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SYMPOSIUM ON THE FUTURE OF A MELTING ARCTIC: CHALLENGES FOR INTERNATIONAL LAW

ARCTIC CLIMATE ENGINEERING

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Introduction

The likely insufficiency of conventional climate mitigation policies to prevent dangerous climate change has prompted increasing interest in technological interventions to cool the planet. Most of the scholarly and policy literature on climate engineering has focused on interventions aimed at influencing the global climate—for example, by injecting reflective particles (aerosols) into the stratosphere, which would reduce the amount of sunlight reaching the surface of the Earth. Our focus here is on a less-studied area: potential Arctic-specific interventions to thicken sea ice, reduce ice melt, or stabilize glaciers, which we argue raise fewer legal and governance issues than global interventions.

Conventional policies to limit (and ultimately halt) global warming have focused on greenhouse gas emissions reductions. But emissions reductions, although essential, cannot by themselves save the Arctic. Even if greenhouse gas emissions were completely eliminated tomorrow, sea ice would simply stabilize at its current (low) levels, not recover anytime soon.[1] And, of course, eliminating emissions tomorrow is a complete impossibility. Global emissions are still increasing and, even on the most optimistic assumptions, will continue for decades. According to current estimates, the world, at best, will warm another half degree and, more likely, will warm much more, causing additional harms to the Arctic.[2]

Opinions vary widely about whether Arctic-specific interventions are technically feasible and, if so, would be scalable, cost-effective, and safe.[3] We express no opinion on these issues, which are outside our areas of expertise. Instead, our focus is on the legal issues raised by Arctic-specific interventions, including the relevant environmental norms.

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[1] Julienne C. Stroeve, Dirk Notz, Jackie Dawson, Edward A.G. Schuur, Dorthe Dahl-Jensen & Celine Giesse, *Disappearing Landscapes: The Arctic at +2.7°C Global Warming*, 387 SCIENCE 616, 616 (2025).

[2] United Nations Environment Programme, Emissions Gap Report, 5, 38 (2025).

[3] *Compare* Martin Siegert et al., *Safeguarding the Polar Regions from Dangerous Geoengineering A Critical Assessment of Proposed Concepts and Future Prospects*, 3 FRONTIERS SCI. 1527393 (2025) (concluding that "none of these geoengineering ideas pass [sic] scrutiny") *with* Pete Irvine, *No, Polar Geoengineering Has Not Been Debunked*, SRM360 (Sept. 26, 2025).

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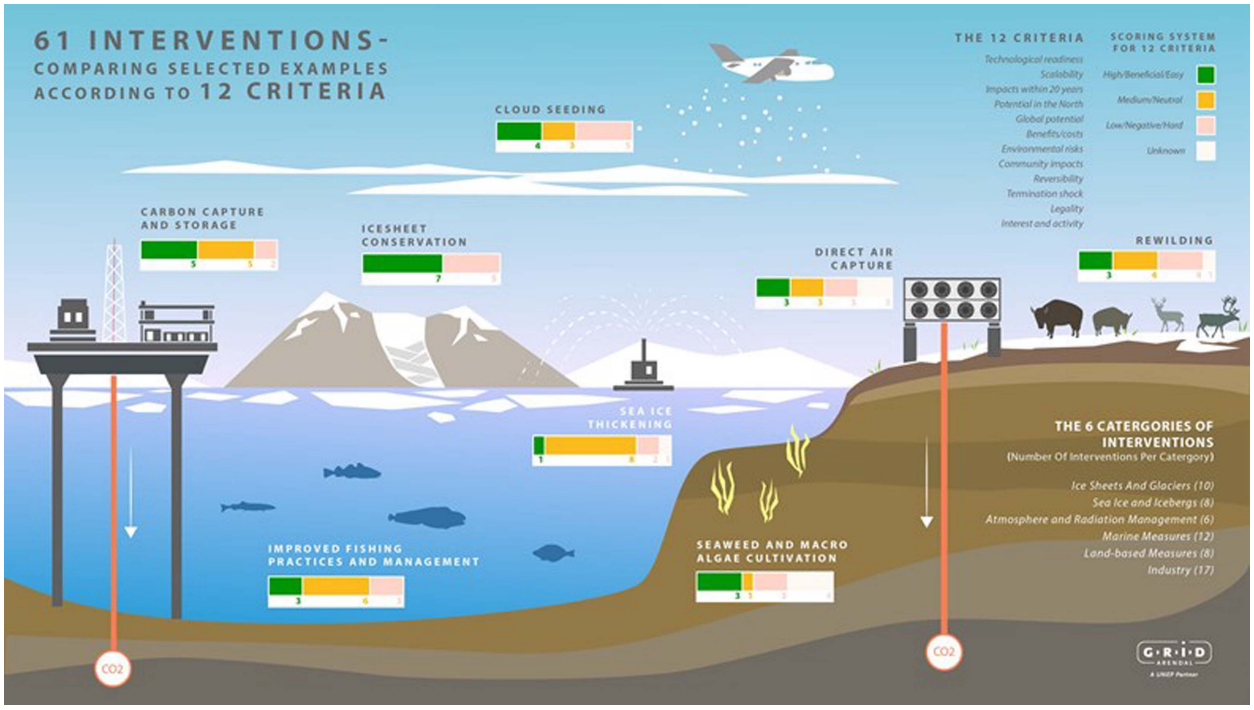


FIGURE 1. Arctic Climate Interventions.[4]

Overview of Arctic Interventions[5]

Arctic interventions fall into four general categories: (1) interventions to thicken sea ice; (2) interventions to slow snow and ice melt on land; (3) interventions to stabilize glaciers, to slow their slippage into the ocean; and (4) so-called "Pleistocene parks."

Thickening sea ice. Sea ice reflects five to ten times more sunlight than water, so when it melts and is replaced by open water, more solar radiation stays in the Earth system and warms the planet. The goal of sea ice thickening would be to add ice during the winter so the ice does not melt through completely in the summer. One proposal is to pump water from beneath the ice and spray it onto the ice surface, where it would be exposed to the air and freeze more quickly.[6] Even if this did not delay global warming,[7] it could at least help ice-dependent species and communities.[8]

[4] ALBERT VAN WIJNGAARDEN ET AL., FROZEN ARCTIC: A COMPENDIUM OF INTERVENTIONS TO SLOW DOWN, HALT, AND REVERSE THE EFFECTS OF CLIMATE CHANGE IN THE ARCTIC AND NORTHERN REGIONS 6–7 (2024).

[5] VAN WIJNGAARDEN ET AL., *supra* note 4; John C. Moore, Ilona Mettiäinen, Liyun Zhao, Rupert Gladstone, Stefan Kirchner & Timo Koivurova, *Targeted Geoengineering: Local Interventions with Global Implications*, 12 (SUPP. 1) GLOBAL POL'Y 108 (2021).

[6] Steven J. Desch et al., *Arctic Ice Management*, 5 EARTH'S FUTURE 107 (2017). Real Ice, a UK start-up, is currently conducting field tests of this general approach.

[7] Lorenzo Zampieri & Helge F. Goessling, *Sea Ice Targeted Geoengineering Can Delay Arctic Sea Ice Decline But Not Global Warming*, 7 EARTH'S FUTURE 1296 (2019).

[8] Moore et al., *supra* note 5, at 110.

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Slowing ice and snow melt. Reducing ice and snow melt has the same goal as sea ice thickening: namely, to prevent reflective snow and ice from being replaced by water and dry land, in order to preserve the Arctic's albedo. In theory, the melting of ice and snow could be inhibited by increasing their reflectivity—for example, by placing reflective materials on the surface of the ice or snow in order to reduce the amount of solar radiation it absorbs.[9] One project, which proposed using glass microspheres as the reflective substance, shut down in 2025, but researchers are continuing to experiment with other reflective materials.[10]

Stabilizing glaciers. In contrast to snow and ice management, which aims to preserve the Earth's albedo, glacial engineering has as its primary goal to limit sea-level rise.[11] Between 1992 and 2020, Greenland is estimated to have lost more than 5 billion tons of ice, adding a half-inch to global sea level.[12] If Greenland's ice sheet was to melt completely, this would raise sea levels globally by more than 7 meters. Proposals to slow the loss of Greenland's ice sheet include:

- Erecting underwater curtains to block warmer sea water from penetrating the base of the ice where it reaches the sea.
- Buttressing ice to prevent it from slipping.
- Pumping out water beneath glaciers that lubricates their slippage downhill.[13]

Pleistocene park. Finally, some scientists have suggested that reintroducing large herbivores into the Siberian tundra could slow the thawing of permafrost.[14] The theory is that large herbivores such as reindeer, horses, and bison would help pack down snow, thereby reducing the snow's insulating effect and accelerating the freezing of the permafrost below. One modeling study found that this approach could reduce the thawing of permafrost by almost 40 percent.[15]

Distinctive Features of Arctic Interventions[16]

Proposed global climate interventions are highly controversial and raise difficult governance issues, given their global effects and potential risks.[17] By contrast, Arctic-specific interventions raise fewer legal and governance issues. They differ from global climate interventions in several important respects:

[9] VAN WIJNGAARDEN ET AL., *supra* note 4, at 28–32; Leslie Field et al., *Increasing Arctic Sea Ice Albedo Using Localized Reversible Geoengineering*, 6 EARTH'S FUTURE 882 (2018).

[10] Sebastian Rodriguez, *Arctic Geoengineering Experiment Shuts Down Over Environmental Risks*, CLIMATE HOME NEWS (Feb. 3, 2025). The Bright Ice Initiative is ongoing and has conducted field tests with a clay-based material. Bright Ice Initiative.

[11] Andrew Lockley, Michael Wolovick, Bowie Keefer, Rupert Gladstone, Li-Yun Zhao & John C. Moore, *Glacial Geoengineering to Address Sea-Level Rise: A Geotechnical Approach*, 11 ADV. CLIMATE CHANGE RSCH. 401 (2020).

[12] Jet Propulsion Laboratory, *NASA Study: More Greenland Ice Lost than Previously Estimated* (Jan. 17, 2024).

[13] VAN WIJNGAARDEN ET AL., *supra* note 4, at 18–22.

[14] Marc Macias-Fauria et al., *Pleistocene Arctic Megafaunal Ecological Engineering as a Natural Climate Solution?*, 375 PHIL. TRANS. ROYAL SOC'Y B 20190122 (2020).

[15] Christian Beer, Nikita Zimov, Johan Olofsson, Philipp Porada & Sergey Zimov, *Protection of Permafrost Soils from Thawing by Increasing Herbivore Density*, 10 SCI. REP. 4170 (2020).

[16] This section draws on: Daniel Bodansky & Hugh Hunt, *Arctic Climate Interventions*, 35 INT'L J. MARINE & COASTAL L. 596, 607–09 (2020).

[17] Daniel Bodansky, *The Who, What, and Wherefore of Geoengineering Governance*, 121 CLIMATIC CHANGE 539 (2013).

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First, Arctic interventions arguably constitute adaptation measures. For example, building a sea curtain to slow the slippage of glaciers into the ocean is not dissimilar to building a sea wall to prevent coastal flooding. Like a sea wall, the function of a sea curtain would be to prevent the movement of seawater that causes damage to the environment—in the case of a sea wall, damage to coastal areas; in the case of a sea curtain, damage to glaciers. Similarly, refreezing seawater would be analogous to reforestation or the development of drought-resistant crops: the goal would be to preserve or restore the status quo ante, rather than to affect the global climate system.

Second, Arctic-specific interventions would have primarily local or regional effects. For example, spraying reflective particles on an ice-covered lake in Canada to inhibit melting would take place within Canadian territory and would not have significant transboundary effects.

Third, Arctic-specific interventions would clearly not be a substitute for emission reductions. They would thus not be subject to one of the objections to global climate interventions raised by critics: namely, that the prospect of being able to limit global warming through technological interventions might undermine efforts to reduce emissions.[18]

Finally, some Arctic interventions, such as Pleistocene parks, can be framed as "natural" rather than technological solutions. In essence, they aim to re-wild regions that were transformed by the hunting of large herbivores by humans.

Legal and Governance Issues

The legal and governance issues raised by Arctic-specific interventions differ for land versus ocean-based interventions. Land-based interventions would be governed primarily by international environmental law, while sea-based interventions would be governed primarily by the law of the sea.

Land-Based Interventions

As discussed above, land-based interventions include spraying reflective particles onto ice and snow and reintroducing large herbivores into permafrost regions. Because they occur on land, these interventions would be within the jurisdiction of the territorial state. Like other such activities, they would be subject to the general principles of international environmental law, which impose rather modest obligations to limit adverse transboundary effects. As spelled out by the International Court of Justice, the primary duty of states is to use due diligence to prevent significant transboundary harms.[19] As part of that duty, states must conduct environmental impact assessments of activities that may have significant adverse transboundary effects and must notify and consult with potentially affected states.[20] If an intervention might affect an Indigenous People or a local community, this would also implicate Indigenous rights and human rights law. In addition, parties to the Polar Bears Agreement would be obliged to "take appropriate action to protect the ecosystems of which polar bears are a part" from any adverse impacts of land-based interventions.[21]

[18] *See, e.g.*, CLIVE HAMILTON, EARTHMASTERS: THE DAWN OF THE AGE OF PLANETARY ENGINEERING (2013). For a rebuttal of the moral hazard argument, see Jesse Reynolds, *A Critical Examination of the Climate Engineering Moral Hazard and Risk Compensation Concern*, 2 ANTHROPOCENE REV. 174 (2015).

[19] Pulp Mills on the River Uruguay (Arg. v. Uru.), Judgment, 2010 ICJ Rep. 14, 55, para. 101 (Apr. 20).

[20] *Id.* at 83, para. 204.

[21] Agreement on the Conservation of Polar Bears, Nov. 15, 1973, 2898 UNTS 243 (entered into force May 26, 1976).

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It is not clear why Pleistocene parks or reflective particles would have significant adverse transboundary effects. But if scientists thought that they might, then the territorial state would have a duty to assess and possibly notify, consult, and take reasonable measures to mitigate. In addition, if an intervention might impact Indigenous Peoples, a state would need to consult and cooperate with the affected group.[22]

Beyond their local and regional effects, Arctic-specific interventions would have global impacts, since what happens in the Arctic does not stay in the Arctic. Indeed, that would be one of their main motivations: glacial engineering aims to limit sea-level rise and slowing snow and ice melt aims to maintain the Arctic's albedo. But compared to global interventions such as stratospheric aerosol injection, which affect the climate system pervasively, Arctic interventions are much more modest. Whether they would have any significant effect on the global climate is unclear. To the extent they did, they would be no different from many other measures states take within their territory to address climate change, such as emission reductions, reforestation, and painting roofs white, none of which are seen as raising difficult governance questions.

Ocean-Based Interventions

Ocean-based interventions in the marine Arctic would be subject to the environmental norms set forth in the UN Convention on the Law of the Sea (UNCLOS)[23] as well as in customary international law. Under Article 192 of UNCLOS, states are obligated to "protect and preserve the marine environment." This obligation is now generally accepted as reflecting a rule of customary international law.[24] As the International Tribunal for the Law of the Sea (ITLOS) stated, the obligation is "one of due diligence."[25] Thus, states would be required to exercise due diligence to protect and preserve the marine environment, including marine species and ecosystems, from environmental harms stemming from ocean-based interventions in the marine Arctic.

Like land-based interventions, states conducting ocean-based interventions would be subject to the no harm principle. For ocean areas, this principle is set out in Article 194(2) of UNCLOS, which has been interpreted as a due diligence obligation.[26] This obligation is linked to an obligation to conduct an environmental impact assessment under Article 206 of UNCLOS because Article 206 constitutes a "particular application" of the more general obligation enunciated in Article 194(2).[27] If ocean-based interventions might affect the rights of Indigenous Peoples, it would be crucial to ensure the participation of Indigenous Peoples in the environmental impact assessment process.[28]

[22] Romain Chuffart & Aaron Cooper, *The Future of a Melting Arctic: Implications for Indigenous Rights*, 120 AJIL UNBOUND __ (2026).

[23] UN Convention on the Law of the Sea, Dec. 10, 1982, 1833 UNTS 397 (entered into force Nov. 16, 1994).

[24] ALAN BOYLE & CATHERINE REDGWELL, BIRNIE, BOYLE, AND REDGWELL'S INTERNATIONAL LAW AND THE ENVIRONMENT 511 (4th ed. 2021); JAMES HARRISON, SAVING THE OCEANS THROUGH LAW: THE INTERNATIONAL LEGAL FRAMEWORK FOR THE PROTECTION OF THE MARINE ENVIRONMENT 24–25 (2017); PHILIPPE SANDS & JACQUELINE PEEL, PRINCIPLES OF INTERNATIONAL ENVIRONMENTAL LAW 461 (4th ed. 2018); Detlef Czybulka, *Article 192*, *in* THE UNITED NATIONS CONVENTION ON THE LAW OF THE SEA: A COMMENTARY 1277, 1284–85 (Alexander Proelss ed., 2017).

[25] Request for an Advisory Opinion Submitted by the Commission of Small Island States on Climate Change and International Law, ITLOS Case No. 31, Advisory Opinion, para. 396 (May 21, 2024) (not yet reported).

[26] *Id.*, paras. 254, 258.

[27] *Id.*, para. 356.

[28] RACHAEL LORNA JOHNSTONE, OFFSHORE OIL AND GAS DEVELOPMENT IN THE ARCTIC UNDER INTERNATIONAL LAW 158–60 (2015).

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Although UNCLOS contains no express obligation to apply the precautionary approach, ITLOS, in its advisory opinion on climate change, interpreted the due diligence obligation under Article 194 as requiring application of the approach.[29] By identifying potential risks that may trigger the application of the precautionary approach, environmental impact assessments of ocean-based interventions would facilitate its application.[30]

It is beyond serious argument that effective implementation of an environmental impact assessment is of critical importance in the protection of the Arctic environment.[31] However, Article 206 of UNCLOS does not specify the content of an environmental impact assessment. Accordingly, as the ICJ stated in *Pulp Mills on the River Uruguay*:

> [I]t is for each State to determine in its domestic legislation or in the authorization process for the project, the specific content of the environmental impact assessment required in each case, having regard to the nature and magnitude of the proposed development and its likely adverse impact on the environment as well as to the need to exercise due diligence in conducting such an assessment.[32]

As concerns marine spaces beyond national jurisdiction in the marine Arctic, however, an environmental impact assessment relating to ocean-based intervention would be subject to the rules and procedures set out in the Biological Diversity Beyond National Jurisdiction (BBNJ) Agreement.[33] Under the BBNJ Agreement, the environmental impact assessment of a planned activity that is to be conducted in marine areas beyond national jurisdiction is to be supervised by the Agreement's Scientific and Technical Body.[34] Thus ocean-based interventions on high seas ice sheets would be subject to a more institutionalized assessment procedures.

It must also be noted that follow-up and monitoring are crucial to reviewing the impacts of ocean-based interventions on the Arctic environment. An obligation of monitoring is provided by Article 204 of UNCLOS and Article 35 of the BBNJ Agreement.

Refreezing marine areas could potentially conflict with navigational rights. The legal status of navigational routes in the marine Arctic is not free from controversy, but it is relevant to note that the coastal state is obliged not to hamper the innocent passage and transit passage pursuant to Articles 24(1) and 44 of UNCLOS and must give "due regard" to freedom of navigation in its exclusive economic zone and on the high seas pursuant to Articles 56(2) and 87(2).[35] The coastal state is also required to give appropriate publicity to any danger to navigation under Articles 24(2) and 44 of the Convention.

[29] ITLOS Advisory Opinion, *supra* note 25, para. 242.

[30] Yoshifumi Tanaka, *Obligation to Conduct an Environmental Impact Assessment (EIA) in International Adjudication: Interaction Between Law and Time*, 90 NORDIC J. INT'L L. 102, 120 (2021).

[31] For a thorough analysis of environmental impact assessment in the Arctic, see TIMO KOIVUROVA, ENVIRONMENTAL IMPACT ASSESSMENT IN THE ARCTIC: A STUDY OF INTERNATIONAL LEGAL NORMS (2002).

[32] *Pulp Mills*, *supra* note 19, para. 205. However, "the obligation to communicate reports of the results of the assessment [under Article 206] is absolute." The South China Sea Arbitration (Phil. v. China), Award, 33 RIAA 153, 523, para. 948 (July 12, 2016).

[33] Agreement Under the UN Convention on the Law of the Sea on the Conservation and Sustainable Use of Marine Biological Diversity of Areas Beyond National Jurisdiction, June 19, 2023 (entered into force Jan. 17, 2026). Among the Arctic Five, only Denmark and Norway have ratified the BBNJ Agreement.

[34] Yoshifumi Tanaka, *Reflections on the Environmental Impact Assessment in the BBNJ Agreement: Its Implications for the Conservation of Biological Diversity in the Marine Arctic Beyond National Jurisdiction* 55 OCEAN DEV. & INT'L L. 110 (2024).

[35] But, at present, the transpolar passage that crosses the high seas remains hypothetical. Erik Franckx, *Navigational Rights and Freedoms in Polar Regions*, *in* THE ROUTLEDGE HANDBOOK OF POLAR LAW 103, 113 (Yoshifumi Tanaka et al. eds., 2023).

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Conclusion

Arctic-specific interventions are still quite speculative. Major questions exist regarding their feasibility, effectiveness, scalability, and safety. But from a law and governance standpoint, they are more like conventional mitigation and adaptation than like potential global interventions. Given the magnitude of the threats posed by global warming for the Arctic, we cannot afford to exclude, *ex ante*, any options.

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