larger number of smaller droplets, the cloud can become brighter—the first aerosol indirect effect often associated with Twomey. Changes in drizzle, evaporation, mixing, cloud thickness, and cloud lifetime can either strengthen or weaken the initial brightening. The response therefore depends on particle size and number, background aerosol, cloud type, updraft speed, humidity, atmospheric stability, precipitation, and the organization of the cloud field.

MCB differs from stratospheric aerosol injection in several important respects. The material remains in the lower atmosphere for only days rather than a year or more; the forcing is geographically concentrated; and the immediate scientific problem is an aerosol–cloud–meteorology interaction rather than long-lived stratospheric aerosol chemistry. These features may make MCB more controllable, but they also make performance highly weather-dependent and difficult to scale from a plume to a regional or global climate effect.

MCB would not remove carbon dioxide, stop ocean acidification, or eliminate the need to reduce greenhouse-gas emissions. Potential side effects include changes in regional precipitation, circulation, storm tracks, marine-cloud cover, air quality, visibility, salt deposition, ecosystems, and distant climate patterns such as ENSO. Benefits and harms could be unevenly distributed.

MCB has been studied in models, natural analogues such as ship tracks, laboratory work, and a limited number of outdoor aerosol-generation campaigns. It has not been demonstrated as a global climate intervention. A credible research program should therefore focus on whether sea-salt particles can be generated, transported, measured, modeled, and shown to produce repeatable cloud and radiative responses under defined conditions—without assuming that technical feasibility implies permission to deploy.

MCB Field Experiments - $1B Fund

Prompt to AI: If a Funding Source wants to spend $1B on Marine Cloud Brightening research, especially field experiments, over 5 years, what experiments should it consider?

Response From AI:

A $1 billion, five-year program should not attempt to demonstrate regional or global climate control. It should determine whether MCB can be predicted, measured, governed, and stopped well enough to justify any later research. The most important scientific chain is:

> Seawater intake and aerosol generation → near-source plume evolution → boundary-layer transport and dilution → arrival at cloud base → cloud-droplet activation → cloud optical and dynamical response → regional radiative and weather effects

Major uncertainty remains at every link. The program should therefore combine laboratory work, source engineering, natural experiments, carefully bounded outdoor releases, aircraft and ship observations, cloud-resolving models, regional and global models, ecological monitoring, and independent governance.

Illustrative $1 billion portfolio

Program	Five-year budget	Main purpose
1. Baseline marine-cloud and aerosol observatory network	$90M	Measure untreated clouds, aerosol, meteorology, radiation and precipitation across candidate regions.
2. Sea-salt source engineering and laboratory characterization	$100M	Develop controllable particle generators; map size, number, energy, salinity and impurities.
3. Shore-based source-and-plume experiments	$100M	Measure near-field evaporation, crystallization, coagulation, lofting, deposition and detectability.
4. Ship and autonomous-platform plume campaigns	$120M	Track sea-salt plumes from moving marine sources to cloud-base height under varied conditions.
5. Small cloud-response experiments	$180M	Conduct tightly bounded releases beneath susceptible clouds and measure microphysical and radiative response.
6. Replicated multi-platform cloud campaigns	$120M	Repeat cloud-response experiments across seasons, regions and cloud regimes with aircraft and remote

Program	Five-year budget	Main purpose
		sensing.
7. Natural experiments and ship-track program	$60M	Use shipping-emission changes and other perturbations to constrain aerosol–cloud causal effects.
8. Deposition, ecology, air quality and marine effects	$55M	Measure salt deposition, visibility, coastal exposure and ecological consequences.
9. Cloud-resolving, regional and global modeling	$70M	Assimilate observations; test scale-up, regional teleconnections and control strategies.
10. Shared aircraft, ships, drones, lidar, radar and instruments	$55M	Build reusable observing and mission-control capability.
11. Governance, permitting, engagement and international participation	$30M	Independent review, public process, Indigenous and climate-vulnerable participation.
12. Independent replication and rapid-response reserve	$20M	Repeat key results and respond to natural analogues, instrument failures or unexpected findings.

Approximately $600–700 million would directly support observations and field campaigns. The remainder would make those campaigns interpretable, reproducible, and publicly credible.

The most valuable experiments

1. Baseline mapping of susceptible cloud regimes

Before deliberate releases, conduct repeated campaigns in eastern-boundary stratocumulus regions, trade-wind cumulus regions, mid-latitude marine clouds, and one coral-reef region. Measure aerosol number and size, cloud-condensation nuclei, cloud-droplet number, liquid-water path, cloud fraction, drizzle, precipitation, updrafts, turbulence, inversion strength, humidity, winds, radiation and sea-surface temperature. Baselines must capture seasonal cycles and day-to-day meteorological variability because cloud changes caused by weather can easily exceed the expected signal from a small experiment.

2. Aerosol-generator characterization

Test multiple methods for producing submicron sea-salt particles from seawater. Characterize dry-particle size distribution, production rate, energy use, droplet evaporation, salt composition, organic impurities, nozzle fouling, corrosion, wind sensitivity and reliability. The acceptance metric should not be litres of seawater sprayed; it should be the number of useful cloud-active particles delivered per unit of energy and per hour of operation, with tight control of the coarse-particle tail.

3. Shore-based source-and-plume experiments

Operate a generator from a coastal or offshore research facility without attempting to brighten clouds. Use towers, drones, tethered balloons, lidar, aerosol counters and downwind boats to measure the first seconds through several hours of plume evolution. This is the least expensive way to resolve evaporation, crystallization, coagulation, salt deposition, plume rise, entrainment and the effect of ambient humidity and turbulence.

4. Moving-vessel plume transport experiments

Mount a modular generator on a research ship or autonomous surface vessel and follow the plume with a second vessel, drones, aircraft and remote sensing. Vary vessel speed, release height, wind direction, source rate and particle distribution. Determine what fraction of emitted particles survives and reaches cloud base, and whether source-inversion models can reconstruct the known release.

5. Natural ship-track and shipping-regulation studies

Use satellite imagery, aircraft measurements and changes in shipping emissions to quantify how aerosol perturbations affect real marine clouds. Ship tracks are imperfect analogues because combustion particles differ from sea salt, yet they provide a much larger observational sample than deliberate experiments. The program should maintain an open global ship-track database linked to meteorology, ship activity, fuel rules and cloud state.

6. Small cloud-response experiments

Conduct short releases beneath or upwind of a single cloud element or a small cloud field. Compare treated and untreated air using a crossing or randomized release design. Measure aerosol at cloud base, cloud-droplet number, droplet radius, liquid-water content, optical depth, reflected shortwave radiation, cloud-top height, drizzle and entrainment. The success criterion is a closed causal chain from known emission to measured radiative response—not a surface-temperature change.

7. Paired particle-size experiments

Under closely matched conditions, compare a narrow distribution centered in the expected useful submicron range with distributions containing more ultrafine or coarse particles. This directly tests a central result of models: too-small particles may not activate, while a small coarse-particle tail can accelerate collision–coalescence and drizzle, potentially reducing cloud water and offsetting brightening.

8. Cloud-regime comparison

Repeat the same source and measurement design in closed-cell stratocumulus, open-cell stratocumulus, precipitating and nonprecipitating clouds, and shallow cumulus. MCB may work only in a subset of conditions. A program should learn when not to spray as clearly as when spraying produces an effect.

9. Radiative and dynamical closure campaigns

For selected releases, combine in-situ aerosol and cloud probes, airborne and ground-based radar and lidar, microwave radiometers, broadband and spectral radiometers, satellite retrievals, and large-eddy simulations. Require agreement among released particle number, observed activation, cloud optical response and top-of-atmosphere shortwave change within a stated uncertainty budget.

10. Downwind, deposition and ecological monitoring

Track sea-salt aerosol and altered clouds after the primary sampling period. Measure salt deposition on the ocean and coast, aerosol exposure, visibility, chemistry, impacts on solar generation, marine-surface microlayer properties, and any detectable ecological response. Small experiments are unlikely to produce measurable ecosystem effects, but methods and baseline data must be established before larger research.

11. Blind detection and attribution exercise

An approved release team would disclose the experiment to regulators and independent oversight but withhold exact time and route from a second scientific team. The second team would use radar, lidar, satellites, aircraft, drones and trajectory models to determine whether a release occurred, where it went, and whether a cloud response can be attributed to it.

12. Regional-model falsification tests

Before each field campaign, modeling teams should preregister predictions of plume location, cloud-droplet response, optical depth, drizzle and reflected sunlight. After the campaign, compare predictions against withheld data. Models that cannot reproduce small, observed perturbations should not be trusted to project regional or global MCB impacts.

Five-year sequence

- Year 1: governance, baseline observations, aerosol-generator laboratory work, instrument development, natural-experiment analysis and preregistered modeling.
- Year 2: shore-based plume experiments, moving-vessel plume experiments, drone and lidar validation, and first very small cloud-interaction trials if approved.
- Year 3: replicated cloud-response campaigns, paired particle-size tests, radiative closure and expanded ecological and deposition monitoring.
- Year 4: additional regions, seasons and cloud regimes; independent replication; multi-platform campaigns; regional-model evaluation.
- Year 5: repeat the most informative experiments, conduct blinded prediction challenges, complete international assessment and identify explicit stop or proceed criteria. Completion of Year 5 would not authorize deployment.

Boundaries I would impose

- No experiment designed to produce a detectable regional climate or ocean-temperature change.
- No multi-week regional treatment during the first five-year program unless separately authorized after an independent assessment.
- No use of additives other than seawater-derived material without toxicology, chemistry and ecological review.
- No proprietary atmospheric data, undisclosed releases or secret operating routes.
- No claim of efficacy based only on aerosol production; useful delivery to cloud base and a measured cloud/radiative response are required.
- No scale increase unless the preceding stage meets preregistered scientific, environmental, engagement and monitoring criteria.
- No coupling of research authorization to a promise of later commercial deployment.

Source-and-Plume vs Cloud-Response Experiments

Prompt to AI: MCB field research can be divided into (a) source-and-plume experiments and (b) cloud-response experiments. How much effort and funding would you put into each experiment family, and why?

Response From AI:

I would treat the two families as sequentially linked. Source-and-plume experiments establish whether the program can produce and deliver a known aerosol perturbation. Cloud-response experiments determine whether that perturbation produces a measurable, repeatable and beneficial change in cloud reflectivity.

Recommended division of effort

Experiment family	Share of controlled field budget	Illustrative campaigns	Primary question
Source-and-plume	45%	10–16 campaigns	Can a known, useful particle population be produced, tracked and delivered to cloud base?
Cloud-response	55%	6–10 larger campaigns	Does the delivered perturbation change cloud droplets, cloud amount, drizzle and reflected sunlight as predicted?

Within the overall $1 billion program, an illustrative allocation is $230 million for source-and-plume field work, $280 million for cloud-response field work, $160 million for shared observing platforms and instruments, and $330 million for baseline observations, natural analogues, modeling, ecology, governance, independent evaluation and reserve.

1. Source-and-plume experiments: 45%

These experiments answer the engineering and atmospheric-delivery question. The generator must create a sufficiently narrow distribution of sea-salt particles, avoid an excessive coarse tail, and emit enough useful particles that a measurable fraction survives evaporation, coagulation, dilution and deposition.

The plume will not remain a clean line. Wind shear, turbulence, convective mixing and changes in boundary-layer depth will create a widening three-dimensional filament. Particle measurements should be made from metres behind the source through tens of kilometres downwind and from the ocean surface to cloud-base height.

Key outputs should include useful cloud-condensation-nuclei delivered to cloud base per second, per kilowatt-hour, and per kilogram of seawater; plume width and vertical distribution versus time; salt deposition; and uncertainty in source reconstruction.

Experimental matrix

- Particle median diameter and width of the size distribution.
- Coarse-particle fraction and ultrafine-particle fraction.
- Seawater salinity, temperature, organics and filtration method.
- Nozzle or generator type, pressure, air-to-water ratio and release rate.
- Release height, vessel speed and orientation relative to wind.
- Stable, neutral and convective boundary layers.
- Dry and humid conditions, weak and strong turbulence, and different cloud-base heights.
- Single source versus multiple coordinated sources.

Measurements

- Particle number and size from a few nanometres through several micrometres.
- Cloud-condensation-nuclei spectra and hygroscopicity.
- Salt composition, water content and contamination.
- Wind, turbulence, temperature, humidity and boundary-layer depth.
- Plume geometry from lidar, radar, imaging and tracer measurements.
- Vertical transport and fraction reaching cloud-base height.
- Deposition to ocean, vessel and coastal surfaces.
- Generator power, reliability, corrosion, fouling and maintenance.

2. Cloud-response experiments: 55%

Cloud-response campaigns are more expensive because they require suitable clouds, accurate forecast and targeting, simultaneous aerosol and cloud measurements, treated and control regions, and enough repetitions to separate the aerosol signal from normal meteorological variability.

Each campaign should include several release and no-release periods under matched conditions. Randomization or alternating on/off patterns can improve causal attribution. A second untreated cloud line or nearby control region is desirable when meteorology permits.

The most important metric is top-of-atmosphere or cloud-top shortwave reflection attributable to the known aerosol perturbation, with secondary metrics covering droplet number, droplet size, liquid-water path, cloud fraction, drizzle and cloud lifetime.

Sampling sequence

- Pre-release: 2–6 hours of background aerosol, cloud and radiation measurements.
- Near-source: seconds to 30 minutes after emission.
- Cloud-base interception: repeated aircraft or drone transects as the plume enters cloud.
- In-cloud response: repeated transects through treated and control cloud elements.
- Cloud-top and radiative response: aircraft, lidar, radar and satellite observations over 1–8 hours.
- Follow-up: next-day or multi-day observations only when the perturbation remains detectable and scientific value justifies it.

The highest-value design: paired campaigns

The strongest tests would conduct a source-and-plume campaign immediately followed by a cloud-response campaign using the same generator, particle settings, site, forecast system and observing platforms. Four to six paired campaigns could directly compare the number of particles produced, the fraction reaching cloud base, the fraction activating as droplets, the change in cloud optical depth, and the measured reflected sunlight.

Sequencing over five years

- Years 1–2: approximately 70% source-and-plume and 30% cloud-response.
- Year 3: approximately equal effort, including paired campaigns.
- Years 4–5: approximately 30% source-and-plume and 70% cloud-response, emphasizing replication and radiative closure.
- Across the complete program: approximately 45% source-and-plume and 55% cloud-response.

Project Phases (i.e. what happens first)

Prompt to AI: With each experiment, what are the different phases, and how much might each phase cost?

Response From AI:

An experiment should be defined as a complete campaign containing multiple release and control periods. The figures below are order-of-magnitude planning estimates in constant 2026 dollars. They assume access to a research vessel, a second sampling vessel or aircraft, drones, remote sensing and a common program instrument suite.

1. Source-and-plume campaign

Phase	Principal work	Estimated cost
1. Scientific design	Hypotheses, release matrix, plume models, success criteria and uncertainty budget	\$0.8M–\$1.5M
2. Governance and environmental review	Permits, maritime and airspace review, engagement, environmental monitoring and stop criteria	\$0.7M–\$1.8M
3. Aerosol-source preparation	Generator, seawater intake, filtration, controls, calibration and ground testing	\$1.5M–\$3.0M
4. Instrument preparation	Particle sizing, CCN, chemistry, meteorology, lidar, drone payloads and calibration	\$2.0M–\$4.0M
5. Vessel and platform integration	Deck installation, power, data, structural, electrical and safety integration	\$1.5M–\$3.0M
6. Baseline and rehearsal	Background transects, inert or low-output tests, drone and vessel coordination	\$1.0M–\$2.0M
7. Release operations	Multiple release and control runs over 1–2 weeks	\$2.5M–\$5.0M
8. Plume tracking	Downwind vessel, drones, lidar, balloons and trajectory assimilation	\$1.5M–\$3.5M
9. Data and laboratory analysis	Particle survival, vertical transport, deposition and model comparison	\$2.0M–\$4.0M
10. Independent evaluation	Data audit, blinded prediction comparison, archive and review	\$0.5M–\$1.0M
11. Contingency	Weather, ship time, generator failure, instrument repair and replacement days	\$2.0M–\$4.0M

Repeat campaign after common capability exists: approximately $18M–$28M. First-of-a-kind campaign with substantial new generator and instrument development: approximately $28M–$40M.

2. Cloud-response campaign

Phase	Principal work	Estimated cost
1. Scientific design	Cloud-regime selection, causal design, release pattern, measurement matrix and preregistered predictions	$1.2M–$2.5M
2. Governance and environmental review	Expanded consultation, environmental assessment, aviation and maritime approvals	$1.2M–$3.0M
3. Generator and source validation	Flight/ship-ready source, particle-output verification, controls and safety	$2.0M–$4.0M
4. Cloud and aerosol instrument preparation	In-situ cloud probes, aerosol instruments, radar, lidar, radiometers and satellite products	$4.0M–$8.0M
5. Aircraft and vessel integration	Research aircraft, ship, drones, data links, certification and mission systems	$3.0M–$6.0M
6. Baseline characterization	Several days of untreated cloud, aerosol, radiation and meteorology observations	$2.0M–$4.0M
7. Release-day operations	Ship release, chase aircraft, drones, radar/lidar and mission center	$3.0M–$6.0M
8. Repeated cloud sampling	Multiple release/control days and control-region observations	$8.0M–$15.0M
9. Radiative and dynamical closure	Cloud microphysics, liquid-water path, drizzle, cloud fraction and radiation analysis	$4.0M–$8.0M
10. Regional modeling and attribution	Large-eddy simulations, data assimilation and causal/statistical analysis	$3.0M–$6.0M
11. Independent evaluation	External audit, withheld-data challenge, public archive and workshop	$0.8M–$1.8M
12. Contingency	Weather, unsuitable clouds, aircraft/ship downtime and replacement sorties	$5.0M–$10.0M

Repeat campaign after common capability exists: approximately $40M–$55M. First-of-a-kind campaign: approximately $55M–$75M.

3. Shared capability that should not be rebuilt for every experiment

Shared program capability	Five-year initial investment

Shared program capability	Five-year initial investment
Common sea-salt generator test and calibration facility	$20M–$35M
Modular shipboard generator and certified integration package	$20M–$40M
Aircraft aerosol and cloud microphysics payload	$30M–$50M
Drone, balloon and autonomous-vessel observing systems	$15M–$30M
Cloud radar, lidar and radiometer network	$20M–$40M
Forecasting, mission control and real-time data assimilation	$10M–$20M
Open data, governance and environmental-review infrastructure	$10M–$20M

Practical budgeting conclusion

- Source-and-plume repeat campaign: use approximately $22M as a central planning value.
- Cloud-response repeat campaign: use approximately $48M as a central planning value.
- Paired source/cloud campaign at one site: approximately $55M–$70M because ships, instruments, governance and forecasts can be shared.
- Incremental release during an active source campaign: approximately $300,000–$1M, but only if the scientific design benefits from replication.
- Incremental cloud-response day: approximately $1M–$3M because aircraft, ship, forecast and instrument teams must all remain deployed.

Purchase Orders

Prompt to AI: With each phase of each experiment, what are the different Purchase Orders (POs), grants, task orders, or subawards that might be issued?

Response From AI:

Below is an illustrative procurement structure for one repeat source-and-plume campaign costing approximately $22 million and one cloud-response campaign costing approximately $48 million. “PO” is used broadly; government aircraft, university research and international partners may require reimbursable agreements, grants, cooperative agreements or subawards.

A. Source-and-plume campaign

Phase 1: Scientific design — $1.20M

Procurement package	Deliverable	Estimate
SP1-01 Integrated science-design subaward	Hypotheses, release matrix, science traceability matrix and success criteria	$500,000
SP1-02 Near-field and boundary-layer modeling	Predictions of evaporation, crystallization, coagulation, plume rise and dispersion	$400,000
SP1-03 Independent design review	Published review and authorization, revision or refusal to proceed	$300,000

Phase 2: Governance and environmental review — $1.10M

Procurement package	Deliverable	Estimate
SP2-01 Regulatory and maritime legal services	Permit map, maritime jurisdiction, airspace and liability analysis	$250,000
SP2-02 Environmental assessment	Salt deposition, exposure, alternatives and monitoring plan	$350,000
SP2-03 Stakeholder and Indigenous engagement	Meetings, accessible materials, comment record and response document	$300,000
SP2-04 Independent governance panel	Conflict disclosures, stop/go decision and conditions	$200,000

Phase 3: Aerosol-source preparation — $2.50M

Procurement package	Deliverable	Estimate
SP3-01 Seawater intake and filtration skid	Corrosion-resistant intake, pumps, filters, sensors and cleaning system	$450,000
SP3-02 Aerosol generator modules	Interchangeable generator/nozzle assemblies with characterized output	$800,000
SP3-03 Flow, pressure and control system	Calibrated water/air metering, controls, logging and emergency shutdown	$350,000
SP3-04 Ground plume test stand	Outdoor or chamber tests across the operating envelope	$400,000
SP3-05 Spares, materials and maintenance	Nozzles, pumps, corrosion components, filters and cleaning supplies	$250,000
SP3-06 Independent output calibration	Particle size, number, coarse-tail and energy verification	$250,000

Phase 4: Instrument preparation — $3.00M

Procurement package	Deliverable	Estimate
SP4-01 Aerosol size-distribution package	Nanometre-to-micrometre aerosol number and size measurements	$650,000
SP4-02 CCN and hygroscopicity package	Activation spectra and particle water uptake	$450,000
SP4-03 Aerosol composition package	Sea-salt composition, organics and contamination	$400,000
SP4-04 Meteorology and turbulence package	Fast wind, temperature, humidity and flux measurements	$350,000
SP4-05 Drone and balloon payloads	Vertical profiles of aerosol and meteorology	$450,000
SP4-06 Lidar and optical plume mapping	Plume geometry and boundary-layer structure	$400,000
SP4-07 Calibration and data system	Traceable calibration, synchronization, telemetry and spares	$300,000

Phase 5: Vessel and platform integration — $2.00M

Procurement package	Deliverable	Estimate
SP5-01 Generator-vessel integration	Deck mounts, power, seawater plumbing and release mast	$650,000

Procurement package	Deliverable	Estimate
SP5-02 Sampling-vessel integration	Instrument racks, inlets, drone operations and data links	$450,000
SP5-03 Safety and marine engineering	Structural, electrical, corrosion, stability and emergency review	$350,000
SP5-04 Communications and mission systems	Ship-to-ship, drone and shore communications	$250,000
SP5-05 Acceptance testing	Harbor tests, vibration, electromagnetic and operating checks	$300,000

Phase 6: Baseline and rehearsal — $1.20M

Procurement package	Deliverable	Estimate
SP6-01 Baseline cruise block	Untreated aerosol, meteorology and deposition observations	$450,000
SP6-02 Forecasting and mission planning	Boundary-layer forecasts, trajectories and daily operating plans	$200,000
SP6-03 Low-output rehearsal	Detection test, vessel formation and drone interception practice	$200,000
SP6-04 Field logistics	Port, shipping, lodging, vehicles and workspaces	$250,000
SP6-05 Airspace and maritime coordination	Notices, permits and liaison support	$100,000

Phase 7: Release operations — $3.00M

Procurement package	Deliverable	Estimate
SP7-01 Generator-vessel mission order	Vessel, crew and multiple release/control runs	$950,000
SP7-02 Sampling-vessel mission order	Downwind aerosol transects and plume interception	$700,000
SP7-03 Drone operations	Repeated horizontal and vertical plume mapping	$450,000
SP7-04 Lidar and coastal observing	Plume location, boundary-layer height and transport	$300,000
SP7-05 Mission control and meteorology	Real-time forecasts, guidance and data display	$250,000
SP7-06 Standby and weather option	Reserved vessel and personnel availability	$350,000

Phase 8: Plume tracking — $1.80M

Procurement package	Deliverable	Estimate
SP8-01 Extended downwind vessel block	Longer-range plume searches and deposition sampling	$600,000
SP8-02 Aircraft or long-range drone option	Cloud-base-height and regional plume sampling	$450,000
SP8-03 Distributed balloon/drone profiles	Vertical transport and plume dilution	$250,000
SP8-04 Trajectory data assimilation	Updated plume location and uncertainty envelope	$300,000
SP8-05 Deposition network	Ocean, vessel and coastal deposition measurements	$200,000

Phase 9: Data and laboratory analysis — $3.10M

Procurement package	Deliverable	Estimate
SP9-01 Particle survival and activation analysis	Useful particle number versus distance, height and time	$600,000
SP9-02 Plume microphysics analysis	Evaporation, crystallization, coagulation and entrainment	$600,000
SP9-03 Vertical transport and source inversion	Cloud-base delivery fraction and reconstructed source	$500,000
SP9-04 Composition and deposition laboratory work	Salt, organics, contamination and deposition	$350,000
SP9-05 University science subawards	PI, postdoctoral and graduate analysis	$650,000
SP9-06 Computing, archive and quality control	Processing, uncertainty, metadata and synchronized dataset	$400,000

Phase 10: Independent evaluation — $0.70M

Procurement package	Deliverable	Estimate
SP10-01 Data-quality audit	Calibration, completeness and exclusion audit	$200,000
SP10-02 Blinded model challenge	Predictions against withheld plume observations	$250,000
SP10-03 Public repository	Data, code, generator settings and documentation	$150,000
SP10-04 Review workshop	External review and final campaign report	$100,000

Phase 11: Contingency — $2.40M

Procurement package	Deliverable	Estimate
SP11-01 Program-manager reserve	Unforeseen technical and scheduling requirements	$1,000,000
SP11-02 Replacement vessel or weather days	Missed plume, weather or mechanical downtime	$700,000
SP11-03 Generator and instrument repair options	Replacement nozzles, pumps, sensors and calibration	$450,000
SP11-04 Regulatory or schedule extension	Additional consultation, storage or delayed deployment	$250,000

Source-and-plume campaign total: approximately $22.0M.

B. Cloud-response campaign

Phase 1: Scientific design — $1.80M

Procurement package	Deliverable	Estimate
CR1-01 Integrated experiment design	Cloud regime, release/control design, traceability matrix and uncertainty budget	$700,000
CR1-02 Large-eddy and cloud-process modeling	Preregistered predictions of activation, drizzle, optical depth and cloud fraction	$600,000
CR1-03 Statistical and causal design	Randomization, controls, detectable effect and analysis plan	$250,000
CR1-04 Independent design review	Observability, environmental limits and stop/go decision	$250,000

Phase 2: Governance and environmental review — $1.80M

Procurement package	Deliverable	Estimate
CR2-01 Regulatory and legal services	Maritime, aviation, environmental and liability requirements	$350,000
CR2-02 Environmental assessment	Exposure, deposition, alternatives and cumulative-impact analysis	$450,000
CR2-03 Public, Indigenous and jurisdictional engagement	Meetings, accessible materials and response record	$500,000
CR2-04 Independent	Published conditions and authorization decision	$250,000

Procurement package	Deliverable	Estimate
governance panel		
CR2-05 International/transboundary consultation	Notification and consultation plan	$250,000

Phase 3: Generator and source validation — $2.80M

Procurement package	Deliverable	Estimate
CR3-01 Flight/ship-ready generator system	Validated modular source with known particle output	$1,000,000
CR3-02 Seawater conditioning and controls	Intake, filtration, salinity/temperature sensing and data logging	$400,000
CR3-03 Release mast and plume-placement system	Adjustable release height and direction	$350,000
CR3-04 Ground and harbor validation	Operating-envelope, failure and endurance tests	$450,000
CR3-05 Independent particle-output verification	Size, number, coarse-tail, composition and energy audit	$300,000
CR3-06 Spares and consumables	Critical generators, filters, pumps and corrosion components	$300,000

Phase 4: Cloud and aerosol instruments — $6.00M

Procurement package	Deliverable	Estimate
CR4-01 Aerosol and CCN package	Aerosol size, composition, hygroscopicity and cloud-base activation	$900,000
CR4-02 Cloud-droplet and precipitation probes	Droplet spectra, liquid water, drizzle and precipitation	$1,100,000
CR4-03 Cloud radar and lidar package	Cloud boundaries, drizzle, vertical velocity and plume structure	$900,000
CR4-04 Radiometer and spectral optical package	Surface, aircraft and cloud-top shortwave measurements	$700,000
CR4-05 Aircraft inlets and data acquisition	Characterized inlets, synchronization, telemetry and quick-look displays	$750,000
CR4-06 Satellite data and rapid processing	Cloud optical depth, effective radius, albedo and cloud fraction	$350,000
CR4-07 Calibration and intercomparison	Traceable calibration and instrument comparison campaign	$700,000

Procurement package	Deliverable	Estimate
CR4-08 Spares and consumables	Replacement probes, pumps, lasers and calibration standards	$600,000

Phase 5: Aircraft and vessel integration — $4.20M

Procurement package	Deliverable	Estimate
CR5-01 Release-vessel integration	Generator, mast, power, controls and seawater system	$700,000
CR5-02 Primary research-aircraft integration	Aerosol, cloud and radiation payload installation	$1,300,000
CR5-03 Remote-sensing aircraft or ground site	Radar/lidar/radiometer integration	$650,000
CR5-04 Drone and autonomous-platform integration	Payloads, timing, communications and recovery	$400,000
CR5-05 Safety, airworthiness and marine certification	Hazard analyses, tests and approvals	$750,000
CR5-06 Mission communications	Aircraft-vessel-ground data links	$400,000

Phase 6: Baseline characterization — $2.80M

Procurement package	Deliverable	Estimate
CR6-01 Untreated cloud flight series	Cloud, aerosol, radiation and meteorology baseline	$1,100,000
CR6-02 Baseline vessel and remote sensing	Boundary-layer and cloud observations	$500,000
CR6-03 Forecast-system setup	Cloud-regime and plume-placement forecasts	$350,000
CR6-04 Satellite and control-region baseline	Matched treated/control region dataset	$250,000
CR6-05 Field operations center and logistics	Facilities, communications, shipping and personnel	$600,000

Phase 7: Release-day operations — $4.20M

Procurement package	Deliverable	Estimate

Procurement package	Deliverable	Estimate
CR7-01 Release-vessel task order	Release/control patterns and certified emission record	$1,100,000
CR7-02 Primary cloud-sampling aircraft	Repeated below-cloud, in-cloud and above-cloud transects	$1,300,000
CR7-03 Remote-sensing aircraft or ground network	Cloud radar, lidar and radiative mapping	$600,000
CR7-04 Drone and balloon operations	Plume-to-cloud vertical profiles	$350,000
CR7-05 Mission-control center	Real-time forecasts, guidance and data display	$350,000
CR7-06 Standby and weather option	Reserved platforms and crews	$500,000

Phase 8: Repeated cloud sampling — $10.00M

Procurement package	Deliverable	Estimate
CR8-01 Primary aircraft block	Multiple release and control sorties	$3,600,000
CR8-02 Second aircraft or complementary platform	Cloud-top remote sensing or wider-area sampling	$1,600,000
CR8-03 Release-vessel operating block	Repeated source operation and control periods	$1,500,000
CR8-04 Radar/lidar/radiometer network	Continuous cloud and radiation observations	$800,000
CR8-05 Satellite rapid-response processing	Daily treated/control products	$300,000
CR8-06 Forecast and data assimilation center	Twice-daily mission targeting and nowcasts	$650,000
CR8-07 Field personnel, maintenance and logistics	Travel, facilities, repairs and spares	$900,000
CR8-08 Contingency sortie option	Replacement for unsuitable-cloud or aborted mission	$650,000

Phase 9: Radiative and dynamical closure — $5.00M

Procurement package	Deliverable	Estimate
CR9-01 Aerosol activation	Emission-to-cloud-droplet transfer function	$800,000

Procurement package	Deliverable	Estimate
and droplet analysis		
CR9-02 Cloud water, drizzle and lifetime analysis	Microphysical and dynamical response	$850,000
CR9-03 Shortwave radiative closure	Measured and modeled reflection attributable to treatment	$850,000
CR9-04 Cloud fraction and mesoscale organization	Open/closed-cell transitions and cloud-field response	$650,000
CR9-05 Laboratory sample and composition analysis	Sea salt, organics and contamination	$350,000
CR9-06 University science subawards	Independent PI and early-career analysis teams	$1,000,000
CR9-07 Data quality and uncertainty review	Validated final dataset and uncertainty budget	$500,000

Phase 10: Regional modeling and attribution — $3.40M

Procurement package	Deliverable	Estimate
CR10-01 Large-eddy simulation ensemble	Case-specific high-resolution simulations	$900,000
CR10-02 Data assimilation and state reconstruction	Four-dimensional cloud and aerosol analysis	$650,000
CR10-03 Statistical causal attribution	Treated/control comparison and meteorological adjustment	$500,000
CR10-04 Scale-up sensitivity analysis	Local-to-regional extrapolation limits	$500,000
CR10-05 Independent modeling team	Firewalled predictions and comparison	$600,000
CR10-06 Visualization and decision tools	Open 3-D products, uncertainty and dashboards	$250,000

Phase 11: Independent evaluation — $1.20M

Procurement package	Deliverable	Estimate
CR11-01 Data-quality and calibration audit	Completeness, calibration and exclusion review	$300,000
CR11-02 Withheld-data model challenge	Prospective predictions against observations	$400,000

Procurement package	Deliverable	Estimate
CR11-03 Open repository and reproducibility package	Raw/processed data, code, metadata and generator settings	$250,000
CR11-04 International review workshop	External review and final campaign report	$250,000

Phase 12: Contingency — $4.80M

Procurement package	Deliverable	Estimate
CR12-01 Program-manager reserve	Unforeseen technical and operational requirements	$1,800,000
CR12-02 Replacement aircraft and ship options	Weather, unsuitable clouds, aborts and downtime	$1,800,000
CR12-03 Instrument and generator repair	Replacement systems and emergency calibration	$800,000
CR12-04 Regulatory or deployment extension	Additional consultation or schedule extension	$400,000

Cloud-response campaign total: approximately $48.0M.

How I would actually contract it

Issuing more than one hundred unrelated contracts would be inefficient. I would establish approximately eight master agreements, with campaign-specific task orders:

Master agreement	Task orders covered
Research ships and marine operations	Release vessel, sampling vessel, port, crew and standby days
Research aircraft and flight operations	Baseline, cloud sampling, remote sensing and replacement sorties
Aerosol-source engineering	Generator modules, seawater systems, controls, calibration and maintenance
Atmospheric instrumentation	Aerosol, CCN, cloud, radar, lidar, radiation and calibration
Modeling, forecasting and data assimilation	Plume, LES, mission forecasts, causal analysis and source inversion
Drones, balloons and autonomous platforms	Vertical profiles, plume mapping and distributed observations
Scientific-analysis consortium	University, government-lab and international research subawards
Governance and independent review	Environmental review, engagement, audits and open-data oversight

- Each task order must specify measurable deliverables rather than only staff hours.

- Acceptance criteria should include uncertainty and data-completeness requirements.
- All foreground data, code and technical documentation should be open by default.
- Fixed-price milestones are suitable for defined hardware and reports; cost reimbursement is more appropriate for uncertain field operations.
- Replacement-day options should be prepriced but exercised only when scientifically justified.

Recipients of Purchase Orders

Prompt to AI: With each purchase order or equivalent agreement, who might it be issued to?

Response From AI:

The recipients below are illustrative candidates, not endorsements or prequalified bidders. Many would participate through grants, cooperative agreements, reimbursable government agreements or international research subawards rather than ordinary commercial purchase orders.

A strong consortium would combine the University of Washington MCB Research Program, NOAA cloud and aerosol scientists, NSF NCAR/UCAR, Scripps Institution of Oceanography, Pacific Northwest National Laboratory, Southern Cross University and its Australian partners, NASA cloud-observation groups, DOE atmospheric-observation capabilities, and competitively selected engineering and instrument firms.

Role	Strong candidate organizations
Managing Organization	RTI International, Battelle, SRI International or UCAR after competition
Scientific integrator	UCAR/NCAR with NOAA, UW, Scripps, PNNL and international partners
Existing MCB field-experiment lead	Southern Cross University with RRAP, CSIRO, AIMS and partner universities
U.S. MCB science and generator program	University of Washington MCB Program with SRI International
Research ships and marine operations	Scripps, NOAA, Australian partners, university fleets or qualified commercial operators
Research aircraft	NSF NCAR Earth Observing Laboratory, NOAA aircraft programs, NASA research aircraft or qualified contractors
Cloud radar/lidar/radiation	NOAA, NCAR, DOE ARM, NASA Langley and university groups
Independent environmental review	AECOM, Ramboll, RTI or another competitively selected independent firm
Public and Indigenous engagement	Independent regional organizations selected with affected communities
Independent scientific review	National Academies-style panel or separately funded international committee

A. Source-and-plume campaign

Procurement area	Illustrative recipients
Scientific design and plume modeling	UW MCB Program; NOAA; NCAR; Scripps; PNNL; Southern Cross University;

Procurement area	Illustrative recipients
	independent university teams
Environmental and governance review	Independent environmental consultancy; maritime/aviation counsel; community and Indigenous engagement organizations
Aerosol generator and seawater systems	SRI/UW generator team; Southern Cross University and industry partners; competitively selected spray, pump, filtration and corrosion specialists
Aerosol and CCN instruments	NOAA and university instrument groups; Aerodyne Research; TSI; Droplet Measurement Technologies; Handix Scientific; other qualified suppliers
Vessel integration	Research-fleet operator; marine engineering firm; generator prime; independent marine-safety reviewer
Drone and balloon systems	University UAS teams; NOAA/NCAR; qualified commercial operators; Vaisala and specialist payload firms
Lidar and remote sensing	NOAA, NASA Langley, NCAR, DOE ARM or university lidar groups
Data assimilation and source inversion	NOAA, NCAR, PNNL, UW, Scripps and an independent modeling team
Laboratory and deposition analysis	NOAA, Scripps, university aerosol laboratories and independent analytical laboratories
Independent audit and archive	RTI or independent metrology/statistics team; UCAR, NOAA, NASA or a durable open repository

B. Cloud-response campaign

Procurement area	Illustrative recipients
Cloud-regime design and LES	NOAA, NCAR, UW, Scripps, PNNL, University of Arizona, University of Leeds/Manchester/Exeter and other cloud groups
Release vessel and generator	Southern Cross University team or UW/SRI team working with a qualified vessel operator and marine integrator
Primary cloud-sampling aircraft	NSF NCAR C-130 or University of Wyoming King Air 350i for primary cloud sampling; NSF NCAR Gulfstream V for above-cloud/context work; NOAA, NASA or SAFIRE aircraft where mission requirements fit
Aerosol and cloud probes	NOAA, NCAR, NASA, Droplet Measurement Technologies, SPEC and university instrument teams
Radar, lidar and radiometers	DOE ARM, NOAA, NCAR, NASA Langley and university remote-sensing groups
Satellite products	NASA and NOAA science teams; university retrieval groups
Cloud and radiative closure	NOAA, NCAR, Scripps, UW, NASA and independent international teams
Regional and global climate modeling	NCAR, PNNL, NOAA GFDL, UK Met Office/University of Exeter, Max Planck Institute, universities and GeoMIP participants
Marine ecology and deposition	AIMS, CSIRO, Scripps, Southern Cross University, coastal universities and

Procurement area	Illustrative recipients
	independent ecological laboratories
Public archive and review	UCAR/NCAR, NOAA or NASA archive; National Academies-style international review

Recommended prime-contract arrangement

1. RTI International or another competitively selected nonprofit: fiduciary program management, procurement, finance, risk and reporting.

2. UCAR/NCAR: atmospheric-science integration, field-campaign coordination, models and data standards.

3. University of Washington MCB Program and NOAA/Scripps/PNNL partners: U.S. aerosol-cloud science and source research.

4. Southern Cross University/RRAP consortium: outdoor MCB experience, marine operations and regional ecological integration.

5. Research-aircraft and research-vessel operators: independently contracted platform services.

6. Independent oversight consortium: environmental review, public engagement, scientific audit and open-data compliance.

The organization operating a release must not control environmental authorization, public engagement, data audit, or the final decision on whether a larger experiment should proceed.

Project Management

Prompt to AI: Who should be the Managing Organization (MO)? Should it be a foundation, laboratory, university, nonprofit research institute, or company?

Response From AI:

The Managing Organization should be an established, independent nonprofit research institute with strong procurement, financial-control, environmental and international-program capabilities. It should not be a spray-system vendor, vessel operator, university department competing for most of the science funds, or a foundation trying to build a field-operations organization from scratch.

Recommended structure

My first choice would be RTI International as the fiduciary Managing Organization, with UCAR/NCAR as the atmospheric-science integrator. A competitive selection could also consider Battelle, SRI International, UCAR itself, or a consortium.

Funding Source → restricted five-year agreement → Managing Organization → MCB Program Management Office → competitive contracts, grants, task orders and international agreements.

Why an independent nonprofit institute?

Possible MO	Assessment
Independent nonprofit research institute	Best overall balance of fiduciary capacity, scientific credibility, procurement and public-purpose mission
UCAR	Excellent atmospheric-science alternative; potential conflict because NCAR and member universities may receive major awards
Foundation	Better as Funding Source than day-to-day operator
University	Excellent research recipient; weaker as sole manager of a $1B multi-platform program
Government laboratory	Essential technical partner but less flexible as a privately controlled fiduciary
For-profit engineering company	Strong execution but problematic incentives, proprietary interests and deployment conflicts
New nonprofit	Potential long-term home, but initially lacks audited systems, staff and track record

Division of responsibilities

RTI or selected MO: fiduciary and program manager

- Receive and ring-fence funds.
- Employ the program director, project managers, procurement, finance, audit, safety and data staff.
- Issue POs, grants and task orders.
- Evaluate bids, accept deliverables and suspend payments.
- Maintain insurance, records, conflicts and risk controls.
- Commission independent audits and report to the Funding Source.

UCAR/NCAR: scientific integrator

- Coordinate the scientific plan and measurement requirements.
- Organize cloud, aerosol, modeling and observing teams.
- Manage common data standards and field-campaign logistics.
- Organize preregistration, peer review and model challenges.
- Determine whether measurements answer the stated research questions.

Independent Release and Safety Board

- Approve, condition, delay or prohibit outdoor releases.
- Review environmental and community-engagement records.
- Verify that stop criteria and emergency procedures are operational.
- Remain organizationally and financially separate from the release team.

How the Funding Source protects its money

- Commit up to $1B but release it in annual and milestone-based tranches.
- Use a restricted account and monthly cash, obligation and forecast reporting.
- Require competition above defined thresholds and written justification for sole source awards.
- Prohibit the MO from self-awarding technical work without independent and Funding Source approval.
- Pay against accepted deliverables, test results and data packages.
- Maintain Funding Source-appointed financial, procurement, scientific, safety and open-data auditors.

- Cap pass-through overhead on large subcontracts and negotiate a transparent management fee.

Final selection

I would invite RTI, UCAR, Battelle, SRI and at least one purpose-built consortium to a paid four-month competition. The Funding Source should review proposed leadership, governance, conflicts, procurement systems, comparable programs, financial statements, insurance, open-science policy, community-engagement plan and management cost before selecting the MO.

Funding Source Requirements

Prompt to AI: What requirements might be demanded by the Funding Source to maximize climate benefit per dollar spent and reduce waste? Should all funded materials and data be open-source?

Response From AI:

Yes—open by default should be a central requirement

MCB research has unusually high public-interest value and unusually high international sensitivity. The Funding Source should require rapid public release of data, models, software, generator performance, environmental monitoring, negative results and final reports, subject only to narrow safety, privacy and pre-existing intellectual-property exceptions.

1. Stage-gated funding

Release money only after requirements, environmental review, preliminary design, campaign readiness and data-delivery gates.

2. Value-of-information requirement

Every PO must identify the decision it will enable and why the information cannot be obtained more cheaply from models, laboratory work or natural analogues.

3. Preregistration

Publish hypotheses, release conditions, primary outcomes, stop criteria and analysis plans before each campaign.

4. Open data deadlines

Quick-look data within 30 days; calibrated data within 6 months; final data, metadata and code within 12 months unless an independent exception is approved.

5. Complete reproducibility package

Raw and processed data, calibration, uncertainty, software versions, generator settings, flight and vessel tracks, exclusions and change logs.

6. Publication of failures

Generator failures, null cloud responses, missed plume interceptions and negative ecological results must be published.

7. Open foreground intellectual property

Funded designs, software and documentation should use CC BY, CC0, Apache 2.0, BSD/MIT or CERN-OHL-style licenses as appropriate.

8. Narrow exceptions

Protect personal information, security-sensitive details, endangered-species locations and genuinely pre-existing proprietary information—but document every exception.

9. Independent replication

Reserve funds for teams that did not design the original experiment to repeat key results.

10. Competitive procurement

Require qualified competition, anti-self-dealing rules, independent review of large awards and public award summaries.

11. Deliverable-based payment

Tie payments to accepted hardware, measured performance, datasets, reports and reproducibility packages.

12. Dynamic portfolio management

Terminate weak workstreams, expand promising ones and maintain a competition fund for new approaches.

13. Safety and governance

Independent release approval, environmental monitoring, community engagement, emergency stop procedures and public experiment registry.

14. Lifecycle economics

Report useful cloud-active particles delivered per dollar, energy, vessel-hour and maintenance-hour—not merely laboratory aerosol output.

15. Annual value-for-money review

Compare cost, information gained, replication, uncertainty reduction, openness, environmental performance and relevance to a decision.

Suggested scorecard

Metric	Illustrative weight
Reduction in a decision-relevant scientific uncertainty	25%
Quality, calibration and reproducibility of evidence	20%
Independent replication or validation	15%
Cost and schedule performance	10%
Open data, software and technical documentation	10%
Environmental, engagement and governance performance	10%
Training, international participation and institutional capacity	5%
Usefulness for a clear stop/proceed decision	5%

The central contractual principle should be: the program is paying for reliable public knowledge and decision capability—not for activity, publicity, or a predetermined conclusion that MCB should proceed.

Top 25 Papers

Prompt to AI: Summarize the top 25 papers most relevant to a proposed $1B Marine Cloud Brightening experiment fund.

Response From AI:

The list emphasizes foundational aerosol–cloud physics, MCB source and particle-size requirements, cloud and climate modeling, natural analogues, field-research design, risks and the first published outdoor trial. It is not a citation-count ranking.

1. Twomey, 1977 — "The Influence of Pollution on the Shortwave Albedo of Clouds"

Established the core microphysical relationship behind cloud brightening: for a fixed liquid-water amount, more cloud droplets generally produce a larger total scattering area and a brighter cloud. MCB experiments must test this response in real marine clouds while accounting for cloud dynamics and precipitation.

2. Albrecht, 1989 — "Aerosols, Cloud Microphysics, and Fractional Cloudiness"

Proposed that additional aerosol can suppress drizzle and alter cloud lifetime and cloud amount. This second indirect effect may amplify or oppose the immediate Twomey brightening, making measurements of precipitation, entrainment and cloud fraction essential.

3. Latham, 1990 — "Control of Global Warming?"

Introduced the modern proposal to counter greenhouse warming by increasing the reflectivity of marine clouds using sea-salt particles. The paper is conceptually foundational but does not resolve whether suitable particles can be delivered or whether regional climate consequences are acceptable.

4. Latham, 2002 — "Amelioration of Global Warming by Controlled Enhancement of the Albedo and Longevity of Low-Level Maritime Clouds"

Developed the MCB concept and discussed targeted low marine clouds, cloud droplet number and possible climate effect. It frames the two central experimental questions: can the cloud be perturbed predictably, and does the perturbation persist long enough to matter?

5. Bower et al., 2006 — computational assessment of marine stratocumulus albedo enhancement

Used detailed cloud modeling to examine how added particles might alter stratocumulus cloud properties. It helped move the concept from a simple droplet-number argument toward process-level simulations, and it highlights the importance of cloud regime and background aerosol.

6. Salter, Sortino and Latham, 2008 — "Sea-Going Hardware for the Cloud Albedo Method of Reversing Global Warming"

Proposed wind-powered unmanned spray vessels and engineering concepts for producing submicron seawater droplets. Its fleet and hardware estimates are highly preliminary, but the paper defines the source-engineering challenge that a modern equipment and field program must test.

7. Latham et al., 2008 — "Global Temperature Stabilization via Controlled Albedo Enhancement of Low-Level Maritime Clouds"

Combined cloud physics and climate-model reasoning to estimate potential global cooling. It supports targeted research but also illustrates how strongly global conclusions depend on assumed cloud susceptibility and idealized aerosol delivery.

8. Rasch, Latham and Chen, 2009 — "Geoengineering by Cloud Seeding: Influence on Sea Ice and Climate System"

Examined climate-system responses to marine cloud brightening, including high-latitude effects. It showed that localized radiative forcing can generate broad circulation and hydrological responses, motivating regional and global modeling alongside field experiments.

9. Jones, Haywood and Boucher, 2009 — "Climate Impacts of Geoengineering Marine Stratocumulus Clouds"

Demonstrated that brightening selected stratocumulus regions can cool global mean temperature but produce nonuniform regional temperature and precipitation changes. It is a key warning against treating global-average cooling as the sole performance metric.

10. Korhonen, Carslaw and Romakkaniemi, 2010 — "Enhancement of Marine Cloud Albedo via Controlled Sea Spray Injections"

Modeled the influence of emission rate, aerosol microphysics and transport. The study showed that source rate and particle evolution matter strongly and that the useful aerosol burden cannot be inferred simply from the amount of seawater sprayed.

11. Hill and Ming, 2012 — "Nonlinear Climate Response to Regional Brightening of Tropical Marine Stratocumulus"

Found that targeted brightening can generate a La Niña-like response and important remote effects. This paper makes regional teleconnections and ENSO response a core requirement for climate-model evaluation.

12. Partanen et al., 2012 — direct and indirect effects of sea-spray geoengineering and injected particle size

Separated direct scattering by injected salt aerosol from cloud-mediated effects and emphasized particle-size sensitivity. MCB experiments should therefore measure both clear-sky aerosol optical effects and cloud responses.

13. Alterskjær and Kristjánsson, 2013 — "The Sign of the Radiative Forcing from Marine Cloud Brightening Depends on Both Particle Size and Injection Amount"

Showed that poorly chosen particle sizes or excessive injection can produce weak or even warming responses through complex aerosol–cloud and clear-sky effects. This makes particle-size control and dose-response experiments central.

14. Kravitz et al., 2013 — "Sea Spray Geoengineering Experiments in the Geoengineering Model Intercomparison Project"

Established coordinated multi-model MCB experiments and documented substantial differences among models. The work supports standardized scenarios, common diagnostics and independent model comparison before any scale-up.

15. Stuart et al., 2013 — "Reduced Efficacy of Marine Cloud Brightening Geoengineering Due to In-Plume Aerosol Coagulation"

Showed that high particle concentrations near the source can coagulate before dilution, reducing the number of useful particles. It directly motivates metre-to-kilometre plume experiments and multiple distributed sources rather than one extremely intense sprayer.

16. Connolly et al., 2014 — "Factors Determining the Most Efficient Spray Distribution for Marine Cloud Brightening"

Analyzed how particle-size distributions influence cloud activation and energy requirements. It provides practical metrics for source development: useful particles per energy and avoidance of both undersized and oversized particles.

17. Ahlm et al., 2017 — "Marine Cloud Brightening—as Effective without Clouds"

Found that at high injection rates, direct scattering by sea salt can become an important part of the radiative forcing. This complicates attribution and requires experiments to distinguish marine sky brightening from cloud-mediated brightening.

18. Horowitz et al., 2020 — "Effects of Sea Salt Aerosol Emissions for Marine Cloud Brightening on Atmospheric Chemistry"

Examined broader atmospheric consequences of adding sea salt, including chemical effects. It supports measuring composition, reactive chemistry and deposition rather than assuming seawater aerosol is chemically inert.

19. Glassmeier et al., 2021 — "Aerosol-Cloud-Climate Cooling Overestimated by Ship-Track Data"

Used ship tracks to show that cloud adjustments can offset some initial brightening and that visible tracks can bias estimates of persistent climate forcing. Natural analogues are valuable, but field programs must measure the full cloud life cycle.

20. Hoffmann and Feingold, 2021 — "Cloud Microphysical Implications for Marine Cloud Brightening: The Importance of the Seeded Particle Size Distribution"

Demonstrated that a small number of coarse particles can accelerate precipitation and reduce cloud water. This is one of the most directly actionable papers for generator specifications and paired particle-size field experiments.

21. Wood, 2021 — "Assessing the Potential Efficacy of Marine Cloud Brightening for Cooling Earth Using a Simple Heuristic Model"

Linked source particle number, plume lifetime, cloud updraft, background aerosol and sprayer count to potential forcing. It offers a transparent bridge from field-scale measurements to system-level estimates and identifies the parameters experiments must constrain.

22. Diamond et al., 2022 — "To Assess Marine Cloud Brightening's Technical Feasibility, We Need to Know What to Study—and When to Stop"

Proposed a staged research logic and explicit stopping criteria. The paper is especially relevant to funding governance because it argues that research should be organized around falsifiable questions rather than an assumption of eventual deployment.

23. Yuan et al., 2022 — "Global Reduction in Ship Tracks from Sulfur Regulations for Shipping Fuel"

Used satellite observations and shipping changes to create a large natural experiment in aerosol–cloud interactions. The work demonstrates the value of global ship-track detection, emissions data and policy-driven perturbations for constraining cloud response.

24. Feingold et al., 2024 — "Physical Science Research Needed to Evaluate the Viability and Risks of Marine Cloud Brightening"

Provides the most comprehensive recent research agenda, calling for coordinated laboratory, field, monitoring and multiscale modeling work. It emphasizes scale-up, regional distributions of benefits and risks, and the need to connect process observations to climate response.

25. Hernandez-Jaramillo et al., 2025 — "First Generation Outdoor Marine Cloud Brightening Trial Increases Aerosol Concentration at Cloud Base Height"

Reports outdoor generation and transport of sea-salt aerosol in the Great Barrier Reef program, including evidence of increased aerosol concentration at cloud-base height. It is a major proof-of-delivery result, while not by itself demonstrating repeatable cloud brightening or regional cooling.

Most relevant to the proposed $1 billion program

- Feingold et al. (2024) for the integrated research agenda.
- Diamond et al. (2022) for staged feasibility and stopping criteria.
- Hoffmann and Feingold (2021), Alterskjær and Kristjánsson (2013), Connolly et al. (2014) and Stuart et al. (2013) for particle-size and source requirements.
- Glassmeier et al. (2021) and Yuan et al. (2022) for natural experiments and ship-track interpretation.
- Wood (2021) for linking field measurements to system-scale efficacy.
- Hernandez-Jaramillo et al. (2025) for outdoor source-to-cloud-base delivery.
- Jones et al. (2009), Hill and Ming (2012), Kravitz et al. (2013) and Feingold et al. (2024) for regional and global consequences.

Selected current research sources include the 2024 Science Advances research agenda, the University of Washington MCB Research Program, Southern Cross University's outdoor program, the DOE–NOAA MCB workshop report, and the National Academies' 2021 solar-geoengineering research report.

Top Researchers

Prompt to AI: Who are the top researchers in Marine Cloud Brightening and related fields? What are the leading organizations?

Response From AI:

The following names are illustrative candidates based on published work and leadership in aerosol–cloud science, MCB research, field observations, modeling or engineering. Inclusion does not imply endorsement, availability or agreement with deployment.

Leading researchers

Researcher	Relevance
Graham Feingold	NOAA cloud and aerosol process science; lead author of the 2024 MCB research agenda.
Robert Wood	University of Washington; marine low clouds, MCB efficacy and field-program leadership.
Sarah Doherty	University of Washington; MCB program direction, governance, engagement and research integration.
Lynn M. Russell	Scripps Institution of Oceanography; aerosol composition, marine aerosol and field observations.
Daniel P. Harrison	Southern Cross University; outdoor MCB experiments, spray systems and reef-focused field research.
Philip Rasch	Pacific Northwest National Laboratory; aerosol–cloud–climate modeling and geoengineering research.
Armin Sorooshian	University of Arizona; marine aerosol, cloud processing, aircraft observations and field campaigns.
Allison McComiskey	NSF NCAR Earth Observing Laboratory; aerosol–cloud observations and research infrastructure.
Michael S. Diamond	cloud and aerosol interactions, ship-track natural experiments and MCB feasibility framing.
Franziska Glassmeier	cloud adjustments and limits of inference from ship tracks.
Edward Gryspeerdt	satellite aerosol–cloud interactions and causal interpretation.
F. Hoffmann	cloud microphysics and seeded particle-size effects.
Andrew Gettelman	global cloud modeling, climate response and MCB feasibility.
Matthew Lebsock	satellite and aircraft observations of marine clouds and precipitation.

Researcher	Relevance
Jessica Wan	regional MCB climate impacts and time-dependent efficacy.
Chih-Chieh Chen	NCAR climate-model experiments, deployment strategy and regional response.
Dilip Ganguly	aerosol–climate modeling and Global South scientific perspective.
Nicolás Huneeus	aerosol science, South American perspective and research review.
Daniel Rosenfeld	cloud microphysics, aerosol effects and precipitation.
Ilona Riipinen	aerosol microphysics, particle growth and climate interactions.

Top organizations

1. University of Washington Marine Cloud Brightening Research Program

Dedicated MCB collaboration spanning aerosol generation, cloud studies, modeling, governance and engagement.

2. NOAA Chemical Sciences Laboratory and NOAA research programs

Cloud, aerosol, chemistry, ship-track and atmospheric-observation expertise.

3. NSF NCAR and UCAR

Research aircraft, observing systems, field-campaign management, cloud-resolving and global modeling.

4. Southern Cross University MCB program and RRAP partners

World-leading outdoor sea-salt generation and Great Barrier Reef field experiments.

5. Scripps Institution of Oceanography

Marine aerosol and cloud observations, research vessels and atmospheric chemistry.

6. Pacific Northwest National Laboratory

Aerosol–cloud–climate modeling and DOE atmospheric science.

7. DOE Atmospheric Radiation Measurement program

Cloud radar, lidar, radiometers, mobile facilities and long-term cloud observations.

8. NASA and NASA Langley atmospheric research groups

Satellite retrievals, airborne lidar, radiation and cloud remote sensing.

9. CSIRO and Australian Institute of Marine Science

Australian atmospheric, marine, ecological and Great Barrier Reef expertise.

10. UK Met Office, University of Exeter, Leeds and Manchester groups

Cloud modeling, climate response and aerosol–cloud process research.

11. Max Planck Institute for Meteorology and European cloud groups

Cloud-climate dynamics, process modeling and independent assessment.

12. Geoengineering Model Intercomparison Project and World Climate Research Programme networks

Standardized multi-model scenarios and climate-response comparison.

13. SRI International

Nonprofit engineering and aerosol-generator development partner.

14. SilverLining and Degrees Initiative

Research support, network building, governance and broader international participation.

Best consortium for the proposed program

A credible program would not be controlled by one laboratory. It would combine a neutral fiduciary MO; UCAR/NCAR field and model integration; NOAA, UW, Scripps and PNNL process science; Southern Cross University and Australian partners for outdoor MCB experience; NASA/DOE remote sensing; multiple independent modeling teams; marine ecologists; and strong participation from climate-vulnerable regions.

Scientific Advisory Panel

Prompt to AI: If a scientific panel were established to oversee the MCB research, who might serve on it and what expertise should be represented?

Response From AI:

Suggested scientific oversight panel

Seat	Illustrative member or expertise
Independent chair	Senior Earth-system scientist with no current MCB contract; selected through an international search.
Graham Feingold	Cloud–aerosol process science and research-agenda integration.
Robert Wood	Marine low-cloud physics and MCB field requirements.
Lynn M. Russell	Marine aerosol composition and field observations.
Daniel P. Harrison	Outdoor source and plume experiments, marine operations and engineering.
Armin Sorooshian	Aircraft field campaigns, aerosol–cloud interactions and measurement design.
Allison McComiskey	Research infrastructure, observation strategy and independent review.
F. Hoffmann or equivalent cloud microphysicist	Seeded particle-size effects, drizzle and cloud-process modeling.
Climate-response modeler	Regional teleconnections, ENSO, precipitation and global distributional effects.
Marine ecologist	Salt deposition, coastal ecosystems, fisheries and reef impacts.
Atmospheric instrumentation/metrology expert	Calibration, inlets, uncertainty and data-quality systems.
Global South atmospheric scientist	Regional consequences, capacity building and distributional equity.
Indigenous or community knowledge representative	Research-area legitimacy, local impacts, engagement and governance.

Non-voting technical advisers

- Research vessel operator and marine safety officer.
- Research aircraft and flight-safety representative.
- Aerosol-generator engineer.
- Environmental-law and permitting adviser.
- Data and open-source steward.
- Program statistician and causal-inference specialist.

- Funding Source and MO liaisons.

Critical conflict-of-interest rule

Scientists receiving large program awards should not form a voting majority. Members must disclose institutional and financial interests; recuse from reviews of their own work; and permit minority reports. The panel should review scientific adequacy, but an independent release and safety board should retain authority to prohibit an outdoor release.

Suggested voting standard

Ordinary scientific recommendations could use a two-thirds vote. A recommendation to increase release scale should require at least 75% support, no unresolved critical safety finding, and affirmative approval from the independent release board and the Funding Source.

Management Advisory Panel

Prompt to AI: If a panel were established to oversee the agreement with the Managing Organization, who might serve on that panel and what authority should it have?

Response From AI:

Recommended structure: a 9-member Agreement Oversight Board

Seat	Primary function
1. Funding Source representative	Protect purpose, approve tranches and report donor or public obligations.
2. Independent chair with major R&D experience	Lead board, evaluate PM and resolve cross-program issues.
3. Large scientific-field-campaign manager	Evaluate ships, aircraft, schedules, logistics and readiness.
4. Public procurement and audit expert	Review competition, sole source, cost controls and financial reporting.
5. Marine engineering and operations expert	Assess vessel, corrosion, power, maintenance and maritime risk.
6. Aviation safety and research-aircraft expert	Review flight operations, airworthiness and campaign integration.
7. Environmental and community-governance expert	Oversee environmental review, engagement and complaint mechanisms.
8. International climate-governance expert	Review transboundary consultation and distributional consequences.
9. Independent public-interest member	Represent transparency, ethics and long-term public benefit.

Illustrative named candidates

Names below are examples of the level and type of experience desired, not endorsements or claims of availability: Marcia McNutt for Earth-science institutional leadership; Jane Lubchenco for ocean science and public policy; Christine Fox or Ellen Lord for large-program and acquisition experience; Sheila Widnall for engineering and aviation perspective; and an internationally respected public-finance or development leader. Current contractors and prospective PO recipients should not be voting members.

What authority should the board have?

- Hire, evaluate and if necessary remove the MO program director.
- Approve annual plans, major requirement changes and management compensation.
- Approve awards above a threshold and all MO self-performance.
- Release central contingency and recommend Funding Source tranches.
- Require corrective-action plans and suspend a workstream.
- Commission financial, procurement, technical, safety and open-data audits.
- Receive scientific and release-board findings without altering them.
- Recommend continuation, redirection or termination to the Funding Source.

Recommended approval thresholds

Decision	Suggested approval
Ordinary PO within approved annual plan	Program manager under delegated authority
PO above $10M	Independent procurement review and board committee approval
PO above $25M	Full board approval
PO above $50M or major reallocation	Board plus Funding Source concurrence
Release of more than $5M contingency	Board approval
Material increase in outdoor-release scale	Scientific panel recommendation, release-board approval, full board and Funding Source concurrence
MO self-award or affiliate transaction	Independent review, full board and Funding Source approval

Committee structure

Audit and Risk Committee

Financial audit, risk register, insurance, contingency, cybersecurity, safety reporting and whistleblower matters.

Procurement and Compensation Committee

Large awards, competition, conflicts, MO fee, executive compensation and affiliated transactions.

Program Performance Committee

Annual plan, milestones, value of information, schedule, open-data delivery and corrective actions.

A crucial structural distinction

The Agreement Oversight Board supervises the MO and protects the Funding Source's money. It should not decide whether a cloud response is scientifically real or whether an outdoor release is environmentally acceptable. Those judgments belong to independent scientific and release bodies.

Agreements

Prompt to AI: What might the Funding Source–Managing Organization agreement and the Managing Organization–PO recipient agreement look like?

Response From AI:

1. Funding Source–Managing Organization agreement

Master Program Funding and Stewardship Agreement

Clause	Illustrative requirement
Purpose	Create and manage a five-year, $1B MCB research program that produces open, decision-relevant evidence without presuming deployment.
Maximum funding	Up to $1B, subject to annual appropriation or donor commitment and technical gates.
Funding tranches	Transition, approved program plan, readiness gates, annual plans, data delivery and final closeout.
Restricted use	Funds held in a separate account or cost center and used only for approved MCB research.
MO responsibilities	Employ PMO, issue awards, control cost/schedule, accept deliverables, maintain records, publish data and enforce safety.
Reserved decisions	Funding Source approval for major scope, scale, reserve, self-awards, management fee and program termination.
Procurement	Competition thresholds, sole-source justification, conflict rules, price/cost analysis and audit rights.
Open science	Open data, code, models, designs, negative results, metadata and timely publication.
Independent oversight	Scientific panel, release board, financial/procurement auditors and Agreement Oversight Board.
Safety and governance	Environmental review, community engagement, permits, stop-work authority and public registry.
Reporting	Monthly finance; quarterly technical; annual public report; immediate notice of safety, legal or integrity events.
Remedies	Withhold payment, require correction, replace staff, suspend work, recover funds or terminate.
Transition	Orderly transfer of data, property, contracts, software and records to a successor.

Illustrative tranche schedule

Gate	Cumulative Funding Source authorization
MO transition and program design	$15M
Approved five-year program plan	$100M
Baseline and source-system readiness	$250M
First source-and-plume campaign review	$425M
Cloud-response campaign readiness	$650M
Independent replication and Year 4 plan	$850M
Final campaigns, synthesis and closeout	Up to $1.000B

2. Managing Organization–recipient agreement

A. Research subaward

- Research question, hypotheses and decision relevance.
- Statement of work, milestones, key personnel and approved budget.
- Data-management and preregistration plan.
- Open-publication and foreground-IP terms.
- Research integrity, conflicts, human/community engagement and environmental compliance.
- Progress reports, final dataset, code, documentation and publications.
- Stop-work, termination and transition obligations.

B. Procurement contract or PO

- Technical specification and interfaces.
- Deliverables, drawings, software, hardware, calibration and test results.
- Acceptance tests and uncertainty requirements.
- Milestone payment schedule and retainage.
- Configuration control, quality assurance and inspection rights.
- Warranty, spares, maintenance and field support.
- Background IP disclosure and open foreground deliverables.
- Safety, environmental, maritime and aviation compliance.
- Termination for convenience and cause.

Example milestone schedule

Milestone	Payment
Contract start and accepted project plan	10%
Requirements and preliminary design review	15%
Detailed design or campaign readiness review	20%
Hardware/data-system delivery and predeployment tests	20%
Field operation or acceptance test complete	20%
Final data, code, documentation and independent acceptance	15%

Deliverable acceptance

The recipient should not be paid merely because effort was expended. The MO should accept a deliverable only after verifying completeness, stated performance, calibration, uncertainty, open-data package, documentation and correction of material defects.

Change-control clause

Changes to particle-size requirements, release amount, operating region, environmental limits, primary outcomes or data rights require written change control. Major changes need independent review and Funding Source approval.

Flow-down clause

Every subrecipient and subcontractor must receive the same open-data, records, audit, conflict, safety, publication and transition obligations that apply to the prime recipient.

Contract hierarchy

1. Funding Source–MO Master Program Funding and Stewardship Agreement.

2. Approved five-year Program Plan and annual operating plans.

3. Scientific, environmental, procurement, data and engagement policies.

4. Master contract, grant and task-order vehicles.

5. Individual statements of work, budgets, milestones and acceptance plans.

Stopping MCB and Rebound Warming

Prompt to AI: If we reflect sunlight for 10 years to offset the 0.3°C/decade global warming rate to 0.0°C/decade, and then we stop reflecting after 10 years, what is our new warming rate? Alternatively, if we reflect for 200 years and then stop reflecting when the concentration of CO_2 in atmosphere is 1200 ppm, for example, instead of the current 430 ppm, then what would be our new warming rate? Assume ECS = 4°C.

Response From AI:

There is no single permanent "new warming rate." After MCB stops, the underlying greenhouse warming resumes and Earth begins recovering the warming that MCB had masked. Because boundary-layer sea-salt particles remain aloft for only days, the imposed radiative forcing could disappear faster than sulfate SAI forcing; ocean and atmospheric thermal inertia would still spread the temperature response over years and decades.

Assumptions: underlying warming without MCB = 0.3°C per decade; MCB holds temperature approximately flat; abrupt termination; greenhouse forcing continues; ECS = 4°C per CO_2 doubling.

Case 1: stop after 10 years

Without MCB, the world would have warmed about 0.3°C during the decade. MCB therefore creates approximately a 0.3°C temperature gap. After stopping, normal 0.3°C-per-decade warming continues and part of the suppressed 0.3°C emerges as catch-up warming.

Using a simple estimate in which roughly half of an abrupt forcing response appears during the first decade, the first-decade rate after termination is approximately:

0.3°C/decade underlying warming + about 0.15°C/decade catch-up = about 0.45°C/decade.

A reasonable planning range is roughly 0.4–0.6°C per decade during the first decade after stopping, followed by a rate trending back toward the underlying greenhouse-driven rate if greenhouse forcing continues to grow similarly.

Case 2: stop after 200 years at 1,200 ppm

With ECS = 4°C and preindustrial CO_2 = 280 ppm, the equilibrium CO_2-only warming associated with 1,200 ppm is approximately:

$$4 \times \log_2(1{,}200/280) \approx 8.4°C \text{ above preindustrial.}$$

If MCB had held temperature near roughly today's level for 200 years, it could be masking on the order of 6–7°C of eventual warming, depending on non-CO2 forcing and ocean disequilibrium. Abrupt termination would remove the short-lived MCB forcing in days, while the climate system would warm rapidly toward the high-forcing state.

A simple first-decade estimate in which roughly half of a 6–7°C masked response emerges over a decade gives approximately 3–4°C of warming in the first decade, potentially followed by another 1–2°C in the second. This is an illustrative energy-balance estimate, not a precise forecast.

Central conclusion

- Stopping after 10 years could temporarily raise the warming rate from 0.3°C/decade to roughly 0.5°C/decade.
- Stopping abruptly after 200 years at 1,200 ppm could create an extreme termination shock of several degrees within one or two decades.
- MCB's short aerosol lifetime improves controllability during experiments but makes the radiative forcing disappear rapidly when operations stop.
- A long-term program would require gradual phaseout coordinated with deep emissions cuts and carbon removal; termination planning must begin before deployment, not after.

Selected current program and assessment sources

- National Academies of Sciences, Engineering, and Medicine (2021), Reflecting Sunlight: Recommendations for Solar Geoengineering Research and Research Governance.
- Feingold et al. (2024), Physical science research needed to evaluate the viability and risks of marine cloud brightening, Science Advances.
- University of Washington Marine Cloud Brightening Research Program: https://atmos.uw.edu/faculty-and-research/marine-cloud-brightening-program/
- Southern Cross University Marine Cloud Brightening program: https://www.scu.edu.au/research/reefs-and-oceans/marine-cloud-brightening/
- DOE–NOAA Marine Cloud Brightening Workshop Report (2022).
- Glenn Weinreb, MCB Reflectivity Plan: https://www.ma2life.org/g/film/MCB_Reflectivity_Plan.pdf

MCB Aircraft, Instruments and Airborne Measurement Architecture

Prompt to AI: The MCB experimental research program needs aircraft to track sea-salt plumes, measure delivery to cloud base, sample treated and untreated clouds, and close the radiative response. What kinds of research aircraft are needed? What parameters should each measure, what instruments are needed, which existing research-aircraft operators might provide them, and what aircraft or airborne equipment should the program develop or modify?

Response From AI:

MCB needs a coordinated airborne measurement system rather than one special airplane. The intervention source is normally a ship or autonomous surface platform, while aircraft diagnose what happens between the source, cloud base, cloud interior and reflected sunlight. The most useful architecture is a primary in-situ cloud aircraft, an above-cloud remote-sensing/radiation aircraft, smaller plume or boundary-layer aircraft where useful, and uncrewed aircraft that fill vertical and near-source sampling gaps. The aircraft should be treated mainly as reusable sensor buses; most development money should go into modular instruments, characterized inlets, synchronization, plume/cloud targeting and aircraft-vessel-ground data fusion.

Four airborne roles

Airborne role	Key parameters	Representative instruments	Best platform characteristics
M1. Plume and cloud-base sampling	Sea-salt particle number and size; CCN spectrum; hygroscopicity; composition; plume dilution; fraction reaching cloud base; temperature, humidity, winds, turbulence and boundary-layer depth.	CPC and fast aerosol sizers; PCASP/UHSAS-class optical sizing; CCN counter; filter/sample chemistry; fast T/RH; 3-D gust probe; GPS/INS; optional lidar.	Agile low- to mid-tropospheric aircraft that can repeat cross-plume and stacked legs close to cloud base.
M2. Primary in-cloud microphysics	Cloud-droplet number and size; effective radius; spectral width; liquid-water content; drizzle and precipitation; entrainment; vertical velocity; cloud-base activation and any ice where relevant.	Cloud Droplet Probe or equivalent; cloud imaging/precipitation probes; hot-wire LWC; CAPS-class combined cloud probes; fast turbulence and thermodynamic package; aerosol/CCN instruments for below-cloud legs.	Cloud-penetrating aircraft with external probe mounts, good low-altitude handling, substantial cabin/power and repeatable flight

Airborne role	Key parameters	Representative instruments	Best platform characteristics
			control.
M3. Above-cloud radiation and remote sensing	Up/down shortwave and longwave flux; spectral reflectance; cloud-top height; optical depth; cloud fraction; plume/cloud geometry; drizzle structure and aerosol layer height.	Broadband and spectral radiometers; multi-angle polarimeter/imager; HSRL/lidar; W/Ka-band cloud radar where available; microwave radiometer; precision GPS/INS.	Higher-altitude aircraft able to remain above the cloud field for hours while the in-situ aircraft samples below.
M4. Wide-area context and control-region mapping	Mesoscale cloud organization; treated/control cloud fields; precipitation; inversion structure; background aerosol; large-scale winds and humidity; satellite-validation context.	Scanning radar/lidar; imagers; radiometers; dropsondes where useful; aerosol and meteorological suite.	Long-endurance aircraft with wide-area range, remote-sensing ports and reliable data links.

The central MCB causal chain

The aircraft program should be designed to close one sequence quantitatively: known source output -> particles surviving and reaching cloud base -> particles activating as cloud droplets -> changes in droplet spectra, liquid water, drizzle and cloud organization -> change in reflected shortwave radiation. A successful experiment should not rely on a bright satellite image alone. It should reconcile source metrology, cloud-base aerosol/CCN, in-cloud microphysics, cloud dynamics and radiation within a stated uncertainty budget.

For a cloud-response campaign, the primary aircraft should repeatedly fly below cloud, at cloud base, within cloud and near cloud top while following approximately the same air mass. A second aircraft should remain primarily above the cloud deck to measure radiation and remote-sensing structure. Drones can profile the plume between the ship and cloud base without forcing the main aircraft to spend all of its time on near-source sampling.

Illustrative current research-aircraft operators

Aircraft / operator	Illustrative capability	Best MCB role	Comment
NSF/NCAR C-130	Middle/lower troposphere; typical research configuration about 13,000 lb payload and 8-9 hour endurance.	Primary heavily instrumented in-cloud aircraft; cloud microphysics, turbulence, aerosol and	Strong choice for the largest multi-instrument campaigns.

Aircraft / operator	Illustrative capability	Best MCB role	Comment
		precipitation.	
NSF / University of Wyoming King Air 350i	About 3-5 hour endurance, 2,100 nmi range, 33,000-35,000 ft ceiling and up to about 2,970 lb payload.	Agile primary or plume/cloud-base aircraft; cloud microphysics and radar/lidar work.	Attractive when a smaller, lower-cost aircraft can carry the required payload.
NSF/NCAR HIAPER Gulfstream V	About 10 hour endurance, 5,000 nmi range, 5,600 lb payload and altitude above 45,000 ft; optical ports and external mounts.	Above-cloud remote sensing, radiative closure, wider-area context and satellite underflights.	Better as aircraft #2 than as the default low-cloud penetration aircraft.
NOAA WP-3D Orion	Long-duration aircraft designed for severe-weather and atmospheric research, with Doppler/weather radar and dropsonde capability.	Mesoscale organization, precipitation, storm/cloud structure and large campaigns.	Especially useful when precipitation and organized weather are central.
NOAA Gulfstream IV-SP	High, fast, long-range platform; NOAA describes approximately 45,000 ft cruise altitude and 4,000 nmi range.	Wide-area meteorological context, dropsondes and remote sensing around cloud fields.	Less suited than C-130/King Air for routine in-cloud microphysics.
SAFIRE ATR42 (France)	Medium-troposphere research aircraft for chemistry, aerosol/cloud microphysics, remote sensing and turbulence; facility reports up to 9 scientists and about 2 tonnes of instruments.	International alternative for in-situ cloud and aerosol campaigns.	Useful for European/international replication and cross-platform comparison.

These organizations are research user facilities or government operators, not ordinary aircraft-rental suppliers. Access usually requires a scientific proposal, reimbursable agreement, cooperative arrangement or campaign task order. Availability, airworthiness and instrument compatibility should be verified for each campaign.

Airborne instrument suppliers and facility capabilities

Measurement	Illustrative instrument families / suppliers	MCB use
Aerosol number and size	TSI CPC/SMPS families; Droplet Measurement Technologies PCASP and related optical probes; facility fast aerosol instruments.	Quantify emitted and surviving particle distributions from nanometre to micrometre sizes.
Cloud condensation nuclei	Droplet Measurement Technologies CCN-100/200 or equivalent research CCN systems.	Measure which added/background particles activate at relevant

Measurement	Illustrative instrument families / suppliers	MCB use
		supersaturations.
Cloud droplets, drizzle and liquid water	Droplet Measurement Technologies CDP, CIP/CAPS-class probes and hot-wire LWC; SPEC and research-facility probes where appropriate.	Measure droplet number, size, effective radius, precipitation development and liquid water.
Aerosol composition	Aerodyne AMS family for non-refractory aerosol plus filters/single-particle or elemental methods for sea-salt-specific Na/Cl and refractory material.	Separate injected sea salt from background aerosol and characterize organics/contaminants.
Cloud/aerosol vertical structure	NCAR, Wyoming, NOAA, NASA, DOE ARM and university HSRL/lidar and cloud-radar systems.	Map cloud top/base, plume height, drizzle and remote-sensing context.
Radiation	Broadband SW/LW and spectral radiometers, polarimeters and calibrated imaging systems from facility/institutional teams.	Measure the actual radiative response rather than inferring it only from droplet changes.

A standard Aerodyne AMS is primarily a non-refractory aerosol composition instrument, so it should not be the only instrument used to quantify injected sea salt. The MCB program should explicitly include sodium/chloride or other sea-salt-specific measurements and characterize inlet transmission so that large hygroscopic or coarse particles are not silently lost before measurement.

What should be developed

- A modular MCB aerosol/cloud payload with standardized racks, power, cooling, timing, telemetry and data interfaces that can migrate among qualified aircraft.
- Characterized aerosol inlets and external probe installations with documented transmission versus particle size, humidity, airspeed and aircraft attitude.
- A cloud-response mission system that fuses the vessel source record, winds, trajectories, lidar/radar, aircraft observations, satellite imagery and control-region data into a real-time three-dimensional sampling display.
- A matched radiative-closure package for above-cloud, aircraft-level and surface measurements, with common calibration and high-rate attitude correction.
- Reusable cloud-microphysics and turbulence pallets, including droplet, drizzle, liquid-water and precipitation probes with cross-platform intercomparison procedures.

- Lightweight drone payloads for aerosol, CCN where practical, meteorology and vertical plume profiling between the ocean surface and cloud base.

A new purpose-built crewed airplane is not a five-year priority. The program should first exploit and improve existing research aircraft. A new aircraft becomes justified only if repeated campaigns demonstrate a persistent capability gap in low-altitude endurance, payload, external-probe accommodation, icing/severe-weather capability or operating cost that cannot be filled by existing facilities.

How this fits the existing $1B budget

The proposal already allocates $55M to shared aircraft, ships, drones, lidar, radar and instruments and includes aircraft/instrument integration and repeated primary/secondary-aircraft sortie blocks inside cloud-response campaigns. The aircraft chapter should therefore define the architecture and procurement requirements rather than add a new budget line. The program should use master agreements with aircraft facilities and prepriced integration, standby and replacement-sortie options so weather losses do not force emergency sole-source contracting.

Current-status note

Aircraft capabilities above are illustrative as of August 2026 and should be reverified before procurement. The former UK FAAM Airborne Laboratory is not a current provider: FAAM states that operational activity ended on March 31, 2026. International planning should therefore use currently operating facilities such as SAFIRE or other verified providers rather than treating the former FAAM BAe-146 as available.

The practical conclusion is that MCB aircraft are measurement platforms, not spray aircraft. The most valuable investment is a coordinated two-aircraft plus drone architecture that can measure the complete source-to-cloud-to-radiation chain repeatedly under treated and control conditions.

Further Reading

Is it possible to solve the climate problem with a surge of R&D in key areas; and if so, what are those areas and how much might this cost? The following documents hope to answer this question.

Marine Cloud Brightening (MCB)

MCB Reflectivity Plan (7-page PDF)

https://drive.google.com/drive/folders/1Aoz9vLxKLF4qBw1xnjlCfYGXERhTY3rI

Proposed $1B MCB Experimental Research Fund

https://drive.google.com/drive/folders/1ItaJh7OQMeZMInUkArcShi-SGVFmzvD0

Proposed $1B MCB Equipment Development Fund

https://drive.google.com/drive/folders/1Leivbra4GXj5VlPg_jFZfPN1UQyHgR-S

Stratospheric Aerosol Injection (SAI)

SAI Reflectivity Plan (7-page PDF)

https://drive.google.com/drive/folders/1Jf8jmP38b2P-vj9XTWRLGGMuahuLwxB6

Proposed $1B SAI Experimental Research Fund

https://drive.google.com/drive/folders/1KRtdfFEjKmzV5XaxiyzRL4JckPzrF_sM

Proposed $1B SAI Equipment Development Fund

https://drive.google.com/drive/folders/1B0Sko2M2cl_V-_uZcPozD-s0cF8bjV-_

Global Climate Models

Proposed $1B GCM Experimental Research Fund

https://drive.google.com/drive/folders/1i6uLaOv3Yfx9RzXsDUEnDvDJL1E0Dl-6

Nuclear Fission Power

Proposed $1B Nuclear Power Automated Construction Development Fund

https://drive.google.com/drive/folders/1HWNJZ2X3jgx4dXn_7VPq25ljJJuIG1aS

Proposed $1B Nuclear-Integrated Chemical Processing Platform Development

https://drive.google.com/drive/folders/1-G2IHTErH0ETdfpCX-i8Nin0khOlEBru

Climate Laboratory

Climate Moonshot Business Plan (90-page PDF)

https://drive.google.com/drive/folders/1EMb-Tqw49ewj16UeGhR7UOc9HY6POpKC

Atmospheric Research

Proposed Experiments Measure Sunlight Reflecting off Pollution (47-pg PDF)

https://drive.google.com/drive/folders/1X6PBoXXu-VhMOtQ5JOzlt29oW3qjzGhY

Proposed $250M Cloud Experimental Research Fund (13-page PDF)

https://drive.google.com/drive/folders/1apa-sQ4fyz-k6e5cnyvsyO1QKQ8r_ICB

Proposed $2B Atmospheric Experimental Research Fund (400-page PDF)

https://drive.google.com/drive/folders/1e5jvAmJUfBLCpkQVKwR0dS_Ur2UtFLkG

Ocean Iron Fertilization

Proposed $25M Ocean Iron Fertilization Research Fund

https://drive.google.com/drive/folders/12Rn4oc_1sUcttW1_UjKNRLJxFrv0sMj0

Climate Moonshot Conference

Climate Moonshot Conference (3-page PDF)

https://drive.google.com/drive/folders/114b_lLPTVhBuBQ4ZFpTQsjlh29_rKaB7

Climate Moonshot Film

The Climate Kids (docudrama film)

https://drive.google.com/drive/folders/1UyEyyGock43PQpnMMcEmq_94gy4m3GHI