Climate Cooling Approaches and Tipping Points

Understanding their interactions – workshop summary

Executive Summary

As global warming approaches 1.5C, the risk of triggering self-perpetuating tipping points in the Earth system is increasing. Whilst decarbonisation is the only long term solution to climate change, rising temperatures have led to an increase in interest in Earth cooling approaches, otherwise known as Solar Radiation Modification (SRM), 'solar geoengineering' or 'climate interventions', as a way to cool the planet on timescales faster than decarbonisation, and reduce the risk of crossing climate tipping points. SRM's efficacy and its potential to inadvertently destabilise tipping systems remain poorly understood. Acknowledging these uncertainties, physical science experts across the SRM and tipping points communities convened with the aim of identifying critical scientific research gaps. Participants concluded this two day meeting by emphasizing the need for more rigorous, transparent research, an in-depth expert elicitation on the state of the science of the interaction between SRM and tipping points, and targeted funding toward improving process representation in climate models and observations.

Motivation

ARIA's Exploring Climate Cooling programme has moved beyond framing SRM solely in relation to tipping point risk. As the field has evolved, ARIA's priorities as a public-interest funder have increasingly centred on building the evidence base needed to support stronger governance of SRM and more informed decision-making in response to tipping point risks. Nevertheless, questions about the interaction between tipping points and SRM remain important to any consideration of SRM governance. Whilst tipping points and SRM research both raise a number of connected scientific questions, including around Earth system response, uncertainty, and the limits of current modelling and observational capabilities, there has been little structured collaboration between the two communities. As a public funder supporting activity across both areas, ARIA convened a two-day workshop to encourage dialogue and cooperation in order to address these critical gaps in our understanding. The purpose of the workshop was not to suggest that tipping point risks inherently motivate or justify SRM, but rather to support more rigorous and balanced consideration of the questions that arise at their intersection and to help identify shared priorities for future research, in order to equip society with the collective knowledge needed to make better-informed decisions on tipping point risks and SRM.

Ethical Considerations

The focus of this workshop was to convene physical science experts to address questions related to climate science and modelling on the topics of tipping points and SRM. Participants acknowledged, however, that scientific questions represent only one part of the wider debate around tipping points and SRM. The intention was not to overlook governance, ethical, or larger societal issues, but rather to create space for focussed discussions within the expertise of those present. Any scientific research agenda must acknowledge those most impacted by climate change and SRM research, and be designed to empower those communities to make informed decisions by equipping them with the scientific knowledge base they need to do so. All workshop participants further acknowledged the concern that research at this intersection could distract from mitigation, which remains essential for tackling climate change and reducing long-term tipping point risks (IPCC; Siegert et al., 2025; Lenton et al., 2025). Nevertheless, there was broad agreement on the seriousness of tipping point risks and on the importance of improving society's understanding of the impact of SRM on tipping risks.

Climate Tipping Points

Climate tipping points can be defined as occurring when a change in part of the climate system becomes self-perpetuating beyond a critical threshold, leading to substantial, widespread, frequently abrupt, and often irreversible impacts. Coral reefs, polar ice sheets, mountain glaciers, sea ice, tropical forests, subpolar gyre convection, and the Atlantic Meridional Overturning Circulation (AMOC) have all been identified as potential tipping systems and are thus at risk of critical transitions, if not collapse. While interactions between tipping points remain poorly understood, there is a further risk that tipping one element of the climate system increases the probability of others tipping, creating the potential for cascading and compounding tipping events (Wunderling et al., 2024). The impacts of a tipping system crossing such critical thresholds could be significant for both societies and ecosystems (Lenton et al., 2025).

SRM Approaches Considered

Solar Radiation Modification (SRM), or solar geoengineering, refers to proposed climate intervention strategies designed to cool the Earth by reflecting a fraction of incoming solar radiation back into space. Three SRM approaches were discussed at the workshop: Stratospheric Aerosol Injection (SAI), Marine Cloud Brightening (MCB) and Sea-Ice Thickening or Preservation (SIT). For further details on these approaches please refer to the Royal Society report on SRM (The Royal Society., 2025).

The Intersection of Tipping Points and SRM

The threat posed by tipping points and the irreversibility of such transitions remains contentious, and considerable uncertainties exist in our understanding of the processes involved in tipping dynamics. However, given the seriousness of potential tipping points, workshop attendees were motivated by the need for open research into the impact of possible climate interventions, including SRM techniques, on tipping dynamics (Zhao et al., 2025). Given the clear and well-recognised possibility of unwanted impacts from the potential deployment of SRM (Zarnetske et al., 2021; Haywood et al., 2023), as well as the long timescales associated with these approaches (Baur et al., 2024), it is crucial that the full consequences of any potential future use of SRM approaches are carefully tested with multiple numerical models at different levels of complexity and fully understood. Therefore, it is essential to (i) comprehensively assess all associated climate outcomes and (ii) determine whether, and under what conditions, SRM could practically enable humanity to avoid or reverse tipping points. Participants further acknowledged that the current generation of climate models used to assess tipping point-SRM interactions does not fully represent all relevant physical processes. Consequently, model uncertainty should be reduced through model improvements, and remaining uncertainties must be explicitly accounted for in any tipping point-SRM model-based assessment programme - including through the use of multiple earth and climate system models and the use of ensembles of simulations.

Overarching Research Questions

To move forward, the following questions were raised by the participants in relation to each SRM strategy and tipping points considered.

Efficacy and Dynamics	• Does the intervention address the key physical drivers of the specific tipping point? • Can the intervention stop a "tip" already in progress, or even reverse a completed one?

	• Is there a point where it is simply "too late" for an intervention to work?
On Risks and Side Effects	• Would injudicious or poorly timed SRM deployments make tipping risks worse? • What are the full costs and side effects (e.g., shifts in precipitation or extremes) of an intervention targeting a specific tipping point? • How does "termination shock" (the abrupt ceasing of climate intervention deployment) compare to the risks of a no-SRM baseline?
On Evidence and Feasibility	• How reliable is the evidence base supporting our understanding of tipping point-SRM interactions across observations and paleoclimate evidence, model simulations, and theoretical or process understanding, and what additional lines of evidence could be used? • What are the primary obstacles to understanding tipping point-SRM interactions (e.g., missing observational data), and can they be addressed? • Would SRM be feasible or effective on tipping point relevant timescales?

By tackling these questions, research can inform understanding of:

- The climate and environmental side effects from a given SRM approach (e.g. changes in extremes, air pollution, precipitation shifts, and ecological impacts)
- The associated political risks (e.g. mitigation deterrence, geopolitical instability or conflict)
- The technical feasibility of individual SRM approaches as they relate to tipping points.

Conclusions and next steps

Attendees agreed on the need for a near-term research project to define the current state of knowledge on the interaction between SRM and tipping elements, and highlighted that producing a robust synthesis requires input from the wider tipping and SRM research communities. To assess the current state of knowledge and identify research priorities, the group proposed conducting a structured expert elicitation process. Whilst ARIA has not committed to fund such an elicitation, the aim of this proposed process would be to produce a robust and thorough community assessment of the state of knowledge pertaining to the research questions described above, to identify additional gaps in understanding and to generate a targeted set of near- and long-term research priorities for future research planning. This assessment could then be used to inform the wider research community of current uncertainties and potential future research agendas. Any proposed scientific research agenda must also take into consideration the ethical and governance issues central to questions regarding SRM and tipping points. Scientific research does not exist in an ethical vacuum, and all SRM research must be designed to empower communities and society at large with the knowledge base they need to make informed decisions about humanity's shared future.

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