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Solar Radiation Management as a Measure of Last Resort: Biophysical and Political Dimensions in Geoengineering

Environment * Climate Change * Space

Introduction: From Theoretical Concept to Planetary Triage

By January 2026, theoretical debates over climate intervention have been overtaken by nonlinear biophysical instability. The Earth system is crossing critical thresholds faster than projected, moving intentional modification of planetary albedo -- or solar radiation modification (SRM) -- into legislative and security councils.[1][2] Driven by cumulative carbon dioxide, positive radiative forcing, and abrupt regional collapses in the cryosphere and biosphere, the debate has shifted from "moral hazard" to survival calculus.[1] Because stratospheric aerosol deployment is cheap enough for a single state or rogue actor to execute unilaterally, this report examines the empirical tipping points in the climate system, aerosol microphysics, and governance vacuum defining 2026.[1][2]

Signals from the Brink: Biophysical Drivers of Intervention

Two abrupt ecosystem state shifts in 2025-2026 underscore the demand for peak-shaving interventions:[2]

* Cryospheric Collapse of Lake Rouge: In spring 2025, Quebec's post-glacial Lake Rouge drained completely within weeks, as verified by NASA satellite data and Cree testimony.[3][4][5] Intense 2019 and 2023 wildfire seasons and logging degraded insulating soil horizons and underlying permafrost into thermokarst voids.[3][5] Spring snowmelt hydrostatic pressure fractured the basin into the Lake Doda watershed, threatening sturgeon spawning beds and Waswanipi Cree hunting grounds.[3][4][6]

* Australian Flying Fox Die-Off: In January 2026, temperatures exceeding 42 deg C (107 deg F) across southeastern Australia caused the worst mass mortality of Grey-headed flying foxes (Pteropus poliocephalus) since the 2019-2020 Black Summer.[7][8] Above their 40 deg C thermal limit, thermoregulation fails and proteins denature.[7] Because these bats are a keystone species pollinating eucalyptus forests, their loss reduces carbon sequestration.[7] While cutting greenhouse gases acts over decades, only SRM can rapidly shave lethal thermal peaks.[9]

The Mechanics of the Shield: Physics of Solar Radiation Modification

Stratospheric Aerosol Injection (SAI): Replicating the 1991 Mount Pinatubo eruption (~0.5 deg C cooling), SAI disperses reflective aerosols in the stratosphere (20-25 km).[10][11][16] While sulfur dioxide (SO_2) oxidizes into reflective sulfuric acid droplets, it absorbs longwave infrared heat -- warming the stratosphere and shifting circulation -- and catalyzes chlorine reactions that deplete the ozone layer.[11][12][14][15] Alkaline calcite ($CaCO_3$) powders are now studied to scatter

sunlight while neutralizing stratospheric acids.[13] However, SAI faces Mie scattering (~500 nm optimal size) and the Smoluchowski coagulation barrier: particle collision scales with concentration squared, forming heavy aggregates that sediment rapidly and cap cooling efficiency.[17][18][19][20]

Marine Cloud Brightening (MCB) and Glacial Anchoring: In the marine boundary layer (<1 km), MCB exploits the Twomey effect by spraying 30-100 nm sea salt crystals to boost cloud condensation nuclei (CCN) and cloud reflectivity, using 2025 high-frequency flow-pulsation nozzles to avoid drizzle-inducing Giant CCN.[17][21][22][23][24][25][26] Locally, seabed curtains blocking warm Circumpolar Deep Water and basal thermosiphons target West Antarctica's Thwaites Glacier directly.[27][28][29]

| Feature | | Stratospheric Aerosol Injection (SAI) | | Marine Cloud Brightening (MCB) | | Glacial Anchoring (Seabed Curtains) |

| Primary Mechanism | | Backscattering of sunlight via stratospheric aerosols | | Increasing cloud albedo via Twomey effect (CCN injection) | | Physical blocking of warm ocean currents |

| Target Altitude/Location | | 20-25 km (Stratosphere) | | < 1 km (Marine Boundary Layer) | | Seabed / Ice Shelf Cavity (Antarctica) |

| Material Agent | | Sulfur Dioxide (SO2) or Calcite (CaCO3) | | Seawater (Sodium Chloride crystals) | | Geotextiles / Thermosiphons |

| Key Physical Constraint | | Coagulation Efficiency (Smoluchowski limit); Sedimentation | | Aerosol Size Distribution; Updraft velocity limits | | Fluid Dynamics of tidal currents; Iceberg scouring |

| Global Cooling Potential | | High (Global ~1-2 deg C feasible) | | Moderate (Regional/Oceanic focus) | | Low (Local cryosphere preservation) |

| Primary Side Effects | | Ozone depletion; Sky whitening; Precipitation shifts | | Circulation changes; Potential rainfall suppression | | Benthic ecosystem disruption; High cost |

| Termination Risk | | Extreme (Global rapid warming shock) | | Moderate (Rapid but regional rebound) | | Low (Structural failure, not climatic) |

| Governance Status | | Highly controversial; effectively banned in some nations | | Ambiguous; small trials conducting | | Permitted as "conservation" research |

The Governance Vacuum and the Transparency Imperative

* UNEA-6 Deadlock and "Free Drivers": At UNEA-6 (February 2024), Switzerland withdrew its SRM assessment resolution amid opposition from the African Group, Mexico, and Colombia favoring a Non-Use Agreement.[30][31][32][33] Because SAI costs only billions per year, this vacuum heightens unilateral "free driver" deployment risks and geopolitical conflict.[1][34][35][36]

* Domestic Polarization: In January 2026, U.S. Rep. Eli Crane introduced the "Atmosphere Study Act of 2026" (H.R. 6941) mandating a Department of Energy study of geoengineering health and environmental impacts, alongside state proposals like Kentucky's HB 60; both bills remained stalled in committee without enactment as of

November 2026.[9][37][38][39]

* Global Registry and Termination Shock: NOAA and Oxford researchers advocate a public registry with mandatory pre-notification and open data,[40][41][42] alongside the Degrees Initiative funding Global South hydrology modeling.[43][44] Governance must also prevent termination shock -- the rapid warming rebound if an aerosol veil stops abruptly.[45][46][47]

| Date | | Event | | Significance for Geoengineering |

| Feb 2024 | | UNEA-6 (Nairobi) | | Diplomatic Failure: Switzerland withdraws SRM resolution due to lack of consensus. The "Non-Use" bloc (African Group) asserts dominance, leaving a governance vacuum. |

| Spring 2025 | | Lake Rouge Drainage | | Biophysical Tipping Point: Collapse of public trust in "natural stability." Validates fears of nonlinear Arctic change. |

| Jan 2026 | | "Atmosphere Study Act of 2026" (US) | | Political Polarization: Introduction of H.R. 6941 (referred to House Energy and Commerce) alongside state-level geoengineering bills such as Kentucky HB 60 (recommitted in Feb 2026). |

| Jan 2026 | | Australian Heatwave | | Biological Limit: Mass mortality of Flying Foxes at >42 deg C. Demonstrates the "hard limits" of adaptation and the need for peak-shaving cooling. |

| Jan 8, 2026 | | Guardian Commentary | | Public Sentiment: High-profile warning that "rogue" actors will inevitably deploy cheap geoengineering technologies. |

Conclusion: Navigating Between Tipping Points and Unilateralism

The collapse of Lake Rouge and Australia's flying foxes show that ecosystems are fracturing faster than diplomacy.[3][8] Averting chaotic unilateral geoengineering requires respecting physical limits like Smoluchowski coagulation while establishing transparent multilateral registries and Global South scientific leadership.[1][19][40][43]

Updates... (Nov 21, 2026): Corrected H.R. 6941's statutory short title to the Atmosphere Study Act of 2026, noted that both H.R. 6941 and Kentucky HB 60 remained in committee without enactment through November 2026, verified live availability and metadata for all 47 primary sources (adding exact publication dates on Refs. 17 and 30), and converted PubMed Central links to canonical peer-reviewed DOI URLs.

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