Can Ships Cool the Pacific to Stop a Super El Niño?

A Reality-Check on Marine Cloud Brightening over the Southeast Tropical Pacific

Plain-English analyst briefing for policy staff and journalists • *Prepared from satellite and reanalysis records (1979–2026)*

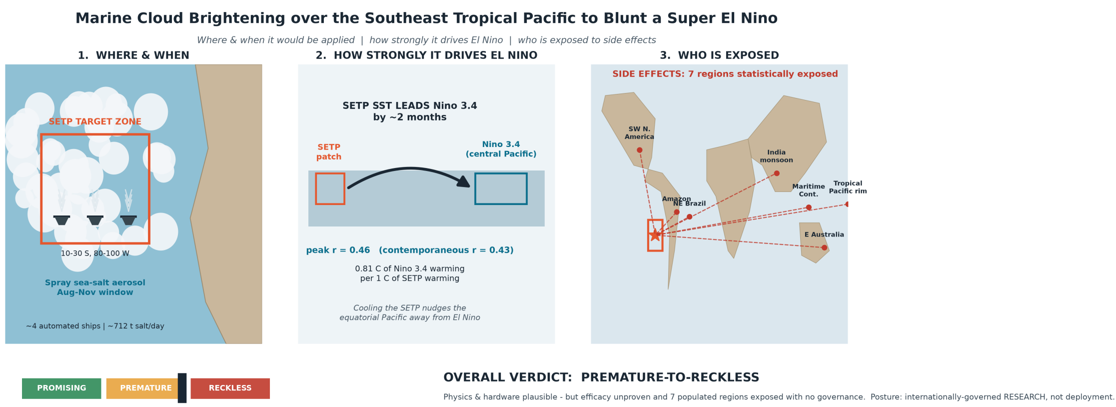

Figure 1. Visual summary of the briefing. **(1)** Where and when the intervention would be applied: sea-salt spray over the bright low-cloud deck off Chile and Peru during the austral-spring window. **(2)** How strongly that patch drives El Niño: its sea-surface temperature (SST) leads the Niño 3.4 index by about two months. **(3)** Who is exposed: seven distant, densely populated regions whose rainfall or temperature is statistically tied to the patch. The bottom bar shows the overall verdict.

EXECUTIVE SUMMARY — Bottom line for a decision-maker

The idea. "Marine cloud brightening" (MCB) means spraying a fine mist of sea salt into the low clouds that blanket the ocean west of South America, making those clouds whiter so they reflect more sunlight and cool the water beneath. Researchers have proposed doing this over the *Southeast Tropical Pacific* (SETP; roughly 10–30°S, 80–100°W) to cool a patch of ocean that helps seed El Niño, in the hope of blunting a developing "super" event.

What the data show. The target patch is real and well chosen: its clouds are brightest and its water coolest from **August to November**, the ideal window to intervene, and cooling there tends to precede cooling in the central Pacific (the SETP leads the Niño 3.4 index by about two months, correlation $r \approx 0.46$). The engineering is *not* the hard part: a fleet of roughly **2–9 automated spray vessels** releasing **∼350–1,500 tonnes of sea salt per day** could, on paper, impose the needed -1.5 to $-3\ \mathrm{W\,m^{-2}}$ of extra cooling over the patch.

Why it is dangerous. The same statistics that make the patch attractive also make it risky. Its influence reaches at least **seven far-away, populated regions** — the Amazon, northeast Brazil, the Maritime Continent, eastern Australia, the Indian monsoon belt, the U.S. Southwest, and the wider tropical Pacific — whose rainfall or temperature moves with it. Deliberately nudging the patch nudges all of them, with no consent, no compensation, and no international rulebook. Efficacy at actually stopping an El Niño remains *unproven*.

Verdict: PREMATURE-TO-RECKLESS — research, not deployment. The binding constraints are side effects and governance, not hardware. The responsible next step is confined, transparent, internationally governed *research* with impact monitoring and an exit plan — not a spray campaign.

1. What is being proposed, and why the Southeast Pacific?

Every few years the tropical Pacific tips into El Niño: the trade winds slacken, warm water sloshes east, and the resulting reorganisation of tropical rainfall reverberates worldwide as droughts, floods, and heat. The strongest "super" events of 1997–98 and 2015–16 pushed the central-Pacific Niño 3.4 index above 2.5°C and are the template for what a warming world may deliver more often (Cai et al., 2014; McPhaden et al., 2006). Faced with that prospect, some researchers have asked whether a targeted engineering intervention could take the edge off an event as it develops.

Marine cloud brightening is the candidate. The physics dates to Twomey (1974), who showed that adding cloud condensation nuclei to a cloud splits its water across more, smaller droplets, which reflects more sunlight for the same amount of water — the "Twomey effect." LATHAM (1990) proposed exploiting this deliberately by spraying sea salt into marine clouds to cool the planet, an idea since developed into detailed engineering concepts (Latham et al., 2012) and, more recently, into a formal research agenda that catalogues both its promise and its many open questions (Feingold et al., 2024). The clouds that respond best are shallow marine *stratocumulus* decks: they are bright, low, and often "clean" (low in background aerosol), so a modest injection of salt produces a large fractional change in droplet number and hence albedo (Wall et al., 2023; Gryspeerdt et al., 2023).

In one sentence: brighten the low clouds over a specific patch of the eastern Pacific, cool the water below, and hope that cooling propagates into the heart of the developing El Niño before the event locks in.

The Southeast Tropical Pacific is the natural target because it hosts one of Earth's largest and most persistent stratocumulus decks, sitting over the cool, upwelling-fed water off Chile and Peru (Wood et al., 2011; Bretherton et al., 2010; Klein and Hartmann, 1993). Figure 2 maps the target zone: relatively cool surface water (the box averages near 19–20°C in spring) beneath a near-continuous sheet of low cloud. This is exactly the "clean, bright, shallow" regime where the Twomey effect is strongest and where global assessments place both the largest aerosol cooling and the largest uncertainty (Bellouin et al., 2020; Mülmenstädt and Feingold, 2018).

2. When to act: the August–November window

Timing is not a detail; it is the difference between a useful intervention and a wasted one. Brightening only works when there is a bright cloud to brighten, and a cool surface that extra reflected sunlight can keep cool. Our analysis of the 1991–2020 climatology (Figure 3) shows both conditions align in austral spring. Sea-surface temperature in the patch bottoms out in **September** (∼19.2°C) while cloud cover peaks in **October** (∼6.2 oktas, or roughly 77% sky coverage). The overlap defines a clean operational window of **August through November**.

This window is also fortunate in timing relative to the calendar of an El Niño. Events typically emerge in boreal spring–summer and peak around December. Acting in August–November means intervening during the crucial *growth* phase, while the Bjerknes ocean–atmosphere feedback that amplifies an event is still building (Yang et al., 2018; Guilyardi et al., 2020; Kim and Kug, 2022) — late enough to know an event is developing, but early enough to matter.

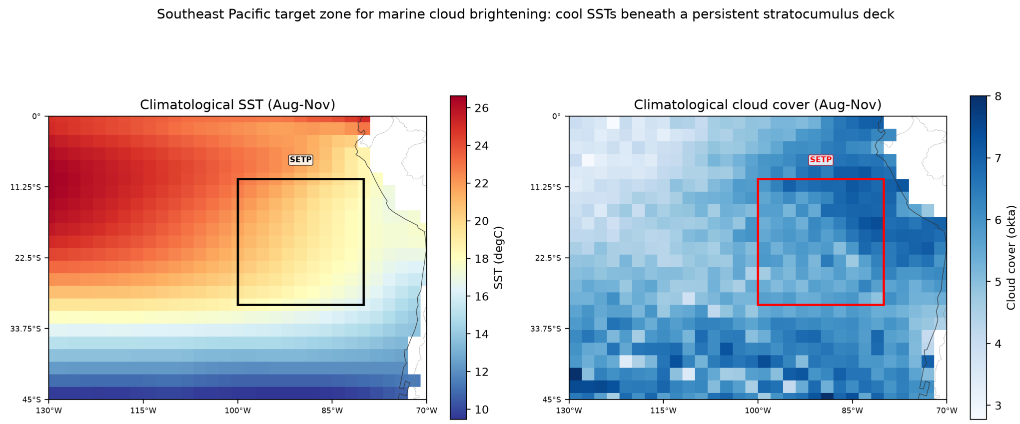

Figure 2. Where. Climatological August–November sea-surface temperature (left) and cloud cover (right) over the southeast Pacific from satellite and reanalysis records. The boxed **SETP target zone** (10–30°S, 80–100°W) combines cool surface water with a dense, persistent low-cloud deck — the physical prerequisites for effective marine cloud brightening. Data: ERSST v5 SST (Huang et al., 2017) and ICOADS cloudiness.

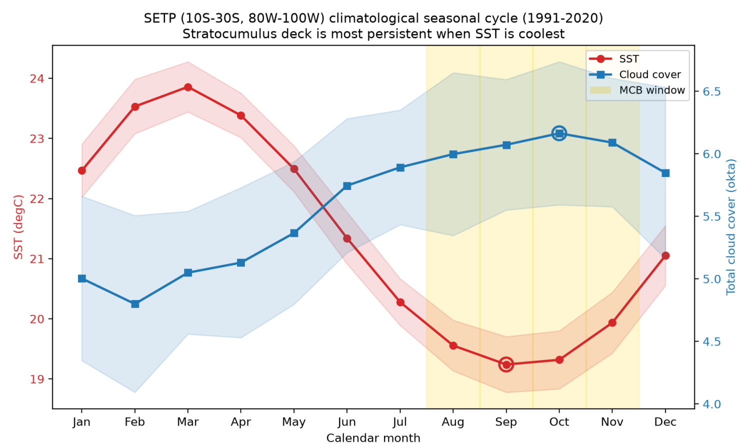

Figure 3. When. Seasonal cycle of SETP sea-surface temperature (red) and low-cloud cover (blue), 1991–2020. The clouds are most persistent precisely when the water is coolest; the shaded band marks the recommended August–November spraying window, when the deck is most susceptible to brightening.

3. How strongly does the patch drive El Niño?

An intervention is only worth attempting if the target actually steers the outcome. We tested this directly by comparing the SETP surface-temperature index with the Niño 3.4 index month by month across the satellite era. Two results stand out.

First, the two are genuinely coupled. Their contemporaneous correlation is $r = 0.43$, and the correlation *peaks at* $r = 0.46$ *when the SETP leads Niño 3.4 by two months* (Figure 4). In plain terms, cooling or warming in the SETP patch tends to show up in the heart of the El Niño region about two months later — the patch is upstream, not merely a passive bystander. Crucially, this correlation survives a strict statistical correction: because monthly climate values are "sticky" from one month to the next, we reduced the effective sample size to an autocorrelation-adjusted $N_{\text{eff}} \approx 45$ (from 570 raw months) before testing significance (Bretherton et al., 1999). The link is still significant ($p < 0.005$).

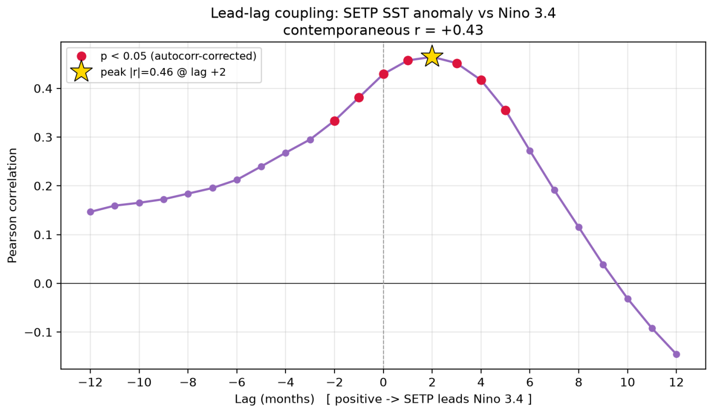

Figure 4. Driving strength. Lead–lag correlation between the SETP SST index and the Niño 3.4 index. Positive lags mean the SETP leads. The correlation peaks at $r = 0.46$ at a two-month lead (gold star), indicating the SETP patch is an upstream driver of central-Pacific El Niño development. Filled points are statistically significant after autocorrelation correction.

Second, the coupling is strong enough to be operationally meaningful. A regression of Niño 3.4 on the SETP index yields a slope of about **0.81°C of Niño 3.4 change per 1°C of SETP change**. Mapping the SETP index onto global sea-surface temperature reproduces the classic ENSO "horseshoe" pattern across the tropical Pacific (Figure 5), confirming that this patch is wired into the basin-scale mode rather than being a local curiosity (McPhaden et al., 2006; Yang et al., 2018).

There is, however, an unavoidable caveat that no observational statistic can settle. A correlation — even a lagged, significant one — shows that the SETP *co-varies with* and *precedes* El Niño; it does not prove that artificially cooling the patch would *cause* a proportional reduction in the event. The real climate system is coupled and nonlinear, and the same feedbacks that let a small perturbation grow could just as easily damp, delay, or redirect an imposed cooling. Establishing genuine efficacy would require controlled Earth-system-model experiments and, ultimately, monitored field trials (Feingold et al., 2024). That gap is central to the verdict in Section 6.

4. Reality-check 1: Who is exposed to the side effects?

The property that makes the SETP attractive — a long reach into the global climate — is also its principal danger. If the patch influences weather far away, then deliberately manipulating it exports consequences far away too. To find out *who* is exposed, we correlated the SETP index against global rainfall and air-temperature records, then applied a false-discovery-rate control to avoid being fooled by the thousands of grid points tested at once (Benjamini and Hochberg, 1995; Wilks, 2016). Seven regions survive this strict test (Figures 6 and Table 1).

The signs tell a coherent story: a warm SETP goes with a drier Maritime Continent, Amazon, northeast Brazil, eastern Australia, and Indian monsoon core, and a wetter U.S. Southwest — the canonical El Niño teleconnection pattern documented for decades (Yang et al., 2018; Lieber et al., 2024). The air-temperature analysis adds a basin-wide warming of the tropical Pacific rim. The uncomfortable implication is symmetric: a *successful* cooling of the SETP would tend to push these same regions in the opposite direction. That could help (a suppressed El Niño means the Amazon and Australia are spared drought) — or, if the intervention overshoots or the real response differs from the statistical average, it could tip drought-prone regions toward flooding, or weaken a monsoon that hundreds of millions depend on. Either way, **these seven regions bear the risk of**

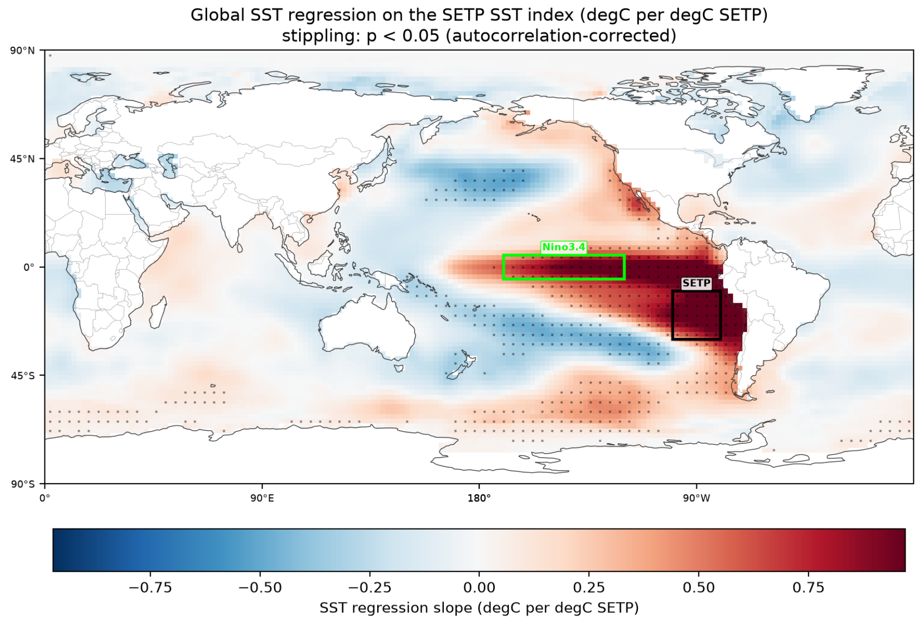

Figure 5. Basin-scale reach. Global sea-surface temperature regressed on the SETP index (°C per °C). The SETP patch (black box) projects onto the full equatorial Pacific "horseshoe," including the Niño 3.4 region (green box). Stippling marks statistical significance ($p < 0.05$, autocorrelation-corrected). This is why a change imposed on the patch does not stay local.

an intervention they did not choose, and every drought or flood during a deployment would be attributed to it, rightly or wrongly.

This is not a hypothetical concern. Earth-system-model studies of solar-geoengineering scenarios repeatedly find that offsetting warming in one place shifts rainfall in another, producing distinct regional winners and losers rather than a clean global fix (Narenpitak et al., 2024). A regional intervention aimed squarely at a teleconnection hub would concentrate exactly that risk.

5. Reality-check 2: How big an effort would it take?

If the science of *whether it works* is unsettled, the engineering of *how much it would take* is comparatively tractable. We built a parameterised physical model linking the desired cooling to the required spray, using the Twomey cloud-albedo relationship and a steady-state budget for sea-salt aerosol in the marine boundary layer, whose sensitivity to injected particles has been quantified in dedicated modelling studies (Ma et al., 2008). The target is an extra -1.5 to $-3.0\ \mathrm{W\,m^{-2}}$ of reflected sunlight averaged over the patch — comparable in magnitude to the global aerosol cooling humans already cause unintentionally (Bellouin et al., 2020).

The headline numbers are modest by the standards of global geoengineering. The target box covers about $4.6 \times 10^6\ \mathrm{km}^2$ (roughly 1% of the world ocean). To brighten its clouds by the required amount requires raising cloud-droplet number by only **∼6–26%**, delivered by a fleet of **a few automated spray vessels** dispersing hundreds to low-thousands of tonnes of dry sea salt per day (Table 2). At the central $-2\ \mathrm{W\,m^{-2}}$ target that is about **four vessels**, **712 tonnes of salt per day**, and **∼20,000 m^3 of seawater atomised per day**. Over a four-month campaign that totals roughly 90,000 tonnes of salt — large, but well within maritime-industrial capacity.

Figure 7 shows how these requirements scale. Two features matter for policy. First, the fleet

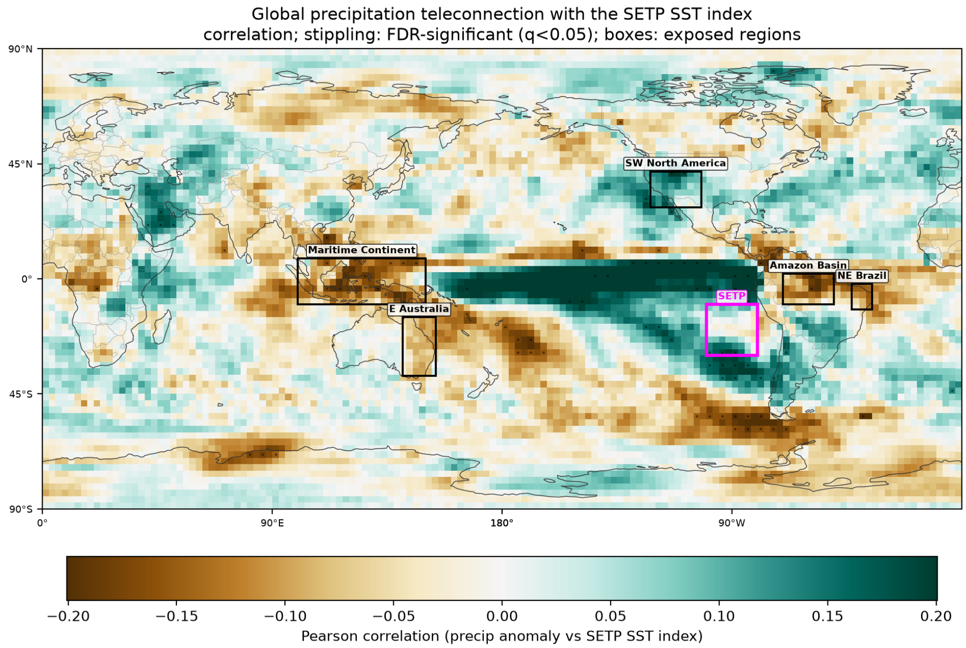

Figure 6. Who is exposed (rainfall). Correlation of global precipitation with the SETP index. Boxes mark regions whose rainfall is statistically tied to the patch; stippling denotes false-discovery-rate significance ($q < 0.05$). The pattern is a recognisable El Niño footprint — drying over the Maritime Continent, Amazon, northeast Brazil, and eastern Australia. Precipitation data: GPCP (Adler et al., 2003, 2018).

size grows roughly linearly with the ambition of the cooling, so a more aggressive intervention is not wildly more expensive — there is no natural "too hard to bother" ceiling. Second, and more importantly, the dominant uncertainty is not the hardware but the *efficiency of the physics*: how many sprayed particles actually reach cloud level and activate, and how long they survive there. The right-hand panel shows the fleet estimate swinging by a factor of several as those two poorly known parameters vary. In other words, we can build the ships; we cannot yet promise the clouds will cooperate (Gryspeerdt et al., 2023; Jia et al., 2021; Varble et al., 2023; Song et al., 2025).

The engineering verdict, then, is a double-edged one. **Feasibility is not the barrier** — which is precisely why governance matters so urgently. A capability that a mid-sized maritime operator or a single motivated state could assemble, aimed at a system that touches seven other regions, is a capability that could be deployed before the world has agreed whether, when, or by whom it should be.

6. Decision aid: promising, premature, or reckless?

Pulling the threads together, we score the proposal across four dimensions that a decision-maker must weigh together: is the science ready, are the socio-ecological risks acceptable, is there a governance framework, and are the ethics resolved? Table 3 summarises the assessment.

Science: PREMATURE The "where" and "when" are solid, and the "how much" is buildable. But the pivotal question — would spraying the patch actually blunt an El Niño? — rests on an observed correlation, not a demonstrated cause. The response of real stratocumulus to sustained salt injection, including whether the clouds thicken, thin, or dissipate, is the single largest uncertainty in the entire chain (Feingold et al., 2024; Mülmenstädt and Feingold, 2018; Possner et al., 2020).

Table 1. Who is exposed to the side effects. The seven far-away regions whose rainfall or temperature is most statistically tied to the SETP patch (false-discovery-rate significant, $q < 0.05$). "Sensitivity" is the change per +1°C of SETP warming; a deliberate cooling would tend to reverse the sign. Populations affected are large and largely agricultural.

Exposed region	Variable	Corr. r	Sensitivity	What is at stake (per +1°C SETP)
Tropical Pacific rim	Temp.	+0.43	+0.31 °C	Basin-scale warming/cooling of tropical air
Maritime Continent (Indonesia)	Rain	−0.23	−0.63 mm/day	Monsoon suppression, drought, peat-fire haze
Amazon Basin	Rain	−0.21	−0.49 mm/day	Rainforest drought and elevated fire risk
SW North America	Rain	+0.17	+0.14 mm/day	Flood/drought swings in the U.S. Southwest
NE Brazil (Nordeste)	Rain	−0.15	−0.43 mm/day	Semi-arid drought; water and crop stress
Eastern Australia	Rain	−0.14	−0.28 mm/day	Drought and bushfire risk
India (monsoon core)	Rain	−0.11	−0.23 mm/day	Weaker summer monsoon rainfall

Table 2. How big an effort. Engineering requirements to impose a sustained cooling over the SETP patch, from a Twomey-effect and boundary-layer aerosol-budget model. Fleet size assumes automated vessels emitting 5×10^{17} particles s^{-1} each; the range in parentheses spans unfavourable-to-favourable aerosol activation efficiency and particle lifetime.

Target forcing ($W\,m^{-2}$)	Droplet # increase	Dry salt (tonnes/day)	Seawater atomised (m^3/day)	Spray fleet (vessels)
−1.0	5.9%	346	9,600	2 (1–6)
−1.5	8.9%	527	14,700	3 (1–10)
−2.0	12.1%	712	19,900	4 (1–13)
−3.0	18.7%	1,100	30,700	7 (1–20)
−4.0	25.7%	1,511	42,100	9 (2–28)

Side effects: RECKLESS Deploying now, before region-by-region impact forecasts and a monitoring system exist, would place uncompensated drought-and-flood risk on seven regions that receive none of the intended benefit and never consented. Geoengineering model studies confirm such interventions create losers as well as winners (Narenpitak et al., 2024).

Governance: RECKLESS Because the physics is transboundary by construction, so is the liability. There is today no treaty, consent mechanism, or independent monitor for deliberate regional ocean-temperature modification, and the international research community is itself in a "geopolitical deadlock" over even studying it (McLaren and Corry, 2025, 2021; Reynolds, 2021; Frumhoff and Stephens, 2018). Unilateral or small-coalition deployment would invite attribution disputes and escalation.

Ethics: PREMATURE Because the cooling must be maintained through the event, a sudden halt risks "termination shock," with the suppressed warming rebounding quickly (Parker and Irvine, 2018). Combined with the "moral hazard" that a perceived quick fix erodes the will to cut emissions, these concerns are governable through transparent, staged research — but they are not yet resolved (National Academies of Sciences, Engineering, and Medicine, 2021).

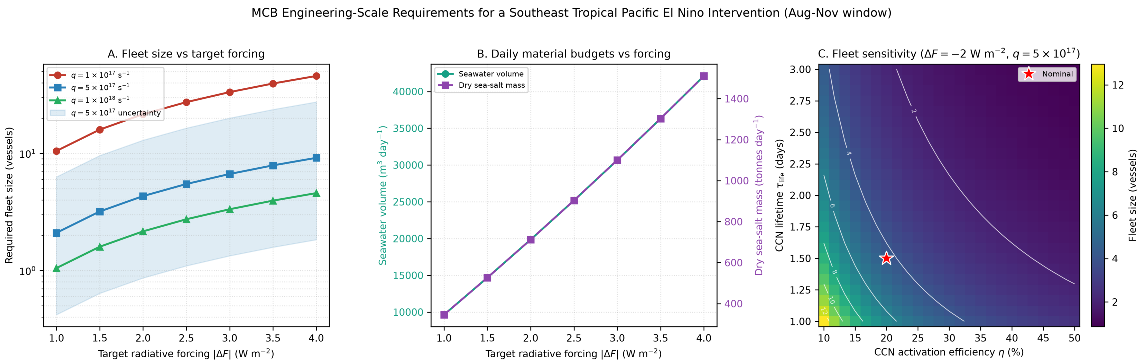

Figure 7. Engineering trade-offs. (A) Required fleet size versus target cooling for three assumptions about per-vessel output; shading spans the uncertainty. (B) Daily sea-salt mass and seawater volume scale linearly with the target. (C) Sensitivity of the fleet estimate (at -2 W m^{-2}) to aerosol activation efficiency and particle lifetime — the physics, not the hardware, dominates the uncertainty.

OVERALL VERDICT — PREMATURE-TO-RECKLESS: not ready for deployment

The target is well characterised and the hardware is achievable, but efficacy is unproven and the intervention is statistically wired to seven distant, populated regions with *no* governance, consent, liability, or monitoring framework in place. The dominant constraints are socio-ecological and geopolitical — not engineering.

Recommended posture: treat SETP marine cloud brightening as a subject for *confined, transparent, internationally governed research* — coupled Earth-system-model efficacy studies, small and heavily monitored field experiments, region-resolved impact forecasting, and an explicit termination-shock exit plan — **before** any operational spraying is contemplated. For a journalist or policy analyst: the honest framing is not “a promising fix we should fund” nor “science fiction to dismiss,” but “a plausible capability racing ahead of the rules needed to use it safely.”

Data and methods, in brief

Analyses use satellite-era (1979–2026) monthly records: sea-surface temperature from ERSST v5 (Huang et al., 2017), precipitation from GPCP (Adler et al., 2003, 2018), land–ocean air temperature from NOAA-GlobalTemp (Huang et al., 2020), and ICOADS cloudiness. Anomalies are departures from the 1991–2020 climatology. The SETP index is an area-weighted average over 10–30°S, 80–100°W; Niño 3.4 over 5°N–5°S, 170–120°W. Correlations use an autocorrelation-adjusted effective sample size (Bretherton et al., 1999); global teleconnection significance uses Benjamini–Hochberg false-discovery-rate control (Benjamini and Hochberg, 1995; Wilks, 2016). The engineering model applies the Twomey cloud-albedo susceptibility and a steady-state marine-boundary-layer salt-aerosol budget (Twomey, 1974; Latham et al., 2012). This is a rapid analyst briefing built on observational statistics and a parameterised engineering model; it is *not* a substitute for peer-reviewed Earth-system-model efficacy studies, and its side-effect estimates are correlational rather than causal.

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Table 3. Decision matrix. Assessment of SETP marine cloud brightening across four dimensions. Colour indicates the verdict for each dimension; the two **Reckless** dimensions are outright deployment blockers.

Dimension	Verdict	Key evidence	The gap that must close
Scientific & technical readiness	**Premature**	Target patch and window well identified; SETP leads Niño 3.4 ($r = 0.46$); hardware scale modest (∼4 ships, 712 t/day).	No field-scale proof that it *works*; cloud response to added aerosol is the largest forcing uncertainty; efficacy shown only by correlation, not experiment.
Socio-ecological risk & teleconnections	**Reckless**	Seven far-away, populated regions are FDR-significantly tied to the patch (Amazon, NE Brazil, Maritime Continent, E Australia, India, SW N. America, tropical Pacific rim).	No region-resolved impact forecasts and no monitoring/attribution system for cross-border harm.
Governance & geopolitics	**Reckless**	Effects are inherently transboundary; no binding international framework governs deliberate regional SST modification.	Absence of multilateral consent, a liability regime, and independent oversight.
Ethics & public perception	**Premature**	Forcing must be sustained through the event; abrupt stop risks "termination shock" as the suppressed El Niño rebounds.	No public-deliberation mandate, no moral-hazard safeguard, no exit strategy.

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