Radical Climate Adaptation in Antarctica

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As the climate crisis intensifies, there is growing interest in policies that might supplement emissions reduction and adaptation, such as carbon removal systems and solar radiation modification. One newly prominent class of proposed interventions, which we call "radical adaptation," would aim to stabilize Antarctic ice sheets, the loss of which threatens significant sea-level rise worldwide. Ice-sheet stabilization does not fit neatly within the conventional taxonomy of climate responses. Like adaptation, it would target the consequences of climate change, not the causes. But it would do so through spatially concentrated, high-leverage developments to reduce harms worldwide, rather than by separate actions in thousands of threatened coastal regions. Furthermore, these interventions would have to be researched, assessed, and executed in the unique geopolitical, legal, and administrative context of Antarctica.

This Article examines how radical adaptation might interact with the governance and geopolitics of the Antarctic Treaty System. It argues that early research into ice-sheet stabilization could readily proceed under the present system. Operational deployment would require substantial governance changes, but these may be less extreme than they initially appear and may even benefit Antarctic governance more broadly. Researching and developing ice-sheet stabilization could provide an avenue to sustain the System's core values of peace, science, and environmental protection, while also strengthening its global legitimacy. The governance challenges under the Antarctic Treaty System are substantial, but they are ultimately surmountable.

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INTRODUCTION

For sixty years, a club of nations has governed Antarctica as a demilitarized continent dedicated to peace, science, and environmental protection. These fifty-four countries have largely succeeded in their task. Antarctica enjoys the strongest environmental protection in international law, and it has more than fifty scientific research stations housing thousands of researchers who cooperate on missions sponsored by dozens of countries. The continent also hosts tens of thousands of tourists each year who come to witness its spectacular icescapes and unique wildlife. In its climate and ecology and in its governance and use, Antarctica is a place like no other on Earth.

It is the only continent administered jointly by a consortium of countries rather than through a patchwork of nation-states.[1] Its system of governance, known as the Antarctic Treaty System (ATS), is not perfect. To make its institutions work, which requires unanimity for many decisions, states tend to avoid contentious issues rather than work through disagreement toward compromise. As a result, key questions of territorial claims, participation in decisions, and resource rights remain unresolved. The success of this unusual regime is largely due to its marginal status in world affairs and lack of a permanent human population to govern. It is too remote, and its environment is too hostile, to attract much investment or economic activity, allowing contentious problems that would demand resolution elsewhere to be deferred indefinitely.[2] These problems notwithstanding, the Antarctic Treaty System has proven able to change with the times while preserving the continent as a place

1. *See* Part I, *infra*.

2. A major exception to this general statement is fishing in the Southern Ocean, which, not incidentally, is also one of the most stressed aspects of the Antarctic Treaty System. *See* Subpart I.C, *infra*.

for peace, nature, and scientific inquiry. The legitimacy of the system depends on its ability to keep adapting.

Climate change now threatens to upend the Antarctic Treaty System and the geopolitical structures that rely on it to keep the peace.[3] The reason is sea-level rise.[4] The western ice sheets of Antarctica contain enough water—on the upper end of estimates—to raise global sea levels by one meter by the end of the century and three meters over several centuries thereafter.[5] Indeed, Antarctic melt is projected to become the primary driver of sea-level rise by 2100 and beyond.[6] This trend threatens more loss of coastal land, more ecosystems poisoned by saltwater seepage, and more people displaced by loss of homes and livelihoods. The impacts of sea-level rise can be seen already in the United States: unprecedented sunny-day flooding in Miami,[7] higher storm surges from Hurricane Sandy and other tropical storms,[8] and vanishing California coastline.[9] The West Antarctic Ice Sheet, as peripheral a locale imaginable, now threatens the centers of global economic and political power.

The impacts of sea-level rise must be understood in the aggregate. One lesson that can be drawn from recent events is that global human systems are surprisingly vulnerable to shocks, even when those risks are anticipated far in advance.[10] Even seemingly minor, local perturbations can be amplified and

3. *See* Jeffrey McGee & Marcus Haward, *Antarctic Governance in a Climate Changed World*, 11 AUSTRALIAN J. MAR. & OCEAN AFFS. 78, 79 (2019).

4. *See* Robert McLeman, *Migration and Displacement Risks Due to Mean Sea-level Rise*, 74 BULL. ATOMIC SCIENTISTS 148, 148–52 (2018) (describing the relationship between sea-level rise and displacement and future conflict); *see also id.* at 149 (highlighting Antarctic melt as a significant contributor to sea-level rise).

5. *See* discussion at Subpart II.A, *infra*.

6. *See* Nerilie Abram et al., *Summary for Policymakers*, *in* IPCC SPECIAL REPORT ON THE OCEAN AND CRYOSPHERE IN A CHANGING CLIMATE 1, 17 & fig.SPM.1 (Hans-Otto Pörtner et al. eds., Intergovernmental Panel on Climate Change 2019) (reporting the possibility of rapid retreat during the twenty-first century). Projections of Antarctic ice mass loss are highly uncertain, and some have already proven to be underestimates. *See* Amro Abd-Elgawad et al., *Technical Summary*, *in* IPCC SPECIAL REPORT ON THE OCEAN AND CRYOSPHERE IN A CHANGING CLIMATE, *supra*, at 37, 45 ("Significant sea level contributions from Antarctic ice sheet mass loss . . . which earlier reports did not expect to manifest this century, are already being observed.").

7. *See* Hamed R. Moftakhari et al., *What Is Nuisance Flooding? Defining and Monitoring an Emerging Challenge*, 54 WATER RES. RSCH. 4218, 4218–19 (2018) (describing "sunny day" or "nuisance" flooding and Miami's vulnerability to it); *see also* Jesse M. Keenan et al., *Climate Gentrification From Theory to Empiricism in Miami-Dade County, Florida*, ENV'T RSCH. LETTERS, Apr. 23, 2018, at 1, 9–10 (empirical analysis of Miami-Dade County housing market finding "robust evidence" for nuisance flooding harming low-elevation property values).

8. *See* Benjamin H. Strauss et al., *Economic Damages from Hurricane Sandy Attributable to Sea-Level Rise Caused by Anthropogenic Climate Change*, NATURE COMMS., May 18, 2021, at 1, 1–2, 5 (arguing climate-related sea-level rise increased Hurricane Sandy's damages by four to fourteen billion dollars).

9. Li Erikson et al., *Projected 21st Century Coastal Flooding in the Southern California Bight. Part 2 Tools for Assessing Climate Change-Driven Coastal Hazards and Socio-Economic Impacts*, J. MARINE SCI. & ENG'G, July 2, 2018, at 1, 5–12 (2018).

10. *See* NAT'L INTEL. COUNCIL, GLOBAL TRENDS 2040: A MORE CONTESTED WORLD 1–9 (2021) (identifying climate change in particular as a driver of cascading global security risks).

cause widespread instability and suffering in ways whose specifics are difficult to predict.[11] The simultaneous loss of so much coastal land worldwide threatens acute destabilization of human populations and economic systems. The all-encompassing nature of sea-level rise makes it an exceptionally difficult threat to plan for.[12] Moreover, other climate impacts will increase in parallel: more heat, drought, wildfire, floods, and so on. Harms will fall unequally, usually worse for those who are socially marginalized and have limited resources to adapt or migrate.[13]

By now it is obvious and widely recognized that nations are doing too little to reduce greenhouse emissions.[14] This is especially so for rich nations like the United States, with their disproportionate shares of both global wealth and historical emissions.[15] Less widely appreciated is that a substantial amount of ice-sheet destabilization in Antarctica is largely irreversible once set into motion.[16] This is because the processes driving the loss of the most vulnerable glaciers are mainly mechanical, not driven directly by heating. Once glaciers have begun to retreat, they will continue until features of the underlying bedrock restabilize them. As a result, even extreme reductions of greenhouse gas emissions will probably be insufficient to prevent much of the Antarctic melt already underway. Moreover, the world is far away from making extreme reduction efforts. Present mid-range emissions projections point to about 3° Celsius heating by 2100,[17] and vast regions of polar ice sheets are at risk from

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11. *See* Nina von Uexkull & Halvard Buhaug, *Security Implications of Climate Change A Decade of Scientific Progress*, 58 J. PEACE RSCH. 3, 6–7 (2021) (literature review reporting the importance of indirect pathways between climate change and violent conflict); Robert McLeman, *Thresholds in Climate Migration*, 39 POPULATION & ENV'T 319, 320–21, 324–28 (2018) (analyzing potential "tipping points" in climate-driven migration); *but see* Jan Selby et al., *Climate Change and the Syrian Civil War Revisited*, 60 POL. GEOGRAPHY 232, 240–41 (2017) (analyzing potential contributing factors to the Syrian Civil War and concluding current evidence for climate change as a significant cause is weak).

12. *See* McLeman, *supra* note 11, at 324–28.

13. *See, e.g.*, Keenan et al., *supra* note 7, at 1–2 (discussing climate gentrification in Miami); *see also* McLeman, *supra* note 11, at 324–28 (analyzing sea-level rise vulnerabilities among low-elevation populations in Bangladesh and the United States).

14. *See, e.g.*, SECRETARIAT OF THE U.N. FRAMEWORK CONVENTION ON CLIMATE CHANGE, NATIONALLY DETERMINED CONTRIBUTIONS UNDER THE PARIS AGREEMENT: SYNTHESIS REPORT 5-6 (2021), https://unfccc.int/sites/default/files/resource/cma2021_08E.pdf; *see also* UNFCCC Exec. Sec'y Patricia Espinosa, *Patricia Espinosa on National Climate Plans Submitted by 31 July*, UN CLIMATE CHANGE NEWS (July 31, 2021), https://unfccc.int/news/patricia-espinosa-on-national-climate-plans-submitted-by-31-july (declaring current pledges "fall far short of what is required" to meet 2 C temperature targets).

15. *See Transcript Olúfẹmi O. Táíwò on Climate Colonialism and Reparations*, FOR THE WILD (Jan. 6, 2021), https://forthewild.world/podcast-transcripts/olufemi-o-taiwo-on-climate-colonialism-and-reparations-216 (examining what justice requires of wealthy nations regarding the climate crisis).

16. *See* discussion at Subpart II.A, *infra*.

17. Richard P. Allan et al., *Summary for Policymakers*, *in* CLIMATE CHANGE 2021: THE PHYSICAL SCIENCE BASIS: WORKING GROUP I CONTRIBUTION TO THE SIXTH ASSESSMENT REPORT OF THE INTERGOVERNMENTAL PANEL ON CLIMATE CHANGE 1, 13–14 (Valérie Masson-Delmotte et al. eds., Intergovernmental Panel on Climate Change 2021) (projecting global average warming by 2100 associated with different emissions pathways); *see also* Zeke Hausfather & Glen P. Peters, Comment, *Emissions – The Business as Usual' Story Is Misleading*, 577 NATURE 618, 619 (2020).

temperatures lower than that. In the last interglacial period, around 100,000 years ago, when the Earth was about 0.5°C to 1°C warmer than today, ice melt from Greenland and Antarctica raised the oceans by six to nine meters.[18]

These grave risks call for exploration of tools to stabilize Antarctica's ice sheets, tools that go beyond the conventional, albeit essential, objective of cutting emissions.[19] *Glacial geoengineering* is one name given for such proposals, so called because they would focus on shoring up key glaciers that stabilize vast ice sheets grounded on the continent's landmass.[20] Possible methods for stabilization include building massive underwater earthworks off of Antarctica's coast to redirect warm-water flows, or vast systems of pumps to drain or redirect sub-glacial bodies of water to slow the movement of ice.[21] Of course, at present, glacial geoengineering is not a concrete, fleshed-out engineering program. It is at the conceptual stage, the early imaginings of large-scale environmental interventions that might one day soften climate change's impacts. In this regard, it resembles longer-established geoengineering proposals like solar geoengineering, which would increase the planet's reflectivity on large scales to reduce warming.[22] Carbon dioxide removal could one day fit this definition, too, since it envisions a system of removing carbon dioxide from the ambient air at scales sufficient to blunt global average warming.[23]

Geoengineering can be understood as a search for leverage over the climate system.[24] A handful of glaciers play outsized roles in stabilizing vast ice sheets and thus over future sea-level rise.[25] Stabilizing them through built interventions, if combined with emissions reductions, could avert some of climate change's most devastating impacts. In many ways, and unlike solar geoengineering or even carbon removal, glacial geoengineering strongly resembles megaprojects already carried out across the world.[26] The proposals recall science fiction less so than vast irrigation systems, like the Colorado River System, including the

18. *See* Abd-Elgawad et al., *supra* note 6, at 55.

19. The governance of Greenland's ice sheet raises issues vastly distinct from Antarctica's governance and is therefore not discussed in this Article. *See* Rachel Lorna Johnstone, *The Impact of International Law on Natural Resource Governance in Greenland*, POLAR REC., Feb. 3, 2020, at 1, 8 (describing Greenland's legal system).

20. *See generally* Andrew Lockley et al., *Glacier Geoengineering to Address Sea-Level Rise A Geotechnical Approach*, 11 ADVANCES CLIMATE CHANGE RSCH. 401 (2020).

21. *See id.* at 404–11.

22. For two prominent treatments of solar geoengineering research and governance, *see* NAT'L ACADS. OF SCIS., ENG'G, & MED., REFLECTING SUNLIGHT: RECOMMENDATIONS FOR SOLAR GEOENGINEERING RESEARCH AND RESEARCH GOVERNANCE (2021) *and* THE ROYAL SOC'Y, GEOENGINEERING THE CLIMATE: SCIENCE, GOVERNANCE AND UNCERTAINTY (2009).

23. *See* EDWARD A. PARSON & ANDREW E. DESSLER, THE SCIENCE AND POLITICS OF GLOBAL CLIMATE CHANGE: A GUIDE TO THE DEBATE 114 (3d ed. 2019).

24. *See* OLIVER MORTON, THE PLANET REMADE: HOW GEOENGINEERING COULD CHANGE THE WORLD 81 (2016).

25. Lockley et al., *supra* note 20, at 401.

26. Solar geoengineering could also play a role in stabilizing ice sheets. *See* Peter J. Irvine et al., *Brief Communication Understanding Solar Geoengineering's Potential to Limit Sea-Level Rise Requires Attention from Cryosphere Experts*, 12 CRYOSPHERE 2501, 2508–10 (2018).

Hoover Dam, or immense earth-moving projects done to construct canals or artificial islands for cities and airports.[27] What would make ice-sheet stabilization unique is its logistical challenges—Antarctica is an exceptionally difficult place to visit, let alone build on—and its purpose of reducing global physical impacts of certain climate-based harms.

For these reasons, this Article considers ice-sheet stabilization a form of *radical adaptation.*[28] Like coastal armoring, rewilding, or other adaptation techniques, ice-sheet stabilization would seek to limit the damage and disruption caused by rising waters. But rather than taking the form of local construction projects, potentially running along thousands of miles of coastline, it would concentrate built interventions at a handful of vulnerable glaciers. It is thus *radical* because it seeks to address a root cause of sea-level rise and because it requires imagination and ambition beyond familiar, localized adaptation proposals.

Engineering projects of such scale, intensity, and intent would also radically depart from how Antarctica is currently understood and governed.[29] Ice-sheet stabilization poses profound challenges to the continent's system of governance, as embodied in the Antarctic Treaty System and other sources of law.[30] In a shallow, immediate sense, challenges arise from potential legal obligations. The Madrid Protocol, which establishes the framework for environmental protection in Antarctica and its ice shelves, prohibits mining and sharply limits non-scientific activities with severe physical impacts on the environment and species.[31] Thus it would likely prohibit, for example, dredging activities necessary to produce massive underwater berms.[32] The Madrid Protocol further

27. *See* Jonas Söderlund et al., *The Past and Present of Megaprojects*, 48 PROJECT MGMT. J. 5, 5 (2018) (characterizing megaprojects in terms of cost, complexity, risk, and duration with profound physical impacts on landscapes).

28. This use of "radical adaptation" was first proposed by HOLLY JEAN BUCK, AFTER GEOENGINEERING: CLIMATE TRAGEDY, REPAIR, AND RESTORATION (2019).

29. *See* Jeffrey McGee, *Frozen Eden Lost? Exploring Discourses of Geoengineering Antarctica*, *in* ANTHROPOCENE ANTARCTICA: PERSPECTIVES FROM THE HUMANITIES, LAW AND SOCIAL SCIENCES 56, 67–70 (Elizabeth Leane & Jeffrey McGee eds., 2019); *see also* McGee & Haward, *supra* note 3, at 88–89 (describing geoengineering proposals as possibly "generative" for the Antarctic Treaty System).

30. Brendan Gogarty et al., Correspondence, *Glacier Engineering Must Mind the Law*, 560 NATURE 167, 167 (2018) (sketching out potential legal challenges); Jesse Reynolds, *Climate Engineering Field Research The Favorable Setting of International Environmental Law*, 5 WASH. & LEE J. ENERGY, CLIMATE, & ENV'T 417, 463–66 (2014); Charles R. Corbett, *Glacial Geoengineering and the Law of Antarctica*, LEGAL PLANET (Dec. 6, 2019), https://legal-planet.org/2019/12/06/glacial-geoengineering-and-the-law-of-antarctica/.

31. Mark P. Nevitt & Robert V. Percival, *Polar Opposites Assessing the State of Environmental Law in the World's Polar Regions*, 59 B.C. L. REV. 1655, 1680–86 (2018); *see also* Phillipe Sands, Jacqueline Peel, Adriana Fabra & Ruth MacKenzie, *The Polar Regions Antarctic and the Arctic*, *in* PRINCIPLES OF INTERNATIONAL ENVIRONMENTAL LAW at 638 (describing the Madrid Protocol as "the most comprehensive and stringent regime of environmental protection rules ever established under the rules of public international law anywhere in the world") (4th ed. 2018).

32. *See* Protocol on Environmental Protection to the Antarctic Treaty art. 3, para. (2)(a)–(b), Oct. 4, 1991, 30 I.L.M. 1461 (entered into force Jan. 14, 1998) [hereinafter Madrid Protocol]; *id.* art. 7.

does not expressly allow for a harms-balancing inquiry that might, in the abstract, justify built interventions to stabilize ice sheets.[33]

The deeper challenges, however, arise from the political structure of the continent. The Antarctic Treaty System is a legacy of twentieth-century land claims and counter-maneuvering of the day's world powers.[34] A radical adaptation program would need to somehow thread these conflicting territorial claims and sovereign ambitions, while also being mindful of the rise of new powers in the system.[35] A related challenge is procedural. Any one of the twenty-nine voting members of the Antarctic Treaty may veto new proposals,[36] slowing the mechanisms of Antarctic governance and requiring widespread buy-in to amend the law.[37] The engineering challenges would also be substantial, perhaps making states hesitant to finance development. Megaprojects are difficult and vulnerable to failure in normal circumstances; Antarctica is a remote region with a punishing climate, surrounded by turbulent seas, and ice-sheet stabilization techniques are untested.[38] Such an intervention would also largely deliver benefits over decades and centuries, with relatively few short-term returns, unlike a dam, airport, or canal.[39] It all raises the question of whether a country or coalition could drive the project forward with sufficient determination.

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33. *See id.* art. 8, para. 1 (requiring environmental impact assessments to tier proposals on the significance and duration of impact, with no mention of harms-balancing); *see also id.* art. 3, para. 2(a)–(b).

34. *See* Gillian Triggs, *The Antarctic Treaty Regime A Workable Compromise or a "Purgatory of Ambiguity"?*, 17 CASE W. RESERVE J. INT'L L. 195, 197–201 (1985); Rüdiger Wolfrum, *Common Interest and Common Heritage in Antarctica*, *in* HANDBOOK ON THE POLITICS OF ANTARCTICA 142, 143 (Klaus Dodds et al. eds., 2017); *see also* discussion at notes 42 to 54 and accompanying text.

35. Peter J. Beck, *The United Nations and Antarctica, 2005 The End of the Question of Antarctica'?*, 42 POLAR REC. 217, 217–18 (2006) (describing historical challenges to the Antarctic Treaty System); Anne-Marie Brady, *The Past in the Present Antarctica in China's National Narrative*, *in* HANDBOOK ON THE POLITICS OF ANTARCTICA, *supra* note 34, at 284, 284–85.

36. *See* Antarctic Treaty, art. IX(4) ("The measures [adopted by the ATCM] shall become effective when approved by all Contracting Parties participating in the meetings."); Rules of Procedure of the Antarctic Treaty Consultative Meeting and the Committee for environmental Protection para. 25 (revised 2015) ("Measures, Decisions and Resolutions . . . shall be adopted by the Representatives of all Consultative Parties present."); *see also* Secretariat of the Antarctic Treaty, *Parties*, https://www.ats.aq/devAS/Parties?lang=e (listing current the 29 state Consultative Parties to the ATS).

37. *E.g.*, Rosemary Rayfuse, *Climate Change and Antarctic Fisheries Ecosystem Management in CCAMLR*, 45 ECOLOGY L.Q. 53, 71 (2018) (describing the challenges in developing adequate rules for fisheries in the Southern Ocean); Cassandra M. Brooks et al., Comment, *Watch over Antarctic Waters*, 558 NATURE 177, 178 (2018) (blaming consensus-based decisionmaking processes in particular).

38. Söderlund et al., *supra* note 27, at 5. Antarctica's remote and hostile environment can be difficult to appreciate, but some works of fiction can help. *See, e.g.*, REBECCA HUNT, EVERLAND (2014) (novel about two Antarctic expeditions a century apart) (cited in Elizabeth Leane, *Fictionalizing Antarctica*, *in* HANDBOOK ON THE POLITICS OF ANTARCTICA, *supra* note 34, at 21, 28); *see also* KIM STANLEY ROBINSON, THE MINISTRY FOR THE FUTURE 119–21 (2020) (imagining an ice-sheet stabilization project).

39. *See* Abram et al., *supra* note 6, at 20 (reporting Antarctic contributions to global sea-level rise greatly increase beyond 2100); Michael Meredith et al., *Polar Regions*, *in* IPCC SPECIAL REPORT ON THE OCEAN AND CRYOSPHERE IN A CHANGING CLIMATE, *supra* note 6, at 203, 245 (describing the "rapid" retreat of the West Antarctic Ice Sheet as occurring on a "centennial time-scale").

This Article's central claim is that the governance challenges posed by radical adaptation in Antarctica are surmountable. Geopolitical and security interests may make states more willing than is now evident to explore ice-sheet stabilization and amend the Antarctic Treaty System accordingly. Moreover, the legitimacy of the system relies on the perception that Antarctica is competently governed with adequate regard for global interests—a perception that would be greatly strengthened by vigorous and effective efforts to understand and, if appropriate, execute interventions to slow the continent's contribution to sea-level rise. If successful, radical adaptation could also support climate justice, in that it would require rich, technologically advanced countries to limit an impact that threatens all. In short, radical adaptation is an opportunity to reorient the Antarctic Treaty System toward the new challenges and opportunities of climate change. Though difficult, circumstances require such shifts in environmental protection toward programs of selective intervention and assisted transformation.[40]

Part I of this Article surveys the Antarctic Treaty System, describing its history and processes and evaluating its effectiveness. Part II then describes the mechanisms of ice-sheet destabilization and the potential role radical adaptation could play in slowing some of those changes. Part III analyzes the challenges that radical adaptation would pose to the Antarctic Treaty System's norms, institutions, and rules and then proposes routes forward.

I. THE ANTARCTIC TREATY SYSTEM

This Part gives an overview of the foundational rules, institutions, and procedures that underlie the Antarctic Treaty System. The goal is not to provide a complete account of the system's procedures and authorities, but to chart how governance is driven by the continent's political undercurrents. Doing so lays the groundwork for understanding how radical adaptation might fit into the Antarctic Treaty System, taken up in Part III.

A. Territory

Antarctica has been called a continent without a sovereign,[41] but it may be better understood as a continent with sovereignty indefinitely deferred. Late-nineteenth- and early-twentieth-century expeditions to Antarctica were difficult and expensive, but they allowed countries to stake claims to territory and resources while also enhancing national prestige.[42] Like virtually every

40. *Cf., e.g.*, NAT'L PARK SERV., U.S. DEP'T OF THE INTERIOR, PLANNING FOR A CHANGING CLIMATE: CLIMATE-SMART PLANNING AND MANAGEMENT IN THE NATIONAL PARK SERVICE 8 (2021) (arguing for a shift in land management practices that facilitate ecosystem change as the planet warms).

41. Env't Def. Fund, Inc. v. Massey, 986 F.2d 528, 529 (D.C. Cir. 1993).

42. *See* Shirley V. Scott, *Three Waves of Antarctic Imperialism*, *in* HANDBOOK ON THE POLITICS OF ANTARCTICA, *supra* note 34, at 37, 40.

landmass on Earth, Antarctica by the mid-twentieth century had been carved up into

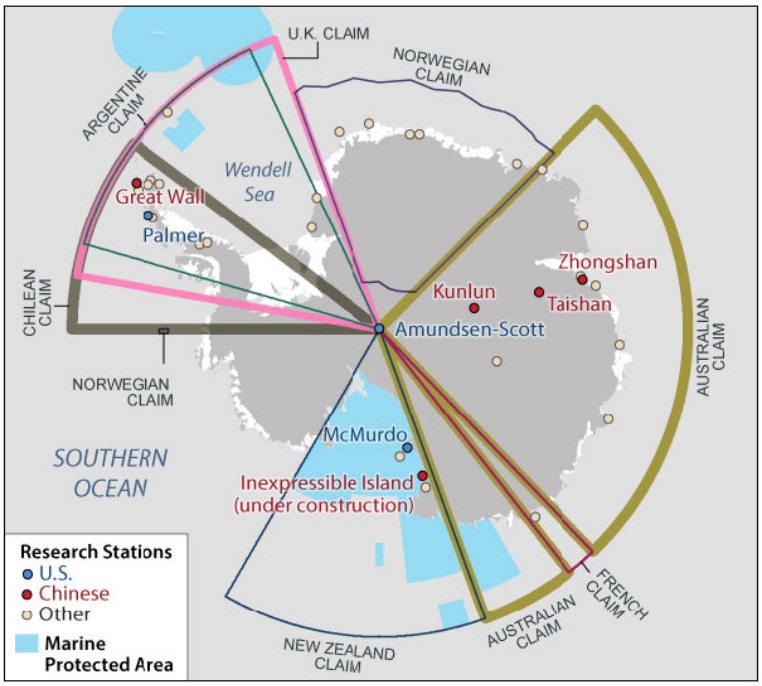

Fig. 1 *Map of Antarctica depicting territorial claims, research stations, and marine protected areas.*[43] *Pine Island Glacier and Thwaites Glacier are located in the unclaimed portion, in the bottom-left quadrant of the map.*

territorial claims, largely by European powers.[44] By the 1950s, claims had been made by Australia, France, New Zealand, Norway, Argentina, Chile, and the United Kingdom, with overlap between the claims of the last three countries.[45] Though the United States and the Soviet Union had not made claims, they had

43. PERVAZE A. SHEIKH ET AL., CONG. RSCH. SERV., R46708, ANTARCTICA: OVERVIEW OF GEOPOLITICAL AND ENVIRONMENTAL ISSUES 5 fig.1 (2021) (adapted from Robert Keith Headland, *Territory and Claims in the Antarctic Treaty Region A Disquisition on Historical and Recent Developments*, 57 CARTOGRAPHIC J. 160 (2020) and Klaus Dodds & Alan D. Hemmings, *Polar Oceans Sovereignty and the Contestation of Territorial and Resource Rights*, *in* ROUTLEDGE HANDBOOK OF OCEAN RESOURCES AND MANAGEMENT 576 (Hance D. Smith et al. eds., 2015)).

44. Alan D. Hemmings et al., *Introduction The Politics of Antarctica*, *in* HANDBOOK ON THE POLITICS OF ANTARCTICA, *supra* note 34, at 1.

45. *The Antarctic Treaty*, SECRETARIAT OF THE ANTARCTIC TREATY, https://www.ats.aq/e/antarctictreaty.html (last visited March 2, 2022); *see also* Editorial, *Reform the Antarctic Treaty*, 558 NATURE 161, 161 (2018).

reserved their rights to do so and had developed legal bases for such.[46] With territorial ambition came competition and the potential for conflict over resources, land, and authority.[47] The Cold War made these risks more worrisome, as unsettled Antarctic land claims risked opening a new theater of conflict that would be expensive, logistically challenging, and with little immediate strategic value.[48]

To allay these concerns, countries negotiating the Antarctic Treaty of 1959 agreed to put their territorial claims on hold.[49] At its core, the Antarctic Treaty is a peace treaty, which declares the continent, ice shelves, and islands beyond 60 degrees South latitude as a place for peace[50] and science,[51] free from militarized use and nuclear weapons.[52] This agreement would grow into the Antarctic Treaty System of today, a network of treaties governed by a consensus-based structure among those countries conducting substantial activities in Antarctica.[53] The system is widely seen as successful in maintaining peace, protecting the environment, and facilitating scientific investigation across the continent.[54]

Article IV of the Treaty addresses the statuses of Antarctic territorial claims and is thus the foundation of the continent's legal system. Article IV begins by stating it does not prejudice pre-existing territorial claims of countries who have joined the treaty (that is, the "Contracting Parties"):

> (1) Nothing contained in the present Treaty shall be interpreted as:
>
> (a) a renunciation by any Contracting Party of previously asserted rights of or claims to territorial sovereignty in Antarctica;
>
> (b) a renunciation or diminution by any Contracting Party of any basis of claim to territorial sovereignty in Antarctica which it may have

46. *See* Boleslaw A. Boczek, *The Soviet Union and the Antarctic Regime*, 78 AM. J. INT'L L. 834, 840–46 (1984); U.S. ANTARCTIC PROGRAM EXTERNAL PANEL, THE UNITED STATES IN ANTARCTICA 17, 21 (1997).

47. *See, e.g.*, Antarctica Cases (U.K. v. Arg.; U.K. v. Chile), 1955 I.C.J. Pleadings 48, 48–53 (May 1955) (detailing competing land claims on the Antarctic Peninsula ("Graham Land") and islands in what would become the Antarctic Treaty Area).

48. Roger D. Launius, *Establishing Open Rights in the Antarctic and Outer Space Cold War Rivalries and Geopolitics in the 1950s and 1960s*, *in* HANDBOOK ON THE POLITICS OF ANTARCTICA, *supra* note 34, at 217, 223.

49. Antarctic Treaty art. IV, Dec. 1, 1959, 12 U.S.T. 794, 402 U.N.T.S. 71 (entered into force June 23, 1961); *see also* Triggs, *supra* note 34, at 199–201 (describing Article IV as preserving the conflicting interests of claimants, potential future claimants, and of states that may contest any territorial claims).

50. Antarctic Treaty, *supra* note 49, art. I, para. 1 ("Antarctica shall be used for peaceful purposes only."); *id.* art. VI (specifying the boundary).

51. *Id.* art. II ("Freedom of scientific investigation in Antarctica and cooperation toward that end . . . shall continue . . . .").

52. *Id.* art. V (prohibiting detonation of nuclear weapons or storage of radioactive waste within the treaty area).

53. *See* McGee & Haward, *supra* note 3, at 84 fig.1 (illustrating the Antarctic regime).

54. Nevitt & Percival, *supra* note 31, at 1656–57.

> whether as a result of its activities or those of its nationals in Antarctica, or otherwise[.][55]

States thus retain the territorial claims they had when they joined the Treaty and need not give up the legal bases for potential future claims based on activities prior to the Treaty's adoption. The next line, however, introduces some ambiguity. The Treaty's language shall further not be read as:

> (c) prejudicing the position of any Contracting Party as regards its recognition *or non-recognition* of any other State's right of or claim or basis of claim to territorial sovereignty in Antarctica.[56]

So in addition to preserving parties' claims or bases of claim, the Treaty also preserves parties' ability to *not* recognize others' claims. This assurance was important to negotiators due to prior disputes between the United Kingdom, Chile, and Argentina.[57] Indeed, this approach was first proposed by Chile as a response to simmering conflict with Britain on the Antarctic Peninsula.[58] The Treaty's solution for both manifest and latent conflicts over territorial claims was to put them on ice for potential resolution at some future time.[59]

The next paragraph of Article IV explains how territorial claims will be treated going forward while the Antarctic Treaty is in place. It is less straightforward than it might first appear:

> (2) No acts or activities taking place while the present Treaty is in force shall constitute a basis for asserting, supporting or denying a claim to territorial sovereignty in Antarctica . . . . No new claim, or enlargement of an existing claim, to territorial sovereignty in Antarctica shall be asserted while the present Treaty is in force.[60]

Under this paragraph, not only can no new claims be made, but parties' ongoing activities—exploring, conducting research, or building research stations—cannot be used to strengthen the basis of an existing claim. But what happens to these assurances should the Antarctic Treaty cease to be in force or if language superseding Article IV paragraph 2 is enacted? What would the last seventy years of activities in Antarctica mean for territorial claims there? It is

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55. Antarctic Treaty, *supra* note 49, art. IV, para. 1(a)–(b).

56. *Id.* art. IV, para. (1)(c) (emphasis added).

57. *See* Antarctica Cases (U.K. v. Arg.; U.K. v. Chile), 1955 I.C.J. Pleadings 48 (May 1955); *see also* Scott, *supra* note 42, at 41–42, 44.

58. *See* Jason Kendall Moore, *A Sort' of Self-Denial United States Policy Toward the Antarctic, 1950–59*, 37 POLAR REC. 13, 13 (2001); Rip Bulkeley, *The Political Origins of the Antarctic Treaty*, 46 POLAR REC. 9, 10 (2010).

59. *See* Alan D. Hemmings, *Antarctic Politics in a Transforming Global Geopolitics*, *in* HANDBOOK ON THE POLITICS OF ANTARCTICA, *supra* note 34, at 507, 516 ("It seems to me that an always contentious proposition is now entirely ridiculous. Quite why any claimant state believes a future may arrive where the global order will concede to them special standing in relation to territories in Antarctica, where their presence was patchy, where discovery and activity was anyway shared with other states, and after an extended period . . . when positions on territorial sovereignty were anyway frozen, frankly eludes me . . . . [Yet], *there is not the slightest indication that any of the claimants is considering abandoning or trading their claim*." (emphasis added)).

60. Antarctic Treaty, *supra* note 49, art. IV, para. 2.

more than an idle question. The Antarctic Treaty, despite its longevity, seems to have a provisional quality, given it does not resolve conflicting territorial claims or establish a vigorous rulemaking authority.[61] The text, however, provides no answer; Article IV's treatment of claims applies only when the Treaty is in force. Some scholars suspect that lifting this provision would cause territorial disputes to become live once again, allowing sovereign claims to be substantiated through discovery, occupation, and actual governance.[62] Many parties to the Antarctic Treaty plan and fund activities in Antarctica with this eventuality in mind.[63]

Article IV has been described as a "purgatory of ambiguity" due to its simultaneous recognition, freezing, and non-recognition of territorial claims.[64] Ambiguity and diverging party interpretations are common in agreements within international law, often intentionally so.[65] It is strange, however, that territorial claims in Antarctica have remained unsettled for so long, when clear and agreed-to boundaries structure the exercise of state sovereignty over land elsewhere and undergird state-to-state relations. The resulting governance, at times, looks less like a "regime," as the Antarctic Treaty System is often described[66] and more like a frontier bound by a demilitarization pact. On the other hand, the Treaty System's standing institutions, its agreed-upon framework for environmental protection,[67] its communities of governance expertise, and its long history of international scientific cooperation all suggest something much more durable and cohesive.[68]

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61. *See* Bulkeley, *supra* note 58, at 11 (noting continued uncertainty as to the permanence of the balance struck by the ATS); Boczek, *supra* note 46, at 840 (arguing Antarctic Treaty System does not settle land claims but "freezes" the pre-1959 status quo); *see also* Barbara Koremenos, *Loosening the Ties That Bind A Learning Model of Agreement Flexibility*, 55 INT'L ORG. 289, 312–15 (2001) (describing the extent to which Contracting Parties view the Antarctic Treaty as provisional and subject to modification); Subpart I.B, *infra* (detailing significant limitations on ATCM rulemaking authority and the onerous procedures for creating new rules).

62. *See e.g.*, Christopher C. Joyner, *Potential Challenges to the Antarctic Treaty*, *in* SCIENCE DIPLOMACY 98, 99 (Paul A. Berkman, ed. 2011) (analyzing risk of states disturbing Article IV over conflict over hydrocarbon resources on Antarctica's continental shelf); Francis M. Auburn, *Aspects of the Antarctic Treaty System*, 26 ARCHIV DES VÖLKERRECHTS 203, 203–04 (1988) ("A fundamental flaw of Article IV is that it does not settle the [territorial] disputes between the parties to it."); *see also* Shirley V. Scott, *National Encounters with the International Court of Justice Avoiding Litigating Antarctic Sovereignty*, 21 MELBOURNE J. OF INT'L L. 1, 12–15 (2021).

63. *See* notes 194–216 and accompanying text, *infra*.

64. Triggs, *supra* note 34, at 200, 245–46; *see also, e.g.*, Patrizia Vigni & Francesco Francioni, *Territorial Claims and Coastal States*, *in* HANDBOOK ON THE POLITICS OF ANTARCTICA, *supra* note 34, at 241, 245–46 (describing legal confusion as to how the ambiguity of territorial claims under Article IV may inform state maritime claims in Antarctic waters); U.S. DEP'T OF STATE, HANDBOOK OF THE ANTARCTIC TREATY SYSTEM 2–3 (Harlan K. Cohen ed., 9th ed. 2002) [hereinafter STATE DEP'T HANDBOOK] (noting much of Antarctic diplomacy is calculated to navigate conflicting party interpretations of Article IV's treatment of territorial claims).

65. *See* FRED C. IKLÉ, HOW NATIONS NEGOTIATE 15–16 (1987).

66. *See, e.g.*, Sands et al., *supra* note 31, at 638.

67. *See* discussion at Subpart I.C (describing the Antarctic Treaty System's environmental protection regime).

68. *See* Wolfrum, *supra* note 34, at 148–49; Alan D. Hemmings, *Subglacial Nationalisms*, *in* ANTHROPOCENE ANTARCTICA: PERSPECTIVES FROM THE HUMANITIES, LAW AND SOCIAL SCIENCES,

The treaty has succeeded at staving off acute conflict and the assertion of new territorial claims, even as membership has expanded and human activities in Antarctica have grown.[69] Its success arises from Article IV's ambiguity, which allows Contracting Parties to read their favored interpretation into the text,[70] paired with a lack of political incentive or desire to resolve conflicting interpretations.[71] This drafting and negotiating strategy is sometimes called the "bifocal approach" within international law.[72] Claimant states can maintain the position that their claims are theirs, if lacking full sovereign rights, while non-claimant states can maintain the opposite.[73] Another way to understand this provision is as a moratorium. A moratorium is usually a lengthy "authorized postponement" or "suspension of a specific activity"[74] where final disposition on the prohibition is uncertain.[75] Article IV could be interpreted as a moratorium because it prohibits new, enlarged, or bolstered territorial claims and postpones resolution of conflicting claims "while the present Treaty is in force,"[76] with considerable uncertainty as to when and how these issues might be finally resolved.[77] However classified—purgatory, bifocal compromise, or a moratorium—Article IV has worked, enabling the elaboration of the Antarctic Treaty System and over sixty years of peaceful activities south of 60° South.[78]

Yet that foundation is fragile. The conflicting interpretations can coexist only as long as no dispute forces their resolution.[79] Furthermore, many of the activities conducted within Antarctica seem carried out, at least in part, to support

supra note 29, at 33, 37 (arguing Antarctic Treaty System "has now operated as a de facto condominium for sixty years"); *see also* Subparts I.B–C, *infra*.

69. *See* Triggs, *supra* note 34, at 200; *see also*, *generally*, Beck, *supra* note 35, at 217 (describing abandonment of efforts to bring Antarctica's governance within mainstream international channels); McGee & Haward, *supra* note 3.

70. *Cf.* IKLÉ, *supra* note 65, at 15 ("According to a French saying, international agreements would be impossible without conflicting mental reservations."); Triggs, *supra* note 34, at 200; STATE DEP'T HANDBOOK, *supra* note 64, at 2–3.

71. *See, e.g.*, Nils Vanstappen & Jan Wouters, *The EU and the Antarctic Strange Bedfellows?*, *in* HANDBOOK ON THE POLITICS OF ANTARCTICA, *supra* note 34, at 269, 277–78 (speculating an environmental disaster or discovery of precious minerals would be needed to raise the priority of Antarctica in the eyes of the European Union).

72. Vigni & Francioni, *supra* note 64, at 242, 250; *see also* Triggs, *supra* note 34, at 203.

73. *See* Vigni & Francioni, *supra* note 64, at 242, 248.

74. *Moratorium*, BLACK'S LAW DICTIONARY (11th ed. 2019).

75. Megan M. Herzog & Edward A. Parson, *Moratoria for Global Governance and Contested Technology The Case of Climate Engineering* 16–18 (UCLA School of Law, Pub. L. & Legal Theory Series, 2016), https://escholarship.org/uc/item/2c28w2tn#author (defining moratoria).

76. Antarctic Treaty, *supra* note 49, art. IV; *see also* Herzog & Parson, *supra* note 75, at 22–26.

77. *See* Triggs, *supra* note 34, at 203.

78. *See* Nevitt & Percival, *supra* note 31, at 1656 (describing Antarctic Treaty System as a success); Hemmings, *supra* note 59, at 508 (same); McGee & Haward, *supra* note 3, at 79 (same); Triggs, *supra* note 34, at 226 (same); Daniela Liggett et al., *Is It All Going South? Four Future Scenarios for Antarctica*, 53 POLAR REC. 459, 461 (2017) (same).

79. *See* Triggs, *supra* note 34, at 203 (arguing such a protracted conflict could cause parts of the Antarctic Treaty System to "break down").

pre-treaty territorial claims or to bolster the legal basis for possible future ones.[80] Given the bulk of investment in Antarctica supports scientific activities, research conducted there should be understood as dual-purpose: creating new knowledge while also advancing geopolitical aims.[81] Conducting scientific projects there creates a physical presence on the continent, justifies the construction of permanent infrastructure, and spurs the establishment of transportation networks between the funding state and Antarctica. These investments are relevant when developing possessory interests that underly territorial claims.[82] The development of Antarctic knowledge networks within a particular country further allows for more influence over Antarctic affairs and policy in international circles and more capable governance of the continent itself.

Operations in Antarctica are expensive and difficult, which means that successfully carrying out a research mission demonstrates the organizer's wealth, capacity, and strength. These ideas are then reinforced through government messaging.[83] In short, science is the "currency" of the realm.[84] It is true that this duality to science is not unique to Antarctic affairs. Nations usually advance many different goals when funding scientific programs, and it is difficult to imagine public funding for the sciences ever being completely disentangled from other national interests. But Antarctica's demilitarized status and the suspension of traditional territorial sovereignty there makes scientific endeavors that much more important when advancing geopolitical goals. In this regard, a useful analogy can be made to national space exploration programs, which seek to advance national prestige, scientific knowledge, and human civilization all at once.[85]

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80. *See* Kevin A. Hughes & Susie M. Grant, *The Spatial Distribution of Antarctica's Protected Areas A Product of Pragmatism, Geopolitics or Conservation Need?*, 72 ENV'T SCI. & POL'Y 41, 48 (2017) (observing high correspondence between location of claimant research stations and territorial claims, whereas locations of research stations by non-claimant states shows no such pattern); *see generally* Klaus Dodds, *Antarctic Geopolitics*, *in* HANDBOOK ON THE POLITICS OF ANTARCTICA, *supra* note 34, at 199 (arguing evolution of Antarctic Treaty System is driven by "anticipatory Antarctic geopolitics" oriented around "what might be rather than what is").

81. Aant Elzinga, *The Continent for Science*, *in* HANDBOOK ON THE POLITICS OF ANTARCTICA, *supra* note 34, at 103.

82. *See generally* Charles Cheney Hyde, *The Case Concerning the Legal Status of Eastern Greenland*, 27 AM. J. INT'L L. 732 (1933) (discussing the Eastern Greenland case, where the Permanent Court of International Justice resolved territorial dispute between Norway and Denmark over conflicting claims in Greenland); *see also generally* Gillian D. Triggs, *Personality and Recognition*, *in* INTERNATIONAL LAW: CONTEMPORARY PRINCIPLES AND PRACTICES 5 (2d ed. 2010).

83. One example is a photograph published on a U.S. National Science Foundation webpage of the flags of the twelve original signatories of the Antarctic Treaty, arranged in a crescent around a ceremonial South Pole. *See Amundsen-Scott South Pole Station*, NAT'L SCI. FOUND., https://www.nsf.gov/geo/opp/support/southp.jsp (last visited June 2, 2021). The U.S. Amundsen-Scott South Pole Station is behind the flag arrangement, with the American flag at the center of the crescent. *Id.*

84. Indi Hodgson-Johnston & Julia Jabour, *Is Australia's Claim to Antarctica at Risk?*, THE CONVERSATION (Oct. 16, 2014, 3:30 PM), https://theconversation.com/is-australias-claim-to-antarctica-at-risk-33074.

85. *See* Nina Tannenwald, *Law Versus Power on the High Frontier The Case for a Rule-Based Regime for Outer Space*, 29 YALE J. INT'L L. 363, 367, 370–71 (2004).

Australia's intentions in Antarctica are especially illustrative in this regard. The country has claimed a vast portion of eastern Antarctica, which is by far the largest national claim on the continent.[86] Because the claimed region lies directly south of Australia, the country views keeping the area demilitarized as a key priority of national security.[87] As a result, Australia dedicates a large amount of resources to developing ice breakers, constructing infrastructure like year-round runways, and financing difficult experiments like ice borehole drilling.[88] The strategy was formalized and announced in the 2016 *Australian Antarctic Strategy and 20 Year Action Plan*, released by Prime Minister Turnbull.[89] Australia, in keeping with this plan, has also invested in domestic transportation infrastructure and research institutions to make the state of Tasmania and the city of Hobart the "premier East Antarctic Gateway."[90] Its strategy bolsters the country's vast territorial claims via occupancy, local investment in permanent structures, and leading academic research.[91] It also strengthens Australia's position within the Antarctic Treaty System, a system it favors for keeping the continent demilitarized and free from hostile possession.

Australia is not unique here. Russia, the United States, and European powers commit resources to their Antarctic programs that seem disproportionate absent broader strategic and geopolitical aims, and thus could be understood through the same lens.[92] Furthermore, this behavior is not limited to states that had claims or legal bases for claims at the time of the Antarctic Treaty's adoption. China, which joined the Antarctic Treaty in the early 1980s, has launched an ambitious research program across the continent, having conducted thirty-four Antarctic expeditions and built four research stations, with construction of a fifth

86. *See* Hemmings et al., *supra* note 44, at 7 fig 1 2 (depicting territorial claims of Australia and the six other claimant states).

87. *See* CLAIRE YOUNG, LOWY INST., EYES ON THE PRIZE: AUSTRALIA, CHINA, AND THE ANTARCTIC TREATY 2 (2021).

88. Hemmings, *supra* note 68, at 42; *see also, e.g.*, *New Funding for Upgrades of Antarctic Research Stations*, AUSTRALIAN ANTARCTIC PROGRAM (Feb. 25, 2019), https://www.antarctica.gov.au/news/2019/new-funding-for-renewal-of-antarctic-research-stations/ (reporting $450 million committed over ten years to improve Australian Antarctic research stations and logistics); DEP'T OF AGRIC., WATER & THE ENV'T, AUSTRALIAN GOV'T, BUDGET 2020–21, https://www.awe.gov.au/sites/default/files/documents/environment-protection-factsheet.pdf (reporting Australia's "ongoing commitment" of $2.8 billion to Antarctic programming). Several other countries fund ice drilling experiments with similar motivations of scientific advancement and national prestige. *See* discussion at Subpart II.B., *infra*.

89. AUSTRALIAN GOV'T, AUSTRALIAN ANTARCTIC STRATEGY AND 20 YEAR ACTION PLAN 3, 17 (2016) [hereinafter AUSTRALIAN ANTARCTIC STRATEGY], https://www.antarctica.gov.au/site/assets/files/53156/20yearstrategy_final.pdf.

90. Hemmings, *supra* note 68, at 42 (quoting AUSTRALIAN ANTARCTIC STRATEGY, *supra* note 89, at 3).

91. AUSTRALIAN ANTARCTIC STRATEGY, *supra* note 89, at 17 ("Australia's national interests in Antarctica [include] . . . preser[v]ing our sovereignty over the Australian Antarctic Territory, including our sovereign rights over adjacent offshore areas.").

92. *See* Simon Naylor et al., *Science, Geopolitics and the Governance of Antarctica*, 1 NATURE GEOSCIENCE 143, 145 (2008); *see also* Boczek, *supra* note 46, at 857–58; V.V. Lukin, *Russia's Current Antarctic Policy*, 4 POLAR J. 199, 209–10 (2014) (citing strategy documents circulated by Russia).

underway.[93] As is the case with Australia, this research program allows China to assert its geopolitical strength within Antarctic affairs and internationally more broadly.[94] The same may be true of many other states with significant operations in Antarctica. Although the Antarctic Treaty prohibits territorial claims and development of mineral resources, China's investment in the continent ensures it will have a seat at the table if the status quo ever changes.[95]

This analysis offers a few insights of potential value for understanding the prospects for, and implications of, proposals for ice-sheet stabilization. First, scientific activities and infrastructure development in Antarctica should be understood both as ends in themselves and as means of advancing national strategic goals regarding the continent. Second, and relatedly, historical territorial claims remain salient in planning decisions and Antarctic diplomacy, as do hopes of developing future claims. That is not to say the continent is a no-man's land or that the stated goals of the Antarctic Treaty System—peace, science, and environmental protection—are untrue. The Antarctic Treaty requires sharing of information produced through research in Antarctica, and there is a long history of peaceful and productive cooperation in conducting experiments, managing logistical networks, and maintaining and occupying research stations.[96] Nonetheless, politics on the continent is never far removed from fundamental concerns of territory, prestige, and sovereignty.

B. Institutions and Membership

Article IX of the Antarctic Treaty establishes regular meetings of the parties to oversee its management and consult on other Antarctic issues.[97] These Antarctic Treaty Consultative Meetings (ATCMs) are the hub of formal governance, meeting once a year to negotiate policy, propose binding measures, and review planned activities with significant physical impacts.[98] Environmental protection is central to the mission of the ATCM, as is maintaining peace and

93. Nengye Liu, *The Rise of China and the Antarctic Treaty System?*, 11 AUSTRALIAN J. MAR. & OCEAN AFFS. 120, 121, 122–23 (2019).

94. *See id.* at 124, 125–27.

95. *See id.* at 126 (arguing there is no indication China wishes to overturn the Antarctic Treaty and has so far complied with its requirements). Interestingly, China, in 2013, proposed establishing an Antarctic Specially Managed Area around its station at Kunlun and began drafting a plan for the area's management. The plan was not approved, however, due to concerns from the United States and Australia that it was a maneuver to use environmental management as a means to "seize control over territory in Antarctica." *Id.* at 125 (quoting Anne-Marie Brady, *China's Undeclared Foreign Policy at the Poles*, THE INTERPRETER (May 30, 2017), https://www.lowyinstitute.org/the-interpreter/china-undeclared-foreign-policy-poles).

96. *See* Antarctic Treaty, *supra* note 49, pmbl.; *id.* arts. I–II; *id.* art. III, para. 2; *id.* art. IV, para. 1(c); *see also* Alan D. Hemmings, *Why Did We Get an International Space Station Before an International Antarctic Station?*, 1 POLAR J. 5, 5–7 (2011); *but see id.* at 13 (blaming territorial claims for limiting the amount of cooperation seen so far, namely the lack of international research stations).

97. *See* Antarctic Treaty, *supra* note 49, art. IX.

98. *See* Sands et al., *supra* note 31, at 642; *see also ATCM and Other Meetings*, SECRETARIAT OF THE ANTARCTIC TREATY, https://www.ats.aq/e/atcm.html (last visited June 18, 2021).

cooperation on scientific endeavors.[99] The Antarctic Treaty and the ATCM's authority encompasses the land south of 60° South, a jurisdiction called the "Treaty Area" that "includ[es] all ice shelves."[100] It does not, however, extend to the Southern Ocean within the Treaty Area.[101] As a result, parties to the Antarctic Treaty have negotiated new agreements when developing rules for marine areas, such as the Convention on the Conservation of Antarctic Marine Living Resources (CCAMLR).[102] These marine conventions are formally distinct from the Antarctic Treaty, with their own ratification procedures and deliberative bodies, but are integrated into the Antarctic Treaty System and harmonized with Antarctic Treaty rules.[103]

Participation in ATCMs has a two-tiered structure. Consultative Parties can participate fully and vote on proposed measures, while Non-Consultative Parties may not vote but can contribute to deliberations.[104] Both groups are Contracting Parties of the Antarctic Treaty and bound by its requirements.[105] To become a Consultative Party (i.e., one with voting power), a state must "demonstrate[] its interest in Antarctica by conducting substantial scientific research activity there, such as the establishment of a scientific station or the despatch [*sic*] of a scientific expedition."[106] Countries seeking consultative status must notify the Antarctic Treaty's depositary, the United States, and report on its past and planned research activities in Antarctica.[107] Current Consultative Parties will then review the application at the next ATCM and decide whether to grant the applicant consultative status; granting an application requires unanimous support.[108] What qualifies as "substantial" research activity for determining voting status is not precisely defined and depends on the judgment of other members.[109] Whatever its precise meaning, the great expense of conducting research in Antarctica means that many states cannot attain voting power.[110] The requirement also

99. *See* Antarctic Treaty, *supra* note 49, art. IX, para. 1.

100. *Id.* art. VI.

101. *Id.* (stating the Treaty does not "prejudice or in any way affect the rights . . . of any State under international law with regard to the high seas . . . .").

102. STATE DEP'T HANDBOOK, *supra* note 64, at 1; *see also* Sands et al., *supra* note 31, at 635–37 (discussing CCAMLR).

103. STATE DEP'T HANDBOOK, *supra* note 64, at 2; *see also* McGee & Haward, *supra* note 3, at 78–79.

104. STATE DEP'T HANDBOOK, *supra* note 64, at 181–82, 186.

105. *Id.* at 183.

106. Antarctic Treaty, *supra* note 49, art. IX, para. 2.

107. *See* FINAL REPORT OF THE TWENTY-EIGHTH ANTARCTIC TREATY CONSULTATIVE MEETING 347–48 (2005), https://documents.ats.aq/ATCM28/fr/ATCM28_fr001_e.pdf.

108. *See id.* at 348; *see also* FINAL REPORT OF THE FOURTEENTH ANTARCTIC TREATY CONSULTATIVE MEETING 22–24 (1987), https://documents.ats.aq/ATCM14/fr/ATCM14_fr001_e.pdf (providing rather vague substantive guidelines for admission).

109. *See* Andrew D. Gray & Kevin A. Hughes, *Demonstration of "Substantial Research Activity" to Acquire Consultative Status Under the Antarctic Treaty*, POLAR RSCH., Jan. 2016, at 1, 2.

110. *See* Launius, *supra* note 48, at 224 (tracing this exclusion to the Treaty's Cold War origins).

emphasizes the role of science as establishing a greater right to influence the continent's politics.[111]

There are twenty-nine Consultative Parties, including the twelve original signatories, plus an additional twenty-five non-Consultative Parties.[112] The Treaty's voting members include many of the largest economies in the world, while non-voting members include many more countries from the Global South—although there are exceptions among both groups of members.[113] The Antarctic Treaty System hence is not a universal organization, like the United Nations, but more like a club with specified requirements for full membership.[114] In fact, ATS Contracting Parties vigorously resisted efforts to bring Antarctica under U.N. oversight during the late twentieth century.[115] That U.N. effort, spearheaded by Malaysia and a coalition of other states, challenged the regime for failing to be representative of the global community or managed for the common benefit of humanity.[116] The challengers ultimately relented, but only after the Antarctic Treaty's leadership instituted more rigorous environmental protections and allowed expanded membership and greater participation in ATCM deliberations.[117] For now, the unusual exclusive arrangement for international governance continues to be tolerated. The legitimacy of the Antarctic Treaty System relies on maintaining the peace and competent environmental management, particularly through the continued prohibition of mining within the Treaty Area.[118]

Rulemaking via the ATCM is consensus-based and therefore difficult. New "measures"—proposed rules within the Treaty Area meant to become binding on the parties—are drafted, discussed, and revised informally by representatives of Consultative Parties.[119] Draft measures are then submitted to the ATCM for consideration. If the ATCM votes to approve and no Consultative Party present objects, the measure is adopted with intent to become binding,[120] and

111. *See* Subpart I.A, *supra*.

112. *Parties*, SECRETARIAT OF THE ANTARCTIC TREATY, https://www.ats.aq/devAS/Parties?lang=e (last visited March 13, 2022).

113. *Id.*

114. *See* Hemmings et al., *supra* note 44, at 3; Launius, *supra* note 48, at 223; Vigni & Francioni, *supra* note 64, at 243.

115. *See generally* Beck, *supra* note 35.

116. *See id.* at 224–26.

117. *See id.* at 220.

118. *See* Wolfrum, *supra* note 34, at 149; Linda A. Malone, *The Waters of Antarctica Do They Belong to Some States, No States, or All States?*, 43 WM. & MARY ENV'T L. & POL'Y REV. 53, 80–81 (2018).

119. Christopher C. Joyner, *Recommended Measures Under the Antarctic Treaty Hardening Compliance with Soft International Law*, 19 MICH. J. INT'L L. 401, 404 (1998); *see also* Antarctic Treaty, *supra* note 49, art. IX (requiring Consultative Parties to regularly convene and granting authority to adopt binding measures); STATE DEP'T HANDBOOK, *supra* note 64, at 121–22 (explaining deliberative procedures under Article IX).

120. FINAL REPORT OF THE NINETEENTH ANTARCTIC TREATY CONSULTATIVE MEETING 89 (1995), https://documents.ats.aq/ATCM19/fr/ATCM19_fr001_e.pdf.

representatives transmit the adopted measure to their country for approval.[121] If the measure is ultimately ratified by all Consultative Parties, it does in fact become binding.[122] But if it is merely adopted and not ratified by all parties, it remains soft law instead.[123]

This structure requires an initial, non-vetoed vote for adoption at the ATCM and subsequent approval by all voting parties to become binding law. It has therefore been called a "double veto" system because any one country with voting power can block a rulemaking at either step.[124] The consensus-based structure is unusual for international rulemaking bodies, which often use two-thirds voting requirements instead.[125] As a result, and especially as voting membership grows and new technology facilitates better access to Antarctica, it has become difficult for the Antarctic Treaty System to establish new, firm rules on contentious issues.[126] The process, however, seems unlikely to change for now due to concerns of claimant parties that a non-unanimous approach to rulemaking would risk interference with their territorial claims.[127]

A handful of other bodies within the Antarctic Treaty System contribute to governance. The Antarctic Secretariat, based in Buenos Aires, Argentina with a permanent nine-member staff, provides "institutional continuity" between annual ATCMs; its duties are administrative rather than executive.[128] The Scientific Committee on Antarctic Research (SCAR), established by the Antarctic Treaty, helps set research agendas within the region and facilitates

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121. Antarctic Treaty, *supra* note 49, art. IX, para. 1; *see also* Triggs, *supra* note 34, at 208–11; STATE DEP'T HANDBOOK, *supra* note 64, at 121–22; Joyner, *supra* note 119, at 404.

122. Antarctica Treaty, *supra* note 49, art. IX, para. 4. "Decisions" regard questions internal to ATCM's operation, such as budgetary matters or membership status. STATE DEP'T HANDBOOK, *supra* note 64, at 121; *see also, e.g.*, 1 FINAL REPORT OF THE FORTY-SECOND ANTARCTIC TREATY CONSULTATIVE MEETING 265–59 (2019), https://documents.ats.aq/ATCM42/fr/ATCM42_fr001_e.pdf. "Resolutions" are precatory, recommending guidelines and the like. STATE DEP'T HANDBOOK, *supra* note 64, at 121; *see also, e.g.*, 1 FINAL REPORT OF THE FORTY-SECOND ANTARCTIC TREATY CONSULTATIVE MEETING, *supra*, at 335. Confusingly, proposed binding rules, now called "measures," used to be called "recommendations" before the ATCM changed the naming conventions, via a "decision," in 1995. STATE DEP'T HANDBOOK, *supra* note 64, at 121; *see also* FINAL REPORT OF THE NINETEENTH ANTARCTIC TREATY CONSULTATIVE MEETING, *supra* note 120, at 89.

123. *See* Joyner, *supra* note 119, at 401–03, 405.

124. Triggs, *supra* note 34, at 208–11.

125. *Id.* at 208.

126. *See Reform the Antarctic Treaty*, *supra* note 45, at 161 ("Individual countries can veto measures they dislike, allowing them to continue activities that the majority may wish to outlaw, which is one reason why [as of 2018] the system has not produced any new binding protocols for . . . two decades."); *see also* Hemmings et al., *supra* note 44, at 11.

127. *Cf.* Triggs, *supra* note 34, at 208 (explaining rationale underlying consensus-based rulemaking requirement); *see also* Leslie Hook & Bendedict Mander, *The Fight to Own Antarctica*, FIN. TIMES (May 24, 2018) ("While there is no indication that anyone is about to take the step of quitting the Treaty System, there is equally little hope that it will be able to reform itself. A risk is that it simply becomes less relevant as it fails to address the challenges facing the continent.").

128. FINAL REPORT OF THE TWENTY-FOURTH ANTARCTIC TREATY CONSULTATIVE MEETING 45 (2001), https://documents.ats.aq/ATCM24/fr/ATCM24_fr001_e.pdf (establishing Secretariat); Elzinga, *supra* note 81, at 106; *see also The Secretariat of the Antarctic Treaty*, SECRETARIAT OF THE ANTARCTIC TREATY, https://www.ats.aq/e/secretariat html (last visited June 21, 2021).

coordination of research between states.[129] It also formally coordinates with international bodies outside the Antarctic Treaty System on areas of shared interest, such as the Intergovernmental Panel on Climate Change (IPCC) on climate research.[130] Separate governance bodies deliberate on marine protection and issue rules as appropriate, such as fishing limits set by the Commission for the Conservation of Antarctica Marine Living Resources under CCAMLR.[131] Meanwhile, the Committee for Environmental Protection, created via the Madrid Protocol, assists the ATCM on environmental protection.[132] This Committee's role is discussed in detail in the next Section.

C. Environmental Rules and Conflicts

The Protocol on Environmental Protection to the Antarctic Treaty (the Madrid Protocol) was adopted after six years of negotiations on Antarctic mineral rights failed to produce a binding legal framework.[133] Negotiators did not address mineral exploration or extraction in the original Antarctic Treaty because the topic was too tightly tied to questions of territorial sovereignty. Asserting ownership over minerals invites the question of who owns the land and seabed they are to be extracted from,[134] and the Antarctic Treaty was drafted to avoid conflicts over such questions.[135] Furthermore, in the 1950s, mineral activity in Antarctica was considered a remote proposition, given the harshness of the climate and the availability of more accessible resources elsewhere.[136] Interest in oil and gas exploration slowly grew, however, following detection of evidence of hydrocarbons within Antarctica's continental shelf in 1972 and 1973

129. DEP'T OF STATE HANDBOOK, *supra* note 64, at 4; *see also* Steven L. Chown, *Polar Collaborations Are Key to Successful Policies*, 558 NATURE 163, 163 (2018) (describing SCAR's longstanding role within the Antarctic Treaty System and arguing for more ambitious and better funded scientific research programming).

130. Chown, *supra* note 129, at 163.

131. Convention on the Conservation of Antarctic Marine Living Resources arts. VII–XIII, Aug. 1, 1980, 1329 U.N.T.S. 48 (entered into force April 7, 1982) [hereinafter CCAMLR]; *see also* Sands et al., *supra* note 31, at 635–36. Similar to the procedures of Consultative Meetings under the Antarctic Treaty, any member of the Commission can object to rulemaking on marine protection by the Commission and decline to be bound by the rule. *See* CCAMLR, *supra*, art. IX, para. 6(c)–(d).

132. Madrid Protocol, *supra* note 32, art. 11.

133. Malcolm W. Browne, *France and Australia Kill Pact on Limited Antarctic Mining and Oil Drilling*, N.Y. TIMES (Sept. 25, 1989), https://www.nytimes.com/1989/09/25/world/france-and-australia-kill-pact-on-limited-antarctic-mining-and-oil-drilling.html (reporting positions of United States and New Zealand).

134. *See* Brian Roberts, *International Co-operation for Antarctic Development The Test for the Antarctic Treaty*, 19 POLAR REC. 107, 111–13 (1978); *see also* Christopher C. Joyner, *The Evolving Antarctic Minerals Regime*, 19 OCEAN DEV. & INT'L L. 73, 83 (1988) (analyzing how proposed mineral rights regime in Antarctica would grant claimant states "veto" power over activities in their claimed territories, and describing controversy over right of claimant states to obtain administrative fees or royalties).

135. *See* Subpart I.A, *supra*.

136. *See* Roberts, *supra* note 134, at 111 (noting technological developments and Arctic oil and gas exploration had forced the issue within the Antarctic Treaty System).

and oil embargos beginning the year after.[137] By the 1980s, it began to appear "inevitable," at least to some, that mineral exploration within Antarctica would occur.[138] Assuming this inevitability was true, the danger seemed that a rush for resources could occur without sufficient legal structure, damaging Antarctica's environment and governance system.[139]

The Convention on the Regulation of Antarctic Mineral Resource Activities (CRAMRA) would have established a framework for regulating mineral and fossil-fuel activities with attendant environmental protections.[140] Negotiations lasted nearly ten years, coinciding with the rise of objections to exclusion and unjust appropriation that drove outside efforts to put Antarctic governance under the control of the United Nations.[141] The prospect of oil and gas extraction clearly posed substantial risks to Antarctica's environment and wildlife, especially if refining or other processing was conducted in the Treaty Area.[142] Moreover, in the event of a spill or leak, the extreme conditions and remoteness of the Southern Ocean would vastly complicate cleanup efforts.[143] The 1980s were also a time of growing power for the international environmental movement. Activists and NGOs gained increasing influence over government decisions in opposition to mining interests worldwide,[144] influencing France's and Australia's decisions not to ratify CRAMRA because it was insufficiently protective of the Antarctic environment.[145]

The Madrid Protocol was negotiated soon after the failure of CRAMRA and entered into force in 1998. The Protocol prohibits "any activity relating to

137. *See* Joyner, *supra* note 134, at 75.

138. *See, e.g.*, Browne, *supra* note 131 (reporting positions of the United States and New Zealand).

139. OFF. OF TECH. ASSESSMENT, U.S. CONG., POLAR PROSPECTS: A MINERALS TREATY FOR ANTARCTICA 3–4 (1989); *see also* Andrew N. Davis, Note, *Protecting Antarctica Will a Minerals Agreement Guard the Door or Open the Door to Commercial Exploitation?*, 23 GEO. WASH. J. INT'L L. & ECON. 733, 742 (1990).

140. *See generally* Antarctic Treaty Special Consultative Meeting on Antarctic Mineral Resources: Final Act and Convention on the Regulation of Antarctic Mineral Resource Activities, June 2, 1988, 27 I.L.M. 859 [hereinafter CRAMRA].

141. *See* Joyner, *supra* note 134, at 82–84, 87–88.

142. *See id.* 85–87.

143. *See* Zheng Syuen Lim, *Bibliometric Analysis of Research on Diesel Pollution Antarctica and a Review on Remediation Techniques*, 11 APPLIED SCI. 1, 6–7, 10 (2021).

144. *See* J.M. Spectar, *Saving the Ice Princess NGOs, Antarctica & International Law in the New Millennium*, 23 SUFFOLK TRANSNAT'L L. REV. 57, 73–78, 81–94 (1999); *see also* Herzog & Parson, *supra* note 75, at 12. Environmentalists' growing power was attributable in part to new telecommunications technologies allowing them to quickly and viscerally publicize environmental damage and disasters caused by international mining interests. Jim Cooney, *Reflections on the 20th Anniversary of the Term Social Licence'*, 35 J. ENERGY & NAT. RES. L. 197, 198 (2017). Doing so helped connect remote areas of the world where harmful natural resource extraction was occurring with the centers of global power where international mining activities were planned. *Id.* As a result, by the 1990s, the public reputation of mining interests had cratered. *See, e.g.*, Joel Gehman et al., *Social License to Operate Legitimacy by Another Name?*, 60 NEW FRONTIERS 293, 294 (2017) (reporting a 1996 opinion poll ranking mining as the worst among "24 U.S. industries . . . behind even the tobacco industry").

145. Sands et al., *supra* note 31, at 639; *see also* Browne, *supra* note 131.

mineral resources" within the Antarctic Treaty area,[146] a rule integral to the Protocol's success given the continent's geopolitics.[147] The Protocol does not define "mineral resources," but it likely tracks the definition given in CRAMRA that includes "fossil fuels [and] metallic and non-metallic minerals."[148] The text makes an exception for "scientific research,"[149] and the Special Consultative Meeting's report accompanying the Protocol adds that "the harvesting of ice" is also excluded from the prohibition.[150] Consultative Parties are, of course, free under the Antarctic Treaty to amend or lift the prohibition at any time, as they could any other measure adopted via Article IX, provided the unanimity requirements of the Treaty are met.[151] The ability of any state to veto Article IX rulemaking, however, and the level of controversy over mining, make revision by this method unlikely.[152] The Protocol does allow a Consultative Party to unilaterally initiate a conference to review the mining prohibition in the year 2048 or thereafter, at which point the rule may be modified by three-quarters majority rather than unanimity.[153] The same article that provides this more flexible decision procedure also, however, requires that such modifications include a binding regulatory regime for mineral activities.[154] Otherwise, the prohibition continues in force. As discussed above, the creation of such a mineral regime may also require ratification by all Consultative Parties, limiting the practical effect of the lower voting threshold.[155]

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146. Madrid Protocol, *supra* note 32, art. 7.

147. *See* Nevitt & Percival, *supra* note 31, at 1682; Malone, *supra* note 118, at 81.

148. CRAMRA, *supra* note 140, art. 1, para. 7. CRAMRA further defines "Antarctic mineral resource activities" to include "prospecting, exploration or development," which in turn are distinguished from other activities by their ultimate intent to exploit mineral resource deposits. *See id.* art. 1, paras. 8–10. Though CRAMRA was not ratified by all parties, it was approved by the Consultative Parties and directly informed the negotiation of the Madrid Protocol, making it a useful authority for construing the Protocol's language. *Cf.* Joyner, *supra* note 119, at 401–03, 405 (analyzing the legal authority of measures that are approved but not ratified).

149. Madrid Protocol, *supra* note 32, art. 7.

150. FINAL ACT OF THE ELEVENTH ANTARCTIC TREATY SPECIAL CONSULTATIVE MEETING 1, 32 (1991), https://documents.ats.aq/keydocs/vol_1/vol1_3_AT_Final_Act_Eleventh_SATCM_e.pdf. The exception was to allow for the possibility of developing freshwater extraction while maintaining the ban against oil and gas activities.

151. Hemmings et al., *supra* note 44, at 9; Sands et al., *supra* note 31, at 639 (citing Madrid Protocol, *supra* note 32, art. 25, para. 1).

152. *See* YOUNG, *supra* note 87, at 5; *e.g.* Nengye Liu, *What Are China's Intentions in Antarctica?*, THE DIPLOMAT (June 14, 2019), https://thediplomat.com/2019/06/what-are-chinas-intentions-in-antarctica/ (noting 2017 statement by China's then-vice minister of foreign affairs in support of the mining ban).

153. Madrid Protocol, *supra* note 32, art. 25, paras. 2–3; *see also* State Dep't Handbook at 471 (reporting the Protocol came into force in 1998). There are a few more technical requirements for ratification not relevant to analysis here. *See* Madrid Protocol, *supra* note 32, art. 25, para. 3.

154. Madrid Protocol, *supra* note 32, art. 25, para. 5(a).

155. *See* Nevitt & Percival, *supra* note 31, at 1685. The Protocol lets any Party withdraw if a modification is adopted but fails to enter into force within three years. *See* Madrid Protocol, *supra* note 32, art. 25, para. 5(b). It is unclear how attractive this withdrawal option would be, as unilateral withdrawal from the Protocol to pursue mining would severely strain the entire Antarctic Treaty System, putting at risk its carefully balanced preservation of demilitarization, open access, and promotion of research. *See*

The Madrid Protocol has been called "the most comprehensive and stringent regime of environmental protection rules ever established under the rules of public international law anywhere in the world."[156] It declares Antarctica a "natural reserve, devoted to peace and science,"[157] to be governed "in the interest of mankind as a whole,"[158] recognizing both the uniqueness of Antarctica's wildlife and the role the continent plays in global environmental systems. To that end, the Protocol sets forth an approach to environmental protection that considers and safeguards the health of "dependent and associated ecosystems" rather than just of individual species or habitats.[159]

Central to this regime is the requirement to conduct environmental assessments before commencing activities that risk significant physical impacts and to limit such adverse impacts.[160] Annexes to the Protocol further limit "harmful interference" with Antarctic wildlife, as well as the introduction of non-native species;[161] regulate waste prevention, disposal, and removal;[162] provide for remediation of contaminated sites;[163] limit marine pollution from ships supporting operations in the Treaty Area;[164] and establish a system to create areas with heightened environmental protection.[165]

The Protocol also establishes the Committee for Environmental Protection, which assists the ATCM in developing environmental policy.[166] The Committee

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Nevitt & Percival, *supra* note 31, at 1685–86; Triggs, *supra* note 34, at 225–26 (arguing unilateral mining would lead to exercise of territorial sovereignty); YOUNG, *supra* note 87, at 10.

156. Sands et al., *supra* note 31, at 638; *see also* Nevitt & Percival, *supra* note 31, at 1680–81.

157. Madrid Protocol, *supra* note 32, art. 2.

158. *Id.* pmbl.

159. *Id.* pmbl.; *id.* arts. 2–3, 6, 8, 10; Sudhir Chopra & Craig Hansen, *Deep Ecology and the Antarctic Marine Living Resources Lessons for Other Regimes*, 3 OCEAN & COASTAL L.J. 117, 144–46 (1997) (analyzing the Madrid Protocol's approach as one sensitive to "deep ecology," emphasizing non-human values and comprehensive management within environmental protection).

160. Madrid Protocol, *supra* note 32, art. 8; *id.* annex I; *see also* FINAL REPORT OF THE TWENTY-EIGHTH ANTARCTIC TREATY CONSULTATIVE MEETING, *supra* note 107.

161. Madrid Protocol, *supra* note 32, annex II.

162. *Id.* annex III.

163. *Id.*

164. *Id.* annex IV. This Annex largely functions to reference requirements of the International Convention for the Prevention of Pollution from Ships (MARPOL). *See id.* annex IV, arts. 3, 5–6; *but see also* Francisco Orrego Vicuña, *The Protocol on Environmental Protection to the Antarctic Treaty Questions of Effectiveness*, 7 GEO. INT'L L. REV. 1, 8 (1994) (arguing that incorporated MARPOL standards are toothless because "warships and all government ships used for non-commercial purposes are exempted from the requirements of [MARPOL] . . . [and] [m]ost activities in Antarctica are carried out by ships of this kind"). The Antarctic Treaty states that its provisions do not interfere with "international law with regard to the high seas" south of 60 South. Antarctic Treaty, *supra* note 49, art. VI. This means that environmental requirements of the U.N. Convention on the Law of the Sea, the 1989 Basel Convention on hazardous waste trade, and the 1972 London Convention and 1996 London Protocol prohibitions on unpermitted ocean dumping all also apply to waters within the Treaty Area. Sands et al., *supra* note 31, at 643.

165. Madrid Protocol, *supra* note 32, annex V. A sixth annex on liability from environmental emergencies has been adopted but not ratified by all necessary parties. *See id.* annex VI; SHEIKH ET AL., *supra* note 43, at 19.

166. Madrid Protocol, *supra* note 32, arts. 11–12.

advises on the need for additional environmental measures and oversees environmental impact assessments submitted by parties.[167] It also reports on the state of the Antarctic environment and identifies additional priorities for scientific study.[168] In its first twenty-five years, the Committee has helped develop guidelines for environmental review procedures, designation of protected areas, protection of Antarctic species, waste cleanup, environmental monitoring, and other issues.[169]

Though the Committee can influence ATCM deliberations, it has no formal enforcement powers.[170] As with all legal obligations under the Antarctic Treaty System, ultimate compliance with the Madrid Protocol is the responsibility of the Contracting Parties themselves.[171] This follows from the basic structure of the Treaty System, under which jurisdiction does not align with territorial claims[172] and Antarctic sovereignty does not reside in a centralized, supranational authority.[173] National persons and other entities instead remain subject to the jurisdiction of their countries of origin while in Antarctica, via treaty requirements enacted in domestic law.[174] For example, the United States enforces the environmental permitting requirements of the Madrid Protocol against U.S. nationals through the Antarctic Conservation Act,[175] and it bans mining exploration and development via the Antarctic Protection Act.[176] Other

167. *Id.* art. 10.

168. *Id.* arts. 11–12.

169. *The Committee for Environmental Protection*, SECRETARIAT OF THE ANTARCTIC TREATY, https://www.ats.aq/e/committee.html (last visited March 22, 2022) (describing what the Committee for Environmental Protection does).

170. *Compare* Madrid Protocol, *supra* note 32, art. 12, para. 1 ("The functions of the Committee [for Environmental Protection] shall be to provide advice and formulate recommendations to the parties in connection with the implementation of the ProtocolFalse") *with id.* at art. 13, para. 1 (assigning enforcement responsibilities to the parties themselves); *see also* Gogarty et al., *supra* note 30, at 167 (describing the Committee's advisory role in assessments of future ice-sheet stabilization proposals).

171. Madrid Protocol, *supra* note 32, art. 13, paras. 1–2.

172. *See* discussion at Subpart I.A, *supra*.

173. *See* Antarctic Treaty, *supra* note 49, art. IX, paras. 1, 4; *see also* DEP'T OF STATE HANDBOOK, *supra* note 64, at 121 (explaining ATCMs "make recommendations to their Governments [for ratification] that do not come into effect after they have been approved by all Consultative Parties . . . [and] have virtually no other decision-making power"). Consultative Parties do occasionally convene Special Consultative Meetings which "may have rights of making decisions, binding on participating Governments, limited to the specific purpose of the meeting." *Id.* at 122. The Madrid Protocol emerged from such a meeting. *See* Final Act of the Eleventh Special Consultative Meeting, *supra*.

174. *See* Antarctic Treaty, *supra* note 49, art. VIII, para. 1.

175. Antarctic Conservation Act of 1978, 16 U.S.C. §§ 2401–2413. The United States has gone even further, asserting that the Madrid Protocol in and of itself does not impose substantive obligations. *See* Environmental Impact Assessment of Nongovernmental Activities in Antarctica, 66 Fed. Reg. 63,454, 63,459 (Dec. 6, 2001) (to be codified at 40 C.F.R. pt. 8) (stating that, based on advice from the U.S. Department of State and National Science Foundation, "[i]t is the U.S. government's position that Article 3 of the Protocol does not impose substantive obligations").

176. Antarctic Protection Act of 1990, 16 U.S.C. §§ 2461–2466.

sources of U.S. law also apply to U.S. Antarctic activities, such as the environmental review standards of the National Environmental Policy Act.[177]

The lack of external enforcement authority has long been seen as a shortcoming of the Madrid Protocol.[178] Parties have also been slow to develop binding environmental rules to address the growth of human activities in the region, especially tourism.[179] Furthermore, it is unclear what the recourse would be in case of a dispute between Parties over how to interpret a Protocol obligation regarding environmental impacts.[180] The result, when combined with the Antarctic Treaty System's sole focus on activities in the area south of 60° South, is that management of emerging environmental issues, particularly climate change, is far from adequate. The Committee on Environmental Protection has recommended a plan identifying issue areas to monitor and research regarding climate change.[181] But concrete, binding commitments from Parties are lacking, as is a centralized and vigorous strategy for assisted adaptation of Antarctica's environment.[182] Leading members of the Antarctic Treaty System, including the United States and China, see it as the job of the U.N. Framework Convention on Climate Change to address greenhouse gas emissions.[183] Accordingly, the relationship between the emissions of Consultative Parties—including the biggest emitters in the world—and the resulting damage done to Antarctica's environment can be only minimally addressed within the region's governance system.

The problem of inadequate environmental governance is even clearer in the context of marine protections, primarily because marine wildlife is the most

177. *See* Env't Def. Fund v. Massey, 986 F.2d 5288, 529, 534 (D.C. Cir. 1993). It is somewhat unclear how recent changes in the doctrine governing extraterritorial application of domestic law might impact the D.C. Circuit's holding. *See generally* Nestlè USA, Inc. v. Doe, 141 S. Ct. 1931 (2021). Whether *Environmental Defense Fund v. Massey* remains good law is an open question, but this Article assumes so for the purpose of analysis.

178. *See, e.g.*, Vicuña, *supra* note 164, at 3.

179. *See* Sands et al., *supra* note 31, at 642; *see also* Zia Mandani, *Emerging Legal, Policy and Scientific Issues in the Antarctic*, 1 POLAR J. 230 (2021). The Antarctic Treaty System has however been able to develop some non-binding guidelines for tourism. *See, e.g.*, FINAL REPORT OF THE THIRTY-FOURTH ANTARCTIC TREATY CONSULTATIVE MEETING 313–18 (2011), https://documents.ats.aq/ATCM34/fr/ATCM34_fr001_e.pdf (recommending that governments endorse the *General Guidelines for Visitors to the Antarctic*, a slim three-page guidance document).

180. The Madrid Protocol urges disagreeing Parties "consult among themselves as soon as possible" and use some "peaceful means" of resolving a dispute. Madrid Protocol, *supra* note 32, art. 18; *see also id.* arts. 19–20 (setting forth an option for arbitration or review by the International Court of Justice).

181. *See generally* FINAL REPORT OF THE THIRTY-EIGHTH ANTARCTIC TREATY CONSULTATIVE MEETING app. 2 (2017) [hereinafter CLIMATE CHANGE RESPONSE WORK PROGRAMME], https://documents.ats.aq/atcm38/ww/atcm38_ww010_e.doc.

182. *Cf.* COMM. FOR ENV'T PROT., CEP FIVE-YEAR WORK PLAN 2019, at 4–5 (2019), https://documents.ats.aq/atcm42/ww/atcm42_ww005_e.pdf (describing a plan for climate-based stressors primarily limited to observing changes and predicting physical impacts).

183. *See* McGee & Haward, *supra* note 3, at 86–88 (noting ATCM's sluggish uptake of climate change in general and that "the Antarctic regime complex has not engaged in any activity to create procedural mechanisms for decision-making on global greenhouse gas reduction").

intensively harvested natural resource in Antarctica.[184] The region is surrounded by the Antarctic Convergence, a vast, wind-driven marine current that rotates around the continent, where temperate ocean waters mix with the colder Southern Ocean.[185] It is also a major site of upwelling and exchange of deep ocean water with the surface. This vast churning circulates nutrients throughout the world's oceans and also introduces the warmer water threatening Antarctica's ice sheets from underneath.[186] The result is turbulent seas and a vital, rich mixture of nutrients sustaining large and unique ecosystems:[187] fish, penguins, whales, seals, and other birds at the surface and in the water column, and rare, seemingly Paleozoic ecosystems on the seafloor.[188] The Southern Ocean's extreme conditions further limit intrusion from biota adapted to more temperate waters, allowing many unique species to develop in relative isolation.

Antarctica has a long history of overfishing, and finfish and even krill stocks have begun to show signs of serious strain.[189] Climate change compounds the problem. As oceans warm, the Antarctic Convergence is moving southward, constricting as it goes, limiting habitat by pushing marine ecosystems closer to the continent.[190] Thinning summer sea ice meanwhile enables more fishing on already over-harvested species.[191]

Marine protections under CCAMLR—the convention within the Antarctic Treaty System that authorizes the development of fishery regulations and other rules to protect the marine environment—have been slow to form and are often

184. *See* U.S. ANTARCTIC PROGRAM EXTERNAL PANEL, *supra* note 46, at 11; IPCC SPECIAL REPORT ON THE OCEAN AND CRYOSPHERE IN A CHANGING CLIMATE AT 236 ("The predominant shipborne activities in Antarctica are fishing, logistical support to land-based stations, and marine research vessels"); Sands et al. at 633 (listing scientific research, tourism, and fishing as the main human activities in Antarctica); *see also* JEFFREY MCGEE ET AL., THE FUTURE OF ANTARCTICA: SCENARIOS FROM CLASSICAL GEOPOLITICS 94 (2022) (describing substantial economic and legal barriers to mineral activity in the region).

185. Richard B. Aronson et al., *Anthropogenic Impacts on Marine Ecosystems in Antarctica*, 1223 ANNALS N.Y. ACAD. SCI. 82, 84 (2011); Jeffrey McGee & Elizabeth Leane, *Anthropocene Antarctica Approaches, issues, and debates*, in ANTHROPOCENE ANTARCTICA 1, 7 (Jeffrey McGee & Elizabeth Leane eds., 2019).

186. Meredith et al., *supra* note 39, at 220–21 ("The Southern Ocean is the key region globally for the upwelling of interior ocean waters to the surface, enabling waters that were last ventilated in the pre-industrial era to interact with the industrial-era atmosphere and the cryosphere . . . . The Southern Ocean overturning circulation [thus] plays a strong role in mediating climate change via the transfer of [ocean] heat and carbon . . . with the atmosphere.").

187. Nevitt & Percival, *supra* note 31, at 1676; Katja Mintenbeck, *Impacts of Climate Change on the Southern Ocean*, *in* CLIMATE CHANGE IMPACTS ON FISHERIES AND AQUACULTURE: A GLOBAL ANALYSIS 663, 663–64 (describing Antarctica's marine ecosystems) (Bruce F. Phillips & Mónica Pérez-Ramírez eds., 2018); *see also* discussion at Subpart II.A, *infra*.

188. Aronson et al., *supra* note 185, at 85 fig.2; *see also id.* at 84 (explaining unique features of Antarctica's ecology).

189. *See id.* at 86 (reporting that, as of 2011, many fish populations were showing signs of collapse); Rayfuse, *supra* note 37, at 58–59 (reporting that krill in the Southern Ocean are sensitive both to warmer waters toward the north and to more acidic waters toward the south).

190. *See* Meredith et al., *supra* note 39, at 220, 231 (predicting optimum environmental conditions for Antarctic krill will move southward).

191. Brooks et al., *supra* note 37, at 179.

inadequate to meet these pressures. On paper, CCAMLR offers a strong set of tools to monitor and protect wildlife and fish within its jurisdiction.[192] Its weakness, as with the Antarctic Treaty System in general, comes from the ability of any voting member to veto proposed binding rules within the Treaty Area.[193] As a result, Japan, China, Russia, and others have been able to obstruct or undermine fishing restrictions by the Commission that they see as unnecessary or *ultra vires*, such as by blocking the creation of new marine protected areas.[194] Routine underestimation of illegal catch is another problem.[195] There is an added wrinkle that the monetary value of Antarctica's fisheries, especially krill, is relatively low; suggesting additional, non-commercial motives for organizing these difficult and expensive long-distance fishing operations.[196] Such operations demonstrate the organizing state's capacity and intention to maintain a strong presence in Antarctic waters, thereby supporting assertion of interests in other resources on or around the continent, beyond the marine resources themselves.[197]

Like other aspects of Antarctica's history and governance, environmental protection is imbued with geopolitical ambitions and anxieties. Nevertheless, the general opinion among experts and stakeholders is that Antarctica's environmental protection rules have largely been successful. Central to that assessment are the prohibition on mining and continued mitigation of political conflict over territorial and resource claims. The scope of the Protocol's environmental protections has also enhanced the legitimacy of the Antarctic Treaty System overall, helping to head off challenges from the broader international community. For example, the requirements of ecosystem-level protection and searching environmental reviews have won the support of international environmental activists who once opposed the regime.[198]

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192. *See* Rayfuse, *supra* note 37, at 60–72 (providing an overview of the system).

193. CCAMLR, *supra* note 131, art. IX, para. 6(c)–(d).

194. *See* Rayfuse, *supra* note 37, at 68–70; Brooks et al., *supra* note 37, at 178; *see also* Cassandra Brooks, *Why Are Talks over an East Antarctic Marine Park Still Deadlocked?*, THE CONVERSATION (Nov. 2, 2017, 11:27 PM), https://theconversation.com/why-are-talks-over-an-east-antarctic-marine-park-still-deadlocked-86681.

195. *See* Rayfuse, *supra* note 37, at 64.

196. *See* L.M. Foster & Namrata Goswami, *What China's Antarctic Behavior Tells Us About the Future of Space*, THE DIPLOMAT (Jan. 11, 2019), https://thediplomat.com/2019/01/what-chinas-antarctic-behavior-tells-us-about-the-future-of-space/ (reporting China's 2014 krill catch was around 50,000 metric tons, worth about 10 million USD). Though China has announced plans to vastly expand its annual krill catch, actual totals have been far lower. *See* Mintenbeck, *supra* note 187, at 672, Jeffrey McGee et al., *"Logrolling" in Antarctic Governance Limits and Opportunities*, 56 POLAR RECORD 1, 4 (2020) (reporting speculation that China's "desire to not limit krill fishing potential in the East Antarctic should also be considered a part of geopolitical power projection"); *cf. also* Anne-Marie Brady, *Introduction, in* The Emerging Politics of Antarctica 5 (Anne-Marie Brady, ed. 2013) (summarizing Republic of Korea's influence in the Antarctic Treaty System growing from an initial modest engagement "through the activities of its fishing fleet in the Southern Ocean").

197. *See* Rayfuse, *supra* note 37, at 70–72; Brooks et al., *supra* note 37, at 178.

198. Adrian Howkins, *Politics and Environmental Regulation in Antarctica A Historical Perspective*, *in* HANDBOOK ON THE POLITICS OF ANTARCTICA 337, 345 (Klaus Dodds et al., eds. 2017).

Yet it also seems true that the success of environmental protection is attributable to the lack of appetite for exploiting Antarctica's mineral resources. The Treaty System's sluggish marine protections illustrate how even modest financial incentives for a handful of states can effectively derail consensus-based decision-making structures. The ability of the system to adapt and grow with the times thus seems to rely on the continent's low importance within global affairs. The question now is whether the regime can continue to succeed given that events in Antarctica are becoming profoundly consequential for countries and cities around the globe.

II. ANTARCTIC GEOGRAPHY AND RADICAL ADAPTATION

This Part gives a brief overview of Antarctica's geography, the forces that drive the flow of its ice sheets, and the climate-driven processes now threatening those formations with destabilization, retreat, and collapse. It then introduces the concept of radical adaptation and several specific radical adaptation proposals that might stabilize some of the most at-risk glaciers. It closes by characterizing the potential physical impacts of these proposals and highlighting the associated scientific questions.

A. Antarctica's Ice Sheets

Antarctica's ice sheets accumulated gradually from millions of years of snowfall, growing with ice ages and receding during interglacial periods.[199] Today they cover nearly 98 percent of the continent with an average depth of one and a half miles, divided into east and west sections by the Transantarctic Mountains.[200] The West Antarctic Ice Sheet rests at a much lower elevation than the East Antarctic Ice Sheet, grounded in places more than a mile below sea level.[201] Much of the ice sheet also directly borders the Southern Ocean, so substantial portions of it are exposed to warming waters and other drivers of marine ice-sheet instability.[202] It is thus more vulnerable to climate change than the East Antarctic Ice Sheet and is projected to be the larger source of future sea-level rise despite its smaller size.[203]

199. Sun Bo et al., *The Gamburtsev Mountains and the Origin and Early Evolution of the Antarctic Ice Sheet*, 459 NATURE 690, 690 (2009). For an accessible overview of Antarctica, its ice sheets, and glacial physics, *see* Bethan Davies, *Antarctica*, ANTARCTICGLACIERS.ORG, www.antarcticglaciers.org/antarctica-2/antarctica/ (last visited June 3, 2021) (learning portal funded by the Scientific Committee on Antarctic Research, the Quaternary Research Association, and others).

200. *See* U.S. ANTARCTIC PROGRAM EXTERNAL PANEL, *supra* note 46, at 9, 16 ex.8; Robert Bindschadler, *The Environment and Evolution of the West Antarctic Ice Sheet Setting the Stage*, 364 PHIL. TRANSACTIONS ROYAL SOC'Y 1583, 1584 (2006).

201. U.S. ANTARCTIC PROGRAM EXTERNAL PANEL, *supra* note 46, at 9.

202. *See* Eric Rignot et al., *Four Decades of Antarctic Ice-Sheet Mass Balance from 1979–2017*, 116 PROC. NAT'L ACAD. SCIS. 1095, 1095 (2019) (documenting ice loss from ocean warming).

203. *See* Meredith et al., *supra* note 39, at 237 (reporting the East Antarctic Ice Sheet constitutes 85 percent of the Antarctic Ice Sheet, but ice mass loss comes predominantly from the West Antarctic Ice Sheet).

Fig. 2 *Visualization of relative size and elevation of Antarctica's ice sheets.*[204]

Ice shelves are floating extensions of ice sheets beyond the grounding line, which play an important role in buttressing those ice sheets.[205] They do so by bracing against stable points, such as islands or the sides of a glacial embayment, providing backward thrust on the ice sheet that slows or blocks the outflow of ice.[206] Occasionally, icebergs calve off the edges of ice shelves to float freely at sea.[207] Together with sea ice—open waters that freeze seasonally—icebergs can form a frothy mixture that further slows glacier outflow.[208] Antarctic icebergs can reach sizes of thousands of square kilometers, especially under conditions of climate change. In 2021, an iceberg twice the size of Chicago calved off the Brunt Ice Shelf and into the Weddell Sea.[209] One five times larger, about the size of Delaware, calved off the Larsen C Ice Shelf a few years earlier.[210]

Icebergs are a particularly dramatic expression of *flow* on the continent. Despite their vast scale and mass, Antarctica's ice formations move, borne by gravity and eased by subglacial streams to ultimately discharge at sea.[211] Indeed,

204. Adapted from U.S. ANTARCTIC PROGRAM EXTERNAL PANEL, *supra* note 46, at 15.

205. Meredith et al., *supra* note 39, at 244. The grounding line is the region of the ice sheet where the ice mass begins to lift off the bedrock and float in the water. *Id.*

206. Ian Joughin et al., *Ice-Shelf Retreat Drives Recent Pine Island Glacier Speedup*, SCI. ADVANCES, June 11, 2021, at 1, 3 (discussed in Sarah Kaplan, *This Melting Glacier Was Already the Biggest Source of Sea Level Rise. Then Things Got Worse.*, WASH. POST (June 11, 2021, 2:00 PM), https://www.washingtonpost.com/climate-environment/2021/06/11/pine-island-ice-shelf-collapse/); *see also* Andrew Lockley et al., *supra* note 20, at 402; Rignot et al, *supra* note 202, at 1101 (documenting the relationship between loss of ice shelves and weakening of structural support).

207. Alexandre K. Magnan et al., *Integrative Cross-Chapter Box on Low-Lying Islands and Coasts*, *in* IPCC SPECIAL REPORT ON THE OCEAN AND CRYOSPHERE IN A CHANGING CLIMATE, *supra* note 6, at 657, 688; *see also* Kevin R. Arrigo et al., *Ecological Impact of a Large Antarctic Iceberg*, 29 GEOPHYSICAL RSCH. LETTERS 8-1, 8-4 (2002) (describing iceberg formation via the Ross Ice Shelf).

208. *See* Alexander A. Robel, *Thinning Sea Ice Weakens Buttressing Force of Iceberg Mélange and Promotes Calving*, NATURE COMMC'NS, March 1, 2017, at 1, 2.

209. Kathryn Hansen, *Breakup at Brunt*, NASA EARTH OBSERVATORY (March 1, 2021), https://earthobservatory.nasa.gov/images/148009/breakup-at-brunt.

210. Maria-Jose Viñas, *Massive Iceberg Breaks off from Antarctica*, NASA: GLOBAL CLIMATE CHANGE (July 12, 2017), https://climate.nasa.gov/news/2606/massive-iceberg-breaks-off-from-antarctica/.

211. *See generally* E. Rignot et al., *Ice Flow of the Antarctic Ice Sheet*, 333 SCIENCE 1427 (2011) (brief overview and visualization of the continent's ice flows); *see also* Lockley et al., *supra* note 20, at 402 (describing the relationship between ice flow and subglacial water).

because of this flow, the U.S. research station at the South Pole drifts about thirty feet per year.[212] In some regions, ice sheets flow via faster-moving streams that converge like rivers and reach the Southern Ocean via outlet glaciers.[213] In East Antarctica, where ice sheets are relatively stable, outlet glaciers can move as slowly as a few meters a year.[214] In West Antarctica, however, outlet glaciers can flow many times faster, with the fastest moving more than a kilometer per year.[215]

Antarctica's net contribution to sea-level rise is the balance of outgoing ice flow against the accumulation of snow on top of the ice sheets.[216] The continent is already losing hundreds of billions of tons in net ice mass per year, a sixfold increase from rates just a few decades ago.[217] The single largest source of loss is the rapid acceleration of outflow from major outlet glaciers on the West Antarctic Ice Sheet.[218] Of greatest concern are Pine Island Glacier and Thwaites Glacier, both flowing from West Antarctica into the Amundsen Sea.[219] Both glaciers are grounded below sea level, leaving their undersides exposed to the Southern Ocean.[220] Surface waters around Antarctica are very cold—partly due to glacial meltwater—but circumpolar air currents cause relatively warm water to upwell from the ocean's depths.[221] When this warmer water moves under an ice sheet, it can melt the base and cause the grounding line to recede.[222] The outlet glacier, meanwhile, continues to discharge ice into the ocean as the grounding line moves inland, but at a faster pace.

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212. *See Amundsen-Scott South Pole Station*, *supra* note 83.

213. Rignot et al., *supra* note 211, at 1428. Both ice sheets and glaciers are large masses of ice grounded on land rather than floating at sea. Ice sheets are larger than 50,000 km^2, while glaciers are smaller than 50,000 km^2. *See Annex I Glossary*, *in* IPCC SPECIAL REPORT ON THE OCEAN AND CRYOSPHERE IN A CHANGING CLIMATE, *supra* note 6, at 676, 686, 688–89. For comparison, the area of Vermont and New Hampshire combined is about 47,000 km^2. *See* U.S. CENSUS BUREAU, *QuickFacts Vermont*, https://www.census.gov/quickfacts/VT (reporting Vermont's land area as about 9,200 square miles, or about 23,800 square kilometers); U.S. Census Bureau, *QuickFacts New Hampshire*, https://www.census.gov/quickfacts/fact/table/NH,US/AFN120212 (reporting Vermont's land area as about 9,000 square miles, or about 23,300 square kilometers).

214. Rignot et al., *supra* note 211, at 1428; *but see also* Rignot et al., *supra* note 202, at 1102 (warning East Antarctic Ice Sheet mass loss is also considerable).

215. Rignot et al , *supra* note 211, at 1428.

216. *See* Nerilie Abram et al., *Framing and Context of the Report*, *in* IPCC SPECIAL REPORT ON THE OCEAN AND CRYOSPHERE IN A CHANGING CLIMATE, *supra* note 6, at 73, 79; Sebastian H. R. Rosier et al., *The Tipping Points and Early Warning Indicators for Pine Island Glacier, West Antarctica*, 15 CRYOSPHERE 1501, 1501 (2021).

217. Rignot et al , *supra* note 202, at 1095.

218. Abram et al., *supra* note 6, at 6; *see also* Rignot et al., *supra* note 202, at 1101 ("[T]he intrusion of warm, salty, circumpolar deep water [] on the continental shelf . . . vigorously melts the ice shelves, reduces buttressing of the glaciers, and allows them to flow faster.").

219. *See* Eric Rignot et al., *Acceleration of Pine Island and Thwaites Glaciers, West Antarctica*, 34 ANNALS GLACIOLOGY 189, 189 (2002).

220. *See* Abd-Elgawad et al., *supra* note 6, at 53.

221. Meredith et al., *supra* note 39, at 244–45.

222. *Id.*

The initial retreat of the grounding line can put in motion a self-sustaining process of retreat called marine ice-sheet instability.[223] This is a largely mechanical process driven by bedrock geometry.[224] The grounding line is unstable on retrograde slopes, where the bedrock slopes down away from the ocean, as shown in Figure 3.[225] As the grounding line moves inland, melting at the base increases due to increased intrusion of warmer water and pressure-induced lowering of the freezing temperature. Ocean-induced melting then moves the grounding line further inland, further accelerating these loss processes and the resultant seaward flow of ice.[226] As the glacier accelerates, it stretches out and thins, making it lighter and thus allowing the ice to float more easily and separate from the bedrock. The loss process continues until the grounding line reaches a point where the bedrock slopes seaward instead, stopping the positive feedback.[227]

According to the IPCC, "even slight increases in ocean temperature have the potential to rapidly melt and destabilize large sections of an ice sheet."[228] Ice-shelf thinning and collapse compounds the destabilization, providing less buttressing for ice sheets as warmer air and water melt the shelves away.[229] As ice shelves disappear, they can also leave behind ice cliffs, towering expanses of ice that are often unstable and can break apart relatively easily.[230]

223. Irvine et al., *supra* note 26, at 2507–08; *see also* Meredith et al., *supra* note 39, at 244; Frank Pattyn, *The Paradigm Shift in Antarctic Ice Sheet Modelling*, 9 NATURE COMMC'NS, July 16, 2018, at 1, 1–2.

224. *See* BUCK, *supra* note 28, at 235–36.

225. Irvine et al., *supra* note 26, at 2507–08.

226. *See, e.g.*, E. Rignot et al., *Widespread, Rapid Grounding Line Retreat of Pine Island, Thwaites, Smith, and Kohler Glaciers, West Antarctica, from 1992 to 2011*, 41 GEOPHYSICAL RSCH. LETTERS 3502, 3507–08 (2014).

227. *See* Irvine et al., *supra* note 26, at 2508.

228. Abram et al., *supra* note 216, at 80.

229. *See* Pattyn, *supra* note 223, at 1–2; *see also* Meredith et al., *supra* note 39, at 244 (identifying surface melt from warmer atmospheric temperatures and basal melt from warmer oceans as weakening ice shelves).

230. *See* Meredith et al., *supra* note 39, at 245; *see also* Irvine et al., *supra* note 26, at 2508.

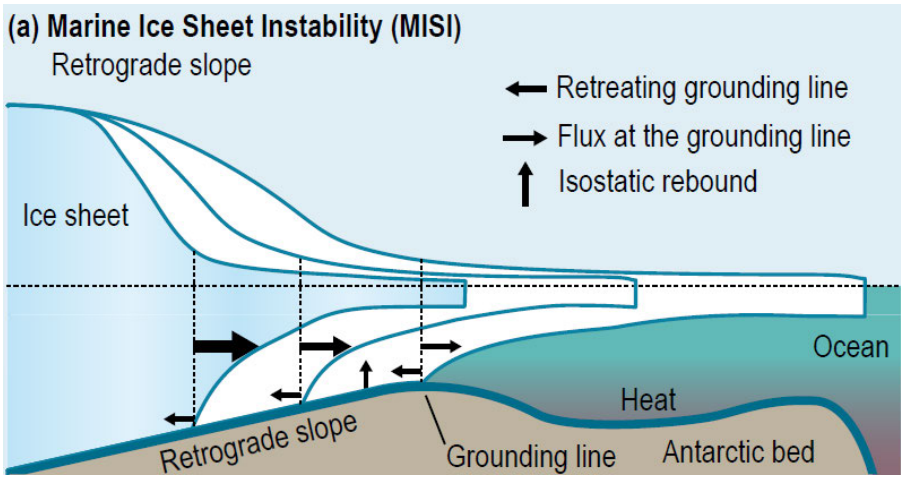

Fig. 3. *Illustration of proposed mechanisms of marine ice-sheet instability*.[231] *The ice sheet begins to the left of the grounding line, the ice shelf to the right. Relatively warm water upwells from the Southern Ocean's depths, melting the base of the glacier and causing the grounding line to recede inland.*

Pine Island Glacier and Thwaites Glacier are of particular concern. Both glaciers lie on retrograde slopes, both are in retreat, and both appear to be in the process of runaway destabilization.[232] The Southern Ocean, and the Amundsen Sea in particular, are experiencing relatively rapid warming, suggesting likely further weakening of ice shelves and exacerbation of ice-sheet stresses.[233] The retreat of these glaciers may thus become self-perpetuating.[234] The possible consequences are grave: complete destabilization of these glaciers could add one meter of global sea-level rise.[235] And given their critical location, their destabilization would also increase ice discharge from most of the West Antarctic Ice Sheet.[236] As a result, the impacts of glacier destabilization could be felt relatively soon, making the West Antarctic Ice Sheet the largest single driver of global-average sea-level rise by 2100.[237] The melt's impacts will be felt long

231. Meredith et al., *supra* note 39, at 245 fig.CB8.1.

232. Michael Oppenheimer et al., *Sea Level Rise and Implications for Low-Lying Islands, Coasts, and Communities*, *in* IPCC SPECIAL REPORT ON THE OCEAN AND CRYOSPHERE IN A CHANGING CLIMATE, *supra* note 6, at 321, 347.

233. *See* Sunke Schmidtko et al., *Multidecadal Warming of Antarctic Waters*, 346 SCIENCE 1227, 1227 (2014) (finding Amundsen Sea has warmed between 0.1 C–0.3 C per decade since the 1990s).

234. Rosier et al., *supra* note 216, at 1501–02, 1512 (modeling ocean warming of 1.2 C); *see also* Abram et al., *supra* note 6, at 10 (reporting recent Antarctic ice-sheet losses may be effectively irreversible); Abd-Elgawad et al., *supra* note 6, at 53.

235. Rignot et al , *supra* note 219, at 189.

236. *Id.* at 189.

237. *See* Abram et al., *supra* note 6, at 17, 20. Recent estimates of global average sea-level rise by 2100 range from 0.6–1.2 meters. *Id.* at 20.

after 2100 as well; the sections of West Antarctic Ice Sheet estimated to be at risk contain enough water to raise global sea level by more than three meters.[238] Although current evidence suggests that complete collapse of these glaciers will take several centuries,[239] remaining uncertainties about processes of marine ice-sheet instability allows for a wide range in the projections for sea-level rise, including the potential for much faster losses than current estimates.[240] For example, researchers were recently surprised to observe significant, unanticipated acceleration in Pine Island Glacier's destabilization over just the last three years.[241] Accordingly, estimates of Antarctica's individual contribution to sea-level rise by 2100 range from as "low" as ten centimeters to as high as one meter—a staggering amount.[242]

The amount of sea-level rise threatened by Antarctica's melt far exceeds other sources worldwide,[243] making these glaciers outsized contributors to one of the most harmful impacts of climate change. The upper end of present modeling projections would be devastating for many coastal cities, risking displacement of hundreds of millions of people and profound stress on governments and economies.[244] Yet the top priority of current climate policy, emissions reduction, can do little to stop sea-level rise from marine ice-sheet destabilization already underway. Reducing anthropogenic emissions immediately to zero would stop only further increase in global average temperature; it would not restore cooler ocean temperatures, nor stop the

238. Oppenheimer et al., *supra* note 232, at 347 (citing P. Fretwell et al., *Bedmap2 Improved Ice Bed, Surface and Thickness Datasets for Antarctica*, 7 CRYOSPHERE 375, 390 tbl.8 (2013)).

239. *See* Michael J. Wolovick & John C. Moore, *Stopping the Flood Could We Use Targeted Geoengineering to Mitigate Sea Level Rise?*, 12 CRYOSPHERE 2955, 2956 (2018) ("Models predict that it will take until the 22nd or 23rd centuries for a collapse to reach full speed. Once a collapse reaches full speed, sea level rise rates of several meters per century are common in modern models, consistent with geological evidence that sea level rise rate peaked at 4.1-5.3m per century in Meltwater Pulse 1a during Earth's last deglaciation." (internal citations omitted)).

240. *See* Irvine et al., *supra* note 26, at 2501 (mentioning one survey predicting 10 centimeters of sea-level rise from Antarctica by 2100 while another predicts 1 meter).

241. Joughin et al., *supra* note 206, at 1. A volcanic heat source beneath Pine Island Glacier may also be contributing to the changes observed by scientists. *See* Brice Loose et al., *Evidence of an Active Volcanic Heat Source Beneath the Pine Island Glacier*, NATURE COMMC'NS, June 22, 2018, at 1, 7.

242. *See* Irvine et al., *supra* note 26, at 2501; *see also* Matthew A. Thomas & Ting Lin, *Illustrative Analysis of Probabilistic Sea Level Rise Hazard*, 33 J. CLIMATE 1523 (2019) (describing the sensitivity of sea-level rise projections to assumed rates of ice-sheet melt and other factors); *id.* at 1531 ("The ice sheet contribution to sea level rise [by 2100] ranges from near 0 [meters] to as high as 3.4 [meters], which is consistent with the range of possible ice sheet projections found in the literature. The highest overall sea level rise predictions arise from especially large ice sheet contributions." (internal citations omitted)).

243. *See* Lockley et al., *supra* note 20, at 402 (reporting total potential sea-level rise from glaciers outside Antarctica and Greenland amount to about 60 cm); BUCK, *supra* note 28, at 249 (explaining Antarctica's contribution to sea-level rise will significantly exceed Greenland's by 2100).

244. *See* Oppenheimer et al., *supra* note 232, at 323–25 (summarizing sea-level rise projections and likely impacts); *see also* Celia McMichael et al., *A Review of Estimating Population Exposure to Sea-Level Rise and the Relevance for Migration*, 15 ENV'T RSCH. LETTERS 2–3, 17, 21 (2020) (literature review reporting various estimates of human displacement in response to 1 meter of sea-level rise by 2100) (noting confidence and consensus is greater for mid-century displacement projections).

dynamic feedback driving grounding-line retreat.[245] As a result, even the most ambitious decarbonization efforts are likely insufficient to stabilize these glaciers and prevent associated sea-level rise.[246] Achieving stabilization would require additional methods of intervention.

B. Radical Adaptation Proposals

This Subpart introduces proposed environmental interventions to slow or halt the loss of Antarctica's ice sheets. We conceptualize these proposed interventions as instances of *radical adaptation*.[247] The Subpart first situates radical adaptation relative to the familiar taxonomy of climate responses. It then summarizes three types of radical adaptation that have been proposed to help stabilize Antarctic ice sheets and characterizes their technical promise, limitations, and potential environmental impacts.

Since climate change first appeared on policy agendas, responses have conventionally been divided into two types: *mitigation* and *adaptation*. Mitigation aims to limit the causes of climate change by reducing human emissions of greenhouse gases.[248] Typical mitigation activities include increasing the efficiency of energy use in buildings, transportation, or industry, or replacing carbon-emitting fossil fuels with non-carbon energy sources such as solar, wind, hydroelectricity, or nuclear power.[249] Because the climate effects of carbon dioxide and other greenhouse gases occur worldwide and depend on total global emissions, mitigation's benefits are felt globally.[250] *Adaptation* aims to reduce the harm done by any given change in climate, by reducing the vulnerability or increasing the resilience of communities and ecosystems.[251] Typical adaptation activities include planting drought-resistant crops, strengthening public health and emergency-response systems, and reducing the vulnerability of coastal zones by some combination of building protective structures and reducing use of low-lying areas. In contrast to mitigation, most

245. *See* Irvine et al., *supra* note 26, at 2507–08. Leveling off rising temperatures could, however, slow the processes that cause new portions of marine ice sheets destabilize. It could also alleviate sea-level rise cause from thermal expansion of the oceans. The point worth emphasizing, though, is that emissions abatement would do little for future sea-level rise caused by the destabilization of marine ice sheets already underway.

246. *See also* Abram et al., *supra* note 6, at 10; Abd-Elgawad et al., *supra* note 6, at 53.

247. BUCK, *supra* note 28, 247–48.

248. DESSLER & PARSON, *supra* note 23, at 113.

249. *See* Jeremy Martinich et al., *Reducing Risks Through Emissions Mitigation*, *in* 2 IMPACTS, RISKS, AND ADAPTATION IN THE UNITED STATES: FOURTH NATIONAL CLIMATE ASSESSMENT 1346, 1350 (David Reidmiller et al. eds., U.S. Global Change Rsch. Program 2018); *but see* Matthias Honegger et al., *Is Carbon Dioxide Removal Mitigation of Climate Change'?*, 30 REV. EUR., COMPAR. & INT'L ENV'T. L. 327, 328–30 (2021) (arguing carbon dioxide removal via direct air capture and other technologies should also be considered mitigation).

250. *See* Martinich et al., *supra* note 249, at 1351 (explaining that global average warming is mostly caused by cumulative anthropogenic carbon dioxide emissions).

251. DESSLER & PARSON, *supra* note 23**Error! Bookmark not defined.**, at 113.

adaptation activities aim to protect a particular community, ecosystem, or stretch of coastline. They involve local efforts to bring local benefits.[252]

It is now recognized that mitigation and adaptation do not exhaust the set of possible climate responses. Other possibilities include active interventions to remove greenhouse gases from the atmosphere after emission—the basis of current "net-zero" targets—or to change Earth's energy balance by slightly reducing the planet's absorption of incoming sunlight.[253] Even within the more familiar categorization of mitigation and adaptation, the dichotomy of globally targeted mitigation versus locally targeted adaptation covers many responses, but not all. Within the complex network of causal linkages that connect emissions to climate impacts, there are occasional examples of adaptation interventions that offer higher leverage and act at larger scale. Sea-level rise from ice-sheet destabilization provides a conspicuous example. Viewing adaptation and mitigation in conventional terms, Antarctica is not a high priority for either. Conventional adaptation measures targeting Antarctica would have very limited impact because the continent is so vast and undergoing such extreme changes.[254] Targeted adaptation measures for particular Antarctic species or ecosystems may be worthwhile, but larger-scale efforts to protect Antarctica from climate change, for its own sake, would be extreme in cost, low in political salience, and in all likelihood simply impossible.[255] For mitigation, meanwhile, all emissions contribute to the global total, but emissions from human activities in Antarctica are so miniscule that emissions reductions there would have only symbolic value.[256]

Yet Antarctica may be a high priority for climate action for different reasons. A handful of Antarctic glaciers are likely to exercise outsized influence on sea-level rise, one of the most prominent dimensions of projected climate

252. Jeffrey Arnold et al., *Reducing Risks Through Adaptation Actions*, *in* 2 IMPACTS, RISKS, AND ADAPTATION IN THE UNITED STATES: FOURTH NATIONAL CLIMATE ASSESSMENT, *supra* note 249, at 1309, 1314–17.

253. NAT'L RSCH. COUNCIL, CLIMATE INTERVENTION: CARBON DIOXIDE REMOVAL AND RELIABLE SEQUESTRATION 1–5 (2015); NAT'L RSCH. COUNCIL, CLIMATE INTERVENTION: REFLECTING SUNLIGHT TO COOL EARTH 5–10 (2015).

254. *See, e.g.*, A. Znój et al., *Rapid Environmental Changes in the Western Antarctic Peninsula Region Due to Climate Change and Human Activity*, 15 APPLIED ECOLOGY & ENV'T RSCH. 525, 527 (2017) ("Recently, a rapid glacier retreat in the whole Antarctic Peninsula region has been observed, causing emergence of vast postglacial areas."). Of course, it is still worth pursuing adaptation programs to assist specific Antarctic species and ecosystems navigate the transformation underway. *See* Meredith et al., *supra* note 39, at 267 tbl.3.4.

255. *See* Znój et al., *supra* note 254, at 527; *see also* Part III, *infra* (discussing marginal role Antarctica plays in international relations and government decision-making).

256. *Compare* Sergey Kakareka, *Air Pollutants and Greenhouse Gas Emission Inventory for Power Plants in the Antarctic*, 31 ADVANCES POLAR SCI. 274, 277 (2020) (estimating 57,000 tons of carbon dioxide emissions per year from electricity generation in Antarctica), *with* EPA, EPA 430-R-21-005, INVENTORY OF U.S. GREENHOUSE GAS EMISSIONS AND SINKS: 1990–2019, at 3-3 tbl.3.1 (2021) (reporting more than 1,600,000,000 tons of carbon dioxide emissions in 2019 from electricity generation in the United States). Reducing Antarctic emissions may be especially symbolically resonant though, given the continent is uniquely under cooperative international governance. *See* Part III, *infra*.

impacts worldwide.[257] This suggests that interventions to stabilize Antarctic ice sheets might be able to reduce or delay sea-level rise worldwide. Such interventions would partly resemble adaptation, in that they would aim to reduce the harms resulting from climate change, not the human activities driving the changes. But they might offer greatly increased leverage relative to most adaptation, providing large benefits to low-lying coastal areas worldwide from interventions that are relatively spatially concentrated. Ice-sheet stabilization may thus promise more effective or less costly risk reduction compared to local adaptation measures such as coastal defense or retreat in every coastal area threatened by sea-level rise.[258]

Like greenhouse gas removal or solar geoengineering, these interventions would not avoid the imperative for extreme cuts in global greenhouse gas emissions.[259] Continued high emissions would eventually raise global temperatures enough to melt Antarctica's glaciers from the top, as is already happening in Greenland.[260] At best, radical adaptation in Antarctica would operate as a stopgap,[261] buying time to expand other climate responses—including massive local adaptation within coastal regions.

We use the term *radical adaptation* to describe these potential interventions.[262] They are adaptation measures in that they aim to reduce the harm from a given climate impact. But they are radical in their scale of effort, their technical challenge and risk of failure, and in their global impact should they succeed.[263] They are also radical in their potential alignment with climate justice.[264] Ice-sheet stabilization's high cost and extreme technical demands would require substantial investments by wealthy, powerful nations.[265] But their potential benefits would necessarily be distributed uniformly across all coastal regions, in rich and poor countries alike. Indeed, the benefits of slowing sea-level rise would likely be relatively greatest in those coastal regions with the fewest

257. *See* discussion at Subpart II.A, *supra*.

258. *See* Jim Morrison, *Who Will Pay for the Huge Costs of Holding Back Rising Seas?*, YALE ENV'T 360 (Aug. 5, 2019), https://e360.yale.edu/features/who-will-pay-for-the-huge-costs-of-holding-back-rising-seas (reviewing sea-level rise damage and adaptation estimates); *see also* MORTON, *supra* note 24, at 81 (discussing leverage and the climate system).

259. *See* Lockley et al., *supra* note 20, at 402–03; *see also* Wolovick & Moore, *supra* note 239, at 2955.

260. *See* BUCK, *supra* note 28, at 248.

261. *See* Holly Jean Buck et al., *Evaluating the Efficacy and Equity of Environmental Stopgap Measures*, 3 NATURE SUSTAINABILITY 499, 499 (2020) (theorizing on environmental stopgap measures to identify the elements of incompleteness, buying time, and perceived urgent need).

262. Buck, *supra* note 28, at 216 (coining usage); *see also A 3°C World Has No Safe Place*, THE ECONOMIST (July 24, 2021), https://www.economist.com/leaders/2021/07/24/a-3degc-world-has-no-safe-place (characterizing solar geoengineering as a form of adaptation, if "spectacular" and "scary").

263. *See* SONJA VERMEULEN ET AL., RADICAL ADAPTATION IN AGRICULTURE: TACKLING THE ROOTS OF CLIMATE VULNERABILITY (Int'l Inst. for Env't & Dev. Briefing Paper, 2015).

264. *See* Stephen M. Gardiner, *Climate Justice*, *in* THE OXFORD HANDBOOK OF CLIMATE CHANGE AND SOCIETY 309, 316 (John S. Dryzek et al. eds., 2011) (analyzing the requirements of climate justice between countries regarding burden-sharing of climate adaptation costs).

265. *See* Wolovick & Moore, *supra* note 239, at 2961–62 (speculating on possible costs).

resources for local adaptation measures. This may be a case where a rising tide truly does lift all boats.

Several scientists have proposed specific interventions that might help stabilize the West Antarctic Ice Sheet.[266] Proposals focus especially on Pine Island Glacier and Thwaites Glacier because they are relatively small, changing rapidly, and projected to make outsized contributions to future sea-level rise.[267] These ideas are in their infancy and should be understood as illustrating possibilities to explore, not concrete plans.[268] Further study of mechanisms of ice-sheet destabilization may inspire new ideas for potential interventions or rule out the entire project as impracticable. Hence the first need is research on both the processes of ice sheet instability and on the promise, limitations, and risks of specific intervention proposals.

Three distinct approaches to ice-sheet stabilization have been proposed, which would intervene at different points to target different mechanisms related to ice-sheet loss and sea-level rise. The first approach would seek to fortify the ice shelves that support ice sheets against outflow and encourage their regrowth. One way to do this would be constructing pinning points: artificial earthen islands rising from the seabed.[269] These pinning points could provide purchase for the development of new ice on ice shelves while also allowing for greater support of the grounded ice sheet.[270] They could be combined with structures that block the flow of warmer water that melts the ice from underneath.[271] The limited modeling available suggests that this combined approach could help protect ice formations currently weakened by marine ice-sheet instability.[272]

Such ideas present a few obvious and daunting challenges. Constructing pinning points would require vast amounts of material, on par with amounts used to construct artificial islands in Dubai and Hong Kong.[273] Unlike those megaprojects, however, these would be constructed in an environment that is

266. The East Antarctic Ice Sheet is much more stable and slower moving due to its size and underlying geography, but portions of it may also become vulnerable to warming oceans over time. *See* N.R. Golledge et al., *East Antarctic Ice Sheet Most Vulnerable to Weddell Sea Warming*, 44 GEOPHYSICAL RSCH. LETTERS 2343, 2348–50 (2017).; *see also* Henry Fountain, *In a First, an Ice Shelf Collapses in East Antarctica*, N.Y. TIMES (March 25, 2022).

267. *See* BUCK, *supra* note 28, at 247. Many of the ideas described could also play a role in stabilizing Greenland's ice sheets. *See generally* Lockley et al., *supra* note 20 (analyzing ice-sheet stabilization proposals for both the Arctic and Antarctic). Greenland's melt, however, is predominantly driven by surface melt from atmospheric warming, whereas ocean warming and bedrock geometry drives Antarctica's, requiring different engineering approaches. Greenland's history and governance structure also differ greatly from Antarctica's, requiring separate legal analysis beyond the scope of this Article. *See* Johnstone, *supra* note 19, at 1, 8–9.

268. *See* Lockley et al., *supra* note 20, at 40; *see also generally id.* (providing comprehensive technical overview of such techniques).

269. *See* Wolovick & Moore, *supra* note 239, at 2957.

270. *Id.*

271. John C. Moore et al., Comment, *Geoengineer Polar Glaciers to Slow Sea-Level Rise*, 555 NATURE 303, 304 (2018).

272. Wolovick & Moore, *supra* note 239, at 2961–63.

273. *Id.* at 2962.

remote and hostile, even by Antarctic standards; the Amundsen Sea is difficult to access during winter for all but the largest icebreakers.[274] The material requirements for an underwater berm would be still larger, with even the smallest designs requiring more than ten times the volume excavated to build the Suez Canal.[275] Preliminary analysis available suggests sharp tradeoffs in the scale of interventions: the largest interventions would present greater costs, engineering and logistical challenges, and environmental impacts, but would also probably be more effective at slowing ice flow and sea-level rise.[276] Underwater berm building would have particularly large and uncertain environmental impacts, including redirecting warm water flows to stabler parts of the West Antarctic Ice Sheet.[277] How much this redirection might increase ice loss elsewhere and offset reductions from Thwaites Glacier and Pine Island Glacier, and how to optimally redirect and distribute flows of warm water, are high-stakes unknowns.[278] Further research on specific characteristics of these glaciers and surrounding waters may suggest finer-tuned and more feasible interventions in this vein.[279]

A second set of ideas would target the subglacial pockets of water that lubricate the flow of ice over bedrock. This would involve some combination of drilling through the ice to pump out water[280] and freezing subglacial water in place,[281] to replicate the friction of ice against rock (so-called bedrock "sticky spots") that slows ice flow in other parts of the continent.[282] A natural analogue for this process and possible proof of concept comes from the Ross Ice Shelf, where two ice streams slowed substantially in recent decades, likely due to loss

274. *See* Twila A. Moon et al., Correspondence, *Geoengineering Is Not a Quick Glacier Fix*, 556 NATURE 436, 436 (2018).

275. Özgür Gürses et al., *Brief Communication A Submarine Wall Protecting the Amundsen Sea Intensifies Melting of Neighboring Ice Shelves*, 13 CRYOSPHERE 2317, 2321 (2019).

276. Wolovick & Moore, *supra* note 239, at 2602; *see also* BUCK, *supra* note 28, at 247–50 (relying on interview with Moore).

277. Gürses et al., *supra* note 275, at 2317, 2319–20.

278. The construction modeled in Gürses et al. was much larger than the largest designs proposed by Wolovick & Moore. *Compare* Gürses et al., *supra* note 275, at 2312, *with* Wolovick & Moore, *supra* note 239, at 2957; *see also* Lockley et al., *supra* note 20, at 411–12 (analyzing Gürses et al.'s findings and noting Gürses et al. modeled an intervention "larger than interventions simulated by Wolovick and Moore"). No comprehensive study modeling water redirection and impacts at various construction sizes has been conducted.

279. *See, e.g.*, Anna Wåhlin et al., Warm Water Flow and Mixing Beneath Thwaites Glacier Ice Shelf, West Antarctica, Presentation to European Geosciences Union General Assembly 2020 (May 6, 2020), https://doi.org/10.5194/egusphere-egu2020-19934 (recharacterizing warm-water flows under Thwaites and Pine Island Glaciers as narrower than previously understood); *see also* John Moore et al., What Role for Targeted Geoengineering to Mitigate Climate Change?, Presentation (Oct. 4, 2021) (presentation deck on file with authors) (proposing alternative concept of smaller, removable geotextile curtains instead); Julian David Hunt & Edward Byers, *Reducing Sea Level Rise with Submerged Barriers and Dams in Greenland*, 24 MITIGATION & ADAPTATION STRATEGIES FOR GLOB. CHANGE 779, 785 tbl.1 (2018).

280. Moore et al., *supra* note 271, at 304–05.

281. *See* Lockley et al., *supra* note 20, at 407–09.

282. *See id.* at 405–07.

of water beneath the ice.[283] Furthermore, there are several precedents for deep ice drilling in Antarctica, including both failures and notable successes.[284] The IceCube Neutrino Observatory, at the U.S. Amundsen–Scott South Pole Station, was constructed using hot water jets to drill over eighty holes two-and-a-half kilometers deep into the East Antarctic Ice Sheet.[285] The effort was expensive and laborious: drilling twenty holes during the 2009-2010 season required 450,000 liters of fuel, 300 tons of equipment, and eighty-eight people working around the clock.[286] Around the same time, a Russian team succeeded at extracting water from Lake Vostok, a subglacial lake lying under nearly four kilometers of ice.[287]

Even assuming success at drilling, creating an artificial sticky spot beneath a glacier presents additional technical difficulties. Keeping the subglacial water flowing would require careful maintenance of conditions beneath the glacier's base.[288] Achieving stabilization might require operating and maintaining many wells spread across the surface of the glacier system.[289] Ironically, techniques for drilling and well pressurizing developed by the oil and gas industry could help the development and maintenance of these glacial water fields.[290] Moreover, any drilling program would have to remain alert for undesired side effects, including the possibility that extracting water may cause ice buildup that accelerates flow.[291] Water pumped to the surface may also require treatment before disposal, whether at sea or on top of the glacier.[292]

A third approach would move off the ice, aiming instead to cool the water and air that are contributing to ice-sheet melting. Interventions that modify the Earth's albedo to make the ice, water, or atmosphere more reflective could cool the ocean surface to thicken the mix of sea ice and icebergs that supports ice

283. *See* Tarun Luthra et al., *Characteristics of the Sticky Spot of Kamb Ice Stream, West Antarctica*, 122 J. GEOPHYSICAL RSCH.: EARTH SURFACE 641, 641–43, 651 (2017).

284. *See, e.g.*, Carolyn Gramling, *British Antarctic Survey Fails to Penetrate Antarctica's Lake Ellsworth*, SCIENCE (Dec. 27, 2012), https://www.sciencemag.org/news/2012/12/british-antarctic-survey-fails-penetrate-antarcticas-lake-ellsworth; Amanda M. Achberger, *Microbial Community Structure of Subglacial Lake Whillans, West Antarctica*, 7 FRONTIERS IN MICROBIOLOGY art. no. 1,457 1 (2016) (describing microbes found in subglacial Antarctic lake via successful deep ice drilling).

285. *See IceCube*, ICECUBE NEUTRINO OBSERVATORY, https://icecube.wisc.edu/science/icecube/ (last visited June 16, 2021).

286. Silvia Bravo, *Drilling IceCube A Story of Innovation, Expertise and Strong Will*, ICECUBE NEUTRINO OBSERVATORY (Dec. 12, 2014), https://icecube.wisc.edu/news/detector/2014/12/drilling-icecube-story-of-innovation-expertise-and-strong-will/.

287. *See* David M. Herszenhorn & James Gorman, *Russian Scientists Bore into Ancient Antarctic Lake*, N.Y. TIMES (Feb. 8, 2012), https://www.nytimes.com/2012/02/09/world/europe/russian-scientists-bore-into-ancient-antarctic-lake.html; *see also* ARCTIC & ANTARCTIC RSCH. INST.: RUSSIAN ANTARCTIC EXPEDITION, WATER SAMPLING OF THE SUBGLACIAL LAKE VOSTOK: FINAL COMPREHENSIVE ENVIRONMENTAL EVALUATION 5 (2010) [hereinafter 2010 LAKE VOSTOK CEE], https://www.southpolestation.com/trivia/10s/01236enCEE_Lake_Vostok_e_final.pdf.

288. *See* Lockley et al., *supra* note 20, at 405.

289. *Id.* at 407; Moon et al., *supra* note 274, at 436.

290. *See* Lockley et al., *supra* note 20, at 406.

291. *See* Moore et al., *supra* note 271, at 305; Moon et al., *supra* note 274, at 436.

292. *See* Lockley et al., *supra* note 20, at 407.

shelves.[293] Similar interventions could also slow some types of surface melt and hydrofracturing that weakens ice formations from above.[294] Albedo modification techniques include marine cloud brightening, which would seed low clouds to make them thicker and brighter,[295] and stratospheric aerosol injection, which would spray a fine veil of reflective aerosols in the upper atmosphere to cool over larger areas.[296]

Like the other ideas discussed here, however, these albedo-modification approaches are scientifically and technically immature and highly uncertain in their effectiveness, controllability, and side effects.[297] They would not address the upwelling of warmer ocean water that is driving ice-sheet destabilization from below.[298] Moreover, these approaches would affect a larger geographic area, including physical and biological systems outside the ice, possibly complicating governance by affecting jurisdictions outside the Antarctic Treaty Area.[299]

Even the techniques that target ice sheets directly and whose implementation is more spatially limited, such as building berms or islands or removing glacial base water, would have impacts on the Antarctic environment far greater than present human infrastructure.[300] The scale of some interventions would rival or exceed the largest civil engineering projects worldwide[301] and would be conducted in an exceptionally remote and harsh region carrying significant wilderness value. The remainder of this Article develops the resultant difficulties for governing such interventions in the context of the Antarctic Treaty System.

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293. *See* John Latham et al., *Marine Cloud Brightening Regional Applications*, PHIL. TRANSACTIONS ROYAL SOC'Y, Dec. 28, 2014, at 1, 5–6.

294. *Cf.* Irvine et al., *supra* note 26, at 2508 (discussing the role of surface melt from warming atmospheric temperatures in the breakup of ice on the Antarctic Peninsula); *see also* Lockley et al., *supra* note 20, at 411.

295. NAT'L ACADS. OF SCIS., ENG'G, & MED., *supra* note 22, at 34–35.

296. *Id.* at 34.

297. *Id.* at 4–5.

298. *See* K. E. McCusker et al., *Inability of Stratospheric Sulfate Aerosol Injections to Preserve the West Antarctic Ice Sheet*, 42 GEOPHYSICAL RSCH. LETTERS 4989, 4989 (2015); *see also* Irvine et al., *supra* note 26, at 2508. There are open questions, however, as to what extent solar geoengineering could modify circumpolar air currents that drive upwelling of this warm water. *See id.* at 2508 (discussing an initial study finding that stratospheric aerosol injection could *increase* warm water upwelling in the Southern Ocean in certain deployment scenarios).

299. *See* Lockley, *supra* note 20, at 412. Due to dissimilarities between albedo-modification technologies and other proposed methods for ice-sheet stabilization, we do not focus on potential ATS governance of albedo modification research in this Article. For more detailed analysis on this question, *see* Reynolds, *supra* note 30, at 463–66. For more general analysis of solar geoengineering research governance as a whole, *see generally* NAT'L ACADS. OF SCIS., ENG'G, & MED., *supra* note 22.

300. *See* BUCK, *supra* note 28, at 247–50 (relying on interview with Moore).

301. *See* Wolovick & Moore, *supra* note 239, at 2692.

III. RADICAL ADAPTATION IN ANTARCTICA

This Part examines potential interactions between radical adaptation proposals and the Antarctic Treaty System, how they might conflict, and how and to what degree such conflicts might be mitigated. Despite the significant ATS governance problems discussed in Part I, we consider governance under the existing regime rather than some hypothetical new system for three reasons. First, despite its challenges, the Antarctic Treaty System is the extant regime. It thus provides a concrete framework for international cooperation whose past operations can ground the analysis. Second, since abandoning or fundamentally reconstructing the system would risk upending the present equilibrium and awakening long-dormant territorial disputes, the present system may well be better than any likely successor in preserving peace and cooperation. Finally, the Treaty System has successfully adapted to significant challenges in the past, providing grounds for optimism that it may adapt to serious new challenges.

Radical adaptation's governance challenges are substantial. Ice-sheet stabilization is untested and unorthodox, presenting deep uncertainties about its efficacy, risks, and impacts. It further does not fit neatly within climate policy as conventionally understood. Unlike mitigation or carbon removal, it would not target greenhouse gases, the underlying cause of climate change. And unlike conventional adaptation, it would aim for a high-leverage, worldwide effect from a single, remote, and relatively spatially confined intervention. It differs even from solar geoengineering, in that its feasibility and impacts are far more uncertain, while its global effects and targeted benefit—avoided sea-level rise—would be more circumscribed and well characterized.[302] Hence our use of the term "radical adaptation," which captures its idiosyncrasies as a local intervention to slow a major mechanism of global change.[303]

Like solar geoengineering, ice-sheet stabilization would be only a stopgap measure.[304] It would aim to slow harmful change already underway, buying time to develop more effective responses. There is no guarantee that the extra time would be used wisely.[305] There are thousands of authorities responsible for coastal management around the world, and the policy responses within these myriad jurisdictions may be highly variable. Radical adaptation would also carry

302. *See* Daniele Visioni et al., *Is Turning Down the Sun a Good Proxy for Stratospheric Sulfate Geoengineering?*, 126 J. GEOPHYSICAL RSCH.: ATMOSPHERES, March 2021, at 1, 17 fig.11 (visualizing mechanisms of solar geoengineering's interference with the planet's atmosphere and their attenuation from locally experienced climate impacts); *see also* discussion at Part II, *supra* (characterizing ice sheet stabilization proposals).

303. *See* Lockley et al., *supra* note 20, at 401 ("It is remarkable that the high-end sea-level rise over the next few hundred years comes almost entirely from only a handful of ice streams and large glaciers.").

304. *See* Buck et al., *supra* note 261**Error! Bookmark not defined.**, at 499 (defining stopgap measures as interim or incomplete policies or projects implemented to "buy time" and "mitigate immediate harm"); *see also* NAT'L ACADS. OF SCIS., ENG'G, & MED., *supra* note 22, at 1–18 (providing overview of solar geoengineering technology, risks, and governance problems).

305. *Cf.* NAT'L ACADS. OF SCIS., ENG'G, & MED., *supra* note 22, at 121 (describing risk of solar geoengineering activities delaying efforts to reduce emissions).

the risk that an intervention might succeed for a while, but then later fail, bringing sudden advances of ice sheets and rapid sea-level rise.[306] Some thus argue against radical adaptation in terms that mirror those used against solar geoengineering: characterizing it as a distraction that could be used to justify weak mitigation efforts and may present unacceptable risk of termination shock.[307]

Radical adaptation nonetheless requires distinct analysis from solar geoengineering because it would directly modify a local landscape rather than the planet's atmosphere and radiative balance.[308] Accordingly, some of the most important policy and governance concerns it presents are specific to Antarctica, such as local and regional physical impacts. Radical adaptation would present political risks of disrupting the delicate balance of relationships woven into the Antarctic Treaty System, and it may raise symbolic objections in using Antarctica for human ends rather than as a wilderness preserve. Moreover, beyond the obvious risks of structural failure, successful radical adaptation may risk encouraging complacency or delay in undertaking more durable forms of coastal adaptation. And perhaps most importantly, radical adaptation would be extremely difficult and costly to realize, with success facing long odds, and benefits that would accrue slowly over a century or more.

Part III's governance analysis proceeds by examining how radical adaptation might interact with the Antarctic Treaty System's norms, structures, and rules. It first explains how prevailing Antarctic norms might be reinterpreted to facilitate a project as revolutionary as ice-sheet stabilization. Next it considers the system's most prominent structural obstacles, notably the delicate balance it maintains on territorial claims and the reliance on unanimous decision-making, and explores how radical adaptation proponents might thread a path through them. It then identifies potential points of conflict with rules for environmental protection under the Madrid Protocol, sketching an approach to radical adaptation research that might satisfy its requirements. It closes by suggesting how the Antarctic Treaty System might one day be amended to supervise project construction. Building any of these interventions would represent an extreme disruption to multiple dimensions of the Antarctic environment. Yet it would also be undertaken for the purpose of environmental protection, suggesting some grounds for hope that the regime could embrace it.

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306. *See, e.g.*, Lockley et al., *supra* note 20, at 411 Moore & Wolovick, *supra* note 239, at 2963 (describing failure mode caused by summer surface melt); NAT'L ACADS. OF SCIS., ENG'G, & MED., *supra* note 22, at 4, 53, 63 (discussing risk of abrupt halt of solar geoengineering and rapid warming that could result).

307. *See, e.g.*, Moon et al., *supra* note 274**Error! Bookmark not defined.**, at 436. "Termination shock" describes scenarios where rapid cessation of an implemented climate engineering measure, such as a planetary program of solar geoengineering, would cause a rapid and catastrophic change in the planetary climate system. *See* NAT'L ACADS. OF SCIS., ENG'G, & MED., *supra* note 22, at 4.

308. Roughly speaking, Earth's radiative balance is the net of incoming solar energy less outgoing energy radiated back into space. *See* Oppenheimer et al., *supra* note 232, at 686, 693, 695.

A. Norms

The central norms of the Antarctic Treaty System concern peace, science, and environmental protection.[309] This Subpart discusses how they have been interpreted and enacted over the decades, and then assesses how these norms and interactions among them might influence the governance of radical adaptation.

The Antarctic Treaty is first and foremost a peace treaty which has defused international tensions from the 1950s to the present day. Since its adoption, "peace" has been interpreted to mean the avoidance of militarization and open conflict on the continent.[310] Treaty provisions against militarization were motivated by the then-urgent need to stop growing tensions over conflicting territorial claims.[311] Treaty negotiators also wished to prevent Antarctica from becoming enmeshed in the Cold War.[312] These purposes have been successfully fulfilled over the treaty's duration.[313] Moreover, given the potential for revival of territorial, geopolitical, or commercial rivalries, this narrow, do-no-harm framing of peace remains important today.[314]

Keeping that peace, however, has largely depended on Antarctica's peripheral role in world affairs. It is a remote place with a hostile climate and few commercially exploitable resources.[315] Its lands have not tempted the commercial interests or investments that have sparked armed conflict and forced appropriation elsewhere.[316] Moreover, Antarctica lacks a permanent population that would demand, and require, civil and political rights at odds with the unique governance structure of the Antarctic Treaty System. Peace in Antarctica is thus mainly characterized by the avoidance of violent conflict and sustained by general disinterest.[317] The regime has proven sufficient for this task, preventing both militarization of the continent and substantial armed conflict within or regarding its territory.

Yet the urgency of the climate crisis suggests the need for a new interpretation of "peace" in Antarctica: not just to do no harm, but to pursue common benefit. Climate change presents diverse risks to peace and security

309. *See, e.g.*, Madrid Protocol, *supra* note 32, art. 2 ("designat[ing] Antarctica as a natural reserve, devoted to peace and science").

310. *See* Antarctic Treaty, *supra* note 49, art. I; Launius, *supra* note 48, at 223.

311. *See, e.g.*, Antarctica Cases, (U.K. v. Arg.; U.K. v. Chile), 1955 I.C.J. Pleadings 48 (May 1955).

312. Launius, *supra* note 48, at 223.

313. Liggett et al., *supra* note 78, at 461 (noting success of Antarctic Treaty System but warning of trouble ahead).

314. *See* discussion at Subpart I.A, *supra*.

315. With the important exception of its fisheries and historically seals and whales, which, not coincidentally, have been the most beleaguered domain of Antarctic governance. *See* discussion in Subpart I.C, *supra*.

316. *See* Elizabeth Nyman, *Contemporary Security Concerns*, *in* HANDBOOK ON THE POLITICS OF ANTARCTICA, *supra* note 34, at 571, 580; *but see* Hemmings, *supra* note 59, at 517–18 (observing technological improvements are reducing difficulty of economic activity).

317. Thomas Lord, *The Antarctic Treaty System and the Peaceful Governance of Antarctica The Role of the ATS in Promoting Peace at the Margins of the World*, 10 POLAR J. 3, 6–8 (2020) (contrasting "negative peace" with a "positive peace" that seeks social justice and equitable distribution of resources).

around the world, including extreme risks in the upper tail of the distribution of uncertain possibilities. Although Antarctica is isolated, not permanently populated, and peripheral to world affairs, it now threatens profound stress and turmoil worldwide through its contributions to future sea-level rise. Under these vastly changed conditions, what it means to use and occupy Antarctica for peaceful purposes may also need to change. The task of governance would no longer be just shielding the continent from geopolitical struggles elsewhere—it may also include active intervention to protect the integrity of Antarctica's cryosphere. To the extent radical adaptation is possible, it could present the opportunity for Antarctic governance to make a large, positive contribution to peace worldwide. Radical adaptation could thus turn the regime's peace paradigm on its head, recognizing and taking responsibility for Antarctica's growing and profound influence on international relations and human welfare.[318] The stakes of Antarctic politics would ratchet up accordingly.

Science, the second foundational norm of the Antarctic Treaty System, would still have a privileged role in governance under such a change, as it has since the negotiation of the first Antarctic Treaty and the earliest research expeditions.[319] Scientific research is enshrined in the Treaty and central to the Antarctic programs of Contracting Parties.[320] It provides a basis for exception from some of the Madrid Protocol's rules for environmental protection,[321] and it is the most frequent justification for building permanent infrastructure on the continent.[322] Moreover, it is the primary means of advancing various state aims within the Treaty Area.[323] Science is "the currency of the realm," and scientists and scientific institutions will help steer Antarctica's governance whichever direction it takes.[324]

One factor that might ease pursuit of radical adaptation is that its early research stages would closely resemble scientific activities already underway. Scientific understanding of ice-sheet destabilization is rapidly evolving, with significant questions remaining on its mechanisms and future trajectories.[325] Improved modeling and observations on glacier retreat would serve established cryosphere research agendas and radical adaptation proposals alike.[326] It may take a decade or more for research to develop and assess ice-sheet stabilization

318. *See* Abram et al., *supra* note 216, at 78.

319. Robert K. Headland, Book Review, 29 POLAR REC. 159, 159–60 (1993) (reviewing G.E. FOGG, A HISTORY OF ANTARCTIC SCIENCE (1992)).

320. *See* Antarctic Treaty, *supra* note 49, pmbl., arts. I–III, VIII–IX.

321. *See, e.g.*, Madrid Protocol, *supra* note 32, annex II, art. 3, paras. 1–3; *id.* annex II, art. 4, paras. 1, 3.

322. *See* discussion of comprehensive environmental evaluations at Subpart III.C, *infra*.

323. *See* discussion at Subpart I.A, *supra*.

324. *See id*.

325. *See* Moore & Wolovick, *supra* note 239, at 2963–64.

326. *See id.* (describing need for more sophisticated modeling of marine ice sheet instability), *and* CLIMATE CHANGE RESPONSE WORK PROGRAMME, *supra* note 181, at 3, 6, 11 (describing research needs to anticipate future changes in Antarctic environment from climate change).

proposals to diverge from research in cryosphere science.[327] During that period, a program by some states to explore radical adaptation could readily coexist with or complement a broader research agenda set by SCAR, the Committee on Environmental Protection, or other groups.[328] Project proponents should not overstate the congruence of the two goals, though. Radical adaptation research would be more strategic and mission-oriented than basic cryosphere science, and the two aims would diverge if early explorations showed promise and larger interventions were contemplated. Yet it is very likely that early research programs can be designed to advance both aims.[329]

The third norm of Antarctic governance is protection of the environment. Thus far, this norm has been sensibly interpreted as preserving nature and minimizing the footprint of human activities.[330] The scope of environmental concern has moreover been limited to the land and ocean within the Treaty Area, with little consideration of the area's relationship with distant regions via earth systems.[331] These values are expressed through a system of environmental rules that are exceptionally comprehensive for local impacts,[332] but somewhat blinkered to global problems[333] and skeptical of proposals to develop physical infrastructure with non-scientific aims.[334] If any of the intervention proposals discussed here were to proceed beyond initial research, they would have local physical impacts vastly greater than those presently tolerated in the Treaty Area. Moreover, virtually all the coastal areas worldwide that would benefit from radical adaptation are located far from Antarctica. Project development would therefore require reconceptualizing Antarctica's environmental norm in terms of its geographic scope, objectives, and enactment.

Environmental analysis to support or inform radical adaptation would have to consider global impacts based on relationships between changes in Antarctica and resultant harms or benefits outside the Treaty Area. Such assessment would also have to consider human welfare beyond the public goods of demilitarization, preserving the Antarctic environment, or the scientific knowledge produced

327. Moore et al., *supra* note 271, at 305.

328. *See* Subpart III.C, *infra*.

329. *Cf.* NAT'L RSCH. COUNCIL, CLIMATE INTERVENTION: REFLECTING SUNLIGHT TO COOL THE EARTH, *supra* note 253, at 10 (arguing information derived from researching solar geoengineering could be applied to improving climate science more generally).

330. Madrid Protocol, *supra* note 32, art. 2.

331. *See* Abram et al., *supra* note 216, at 79 fig.1 (visualizing earth system links); *see also* Madrid Protocol, *supra* note 32, art. 1(b); Antarctic Treaty, *supra* note 49, art. VI (describing extent of Treaty Area).

332. *See* Sands et al., *supra* note 31, at 638 (arguing Antarctic Treaty System provides "the most comprehensive and stringent regime of environmental protection rules ever established under the rules of public international aw anywhere in the world").

333. *See* Tim Stephens, *Governing Antarctica in the Anthropocene*, *in* ANTHROPOCENE ANTARCTICA: PERSPECTIVES FROM THE HUMANITIES, LAW, AND SOCIAL SCIENCES, *supra* note 29, at 17, 27 (describing insufficiencies in climate policy regarding Antarctica).

334. *See* 1 FINAL REPORT OF THE THIRTY-NINTH ANTARCTIC CONSULTATIVE MEETING 317–354 (2016), https://documents.ats.aq/ATCM39/fr/ATCM39_fr001_e.pdf (resolution 1 annex – "Guidelines for Environmental Impact Assessments in Antarctica").

there. Given the influence of Antarctica's ice sheets over global sea levels and the planet's energy balance, much more of the natural and human world is at risk from their destabilization than that south of the 60th parallel.[335] While this line of reasoning does not suggest that radical adaptation is inevitable, desirable, or even possible, it does indicate that prevailing environmental presumptions against large construction projects in Antarctica may not always necessarily hold. Moreover, the scale of physical change already underway in Antarctica makes futile a program of environmental management that focuses exclusively on reducing human interference.[336] An alternative focus—on assisted transformation and, if practicable and desirable, targeted intervention—may now be more aligned with both human and environmental values.[337]

ATS environmental, science, and peace norms are mutually reinforcing. Scientific researchers are generally more interested in unperturbed systems, while prohibitions on militarization and strategic development support both preservation and research objectives. This interaction of norms has helped to maintain the stability of the regime over the long term. Radical adaptation proposals would present considerable challenges to this web of values, yet do not appear to be fundamentally incompatible with it. Moreover, the prospects for radical adaptation—at least initial research—seem more promising when considering the collection of interests that underlie the region's governance.

One interest is legitimacy: all systems of governance, including Antarctica's, seek to cultivate, maintain, and renew their legitimate authority to rule.[338] The larger international community tolerates the Antarctic Treaty System—despite its deference to land claims and its exclusive decision-making structure—because it is seen as capable of managing the region. More specifically, the perception of the regime's success relies on the continued mining moratorium, the protection of the local environment, and the defusing of tensions over territorial sovereignty. For their part, members of the Antarctic Treaty System support the regime because they view it as protecting their national interests: continued demilitarization and conflict avoidance, rights of access for research; influence over decision-making, and holding open the prospect of advancing future resource claims.[339]

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335. *Cf.* Abram et al., *supra* note 216, at 79 (describing global influence of Antarctica and other aspects of the cryosphere on planetary-wide environmental systems). The 60th parallel marks the northern border of the Antarctic Treaty System and is conventionally regarded as the northern boundary of the Southern Ocean. Antarctic Treaty, *supra* note 49, art. VI.

336. *See, e.g.*, Jeroen Ingels et al., *Antarctic Ecosystem Responses Following Ice-Shelf Collapse and Iceberg Calving Science Review and Future Research*, WIREs CLIMATE CHANGE, Oct. 5, 2020, at 1, 10–18.

337. *See* EMMA MARRIS, RAMBUNCTIOUS GARDEN: SAVING NATURE IN A POST-WILD WORLD 1–2 (2011) (arguing for turn away from a "pristine" environmentalism to one that treats the Earth as a "rambunctious garden").

338. *See generally* Steven Bernstein, *Legitimacy in Intergovernmental and Non-State Global Governance*, 18 REV. INT'L POL. ECON. 17 (2011).

339. *See* discussion at Part I, *supra*.

In view of these interests, it is plausible that parties may support pursuit of methods to limit global harms from ice-sheet instability despite the large departure this would represent from governance as usual. Indeed, ATS inaction on a threatened meter or more of sea-level rise might be viewed as gravely incompetent and ineffectual, whereas acting to ameliorate the risk would be a vivid and concrete demonstration of the effectiveness of the Antarctic Treaty System and its leadership. Radical adaptation could thus help renew the Antarctic Treaty System's legitimacy and maintain a status quo that serves the interests of its most influential members.

The threat of extreme harm from sea-level rise raises a second and probably more important motivation for reorienting the Antarctic Treaty System: security.[340] Sea-level rise threatens immense losses in many of the countries that dominate Antarctic governance, including the United States and China.[341] It would also displace large numbers of people around the world, bringing severe strains on global economic, political, and legal systems.[342] Protecting coastal regions one by one will carry very high costs or may in many cases be impracticable.[343] It may thus be more effective, and cheaper, to reduce sea-level rise at a handful of sources of melt rather than armor or relocate many densely populated coastal areas. Exploring radical adaptation is thus likely to align with the self-interest of countries most influential in the Antarctic regime and most capable of executing difficult engineering projects. And because benefits would accrue to coastal regions worldwide, rich and poor, radical adaptation could advance climate justice[344]—if only in a limited form.

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340. *See* Charles R. Corbett, *"Extraordinary" and "Highly Controversial" Federal Research of Solar Geoengineering Under NEPA*, 115 NW. U. L. REV. ONLINE 240, 262–64 (2021) (analyzing aspects of legitimacy as it relates to government research of solar geoengineering).

341. *See* Jochen Hinkel et al., *Coastal Flood Damage and Adaptation Costs Under 21st Century Sea-Level Rise*, 111 PROC. NAT'L ACAD. SCIS. 3292, 3292, 3294–95 (2014) (estimating global costs within various sea-level rise and development scenarios); James E. Neumann et al., *Joint Effects of Storm Surge and Sea-Level Rise on US Coasts New Economic Estimates of Impacts, Adaptation, and Benefits of Mitigation Policy*, 129 CLIMATIC CHANGE 337, 341, 347 (2015); Qu Ying et al., *Future Sea Level Rise Along the Coast of China and Adjacent Region Under 1.5°C and 2.0°C Global Warming*, 11 ADVANCES CLIMATE CHANGE RSCH. 227, 235, 237 (2020).

342. *See* Caleb Robinson et al., *Modeling Migration Patterns in the USA Under Sea Level Rise*, PLOS ONE, Jan. 22, 2020, at 1, 1–2; *see also* OFF. OF THE DIRECTOR OF NAT'L INTEL., ANNUAL THREAT ASSESSMENT OF THE US INTELLIGENCE COMMUNITY 18–19, 21 (2021) (explaining relationship between climate change, human displacement, and global strain on political systems).

343. *See, e.g.*, Neumann et al., *supra* note 341, at 346 (modeling regions of Tampa, Florida where abandonment of coastal property would be the best mode of adaptation to sea-level rise and storm surges).

344. *See* David Schlosberg & Lisette B. Collins, *From Environmental to Climate Justice Climate Change and the Discourse of Environmental Justice*, 5 WIREs CLIMATE CHANGE 359, 362–63, 366–67, 368–70 (2014) (tracing the origin and meanings of environmental justice, including in the context of climate adaptation); *see also* U.N. Framework Convention on Climate Change, May 9, 1992, S. Treaty Doc. No. 102-39, 1771 U.N.T.S. 107, art.3(1) ("The Parties should protect the climate system for the benefit of present and future generations of humankind, on the basis of equity and in accordance with their common but differentiated responsibilities and respective capabilities. Accordingly, the developed country Parties should take the lead in combating climate change and the adverse effects thereof.").

B. Structures

Two features of the Antarctic Treaty System are especially noteworthy and troublesome when considering radical adaptation. The first is its careful geopolitical equilibrium, based on the quasi-suspension of territorial claims. Proponents of radical adaptation research must be careful not to trigger anxieties about threats to that equilibrium, particularly those based on the ambiguities in Article IV.[345] The second concerns the Treaty System's unanimity decision rules.[346] The power of any one Consultative Party to veto new programs or changes to Antarctica's governing law presents a substantial barrier to any controversial proposals. Both obstacles may present difficulties even at early stages of research on ice-sheet stabilization.

Of the two obstacles, the more challenging may be the issue of territorial claims. Proposals by some states to develop land within the Treaty Area or exert more control over management of its environment can prompt concerns of subterfuge among other parties.[347] Claimant states are likely to be especially sensitive to resource-related activities within their claimed areas.[348] Proposals to build permanent infrastructure, particularly of the scale and cost required for ice-sheet stabilization, could be interpreted as attempts to establish an interest in the project area or interfere with another state's interest.[349] A separate possible aggravator is the potential discovery of mineral resources, actual or merely anticipated, which might unsettle the Madrid Protocol.[350] After all, the discovery of signs of hydrocarbons in the continental shelf sparked interest and exploration for oil and gas in the 1970s and 1980s.[351] Even exploratory research related to radical adaptation may cause concerns about incidental discovery and renewed interest in mineral resources. The superficial resemblance between surveying and drilling activities may surface such concerns, especially since the research would inform potential development of megaprojects.

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345. *See* Subpart I.A, *supra*.

346. *See* Subpart I.B, *supra*.

347. Jeffrey McGee et al., *"Logrolling" in Antarctic Governance Limits and Opportunities*, 56 POLAR RECORD 1, 4 (2020) (analyzing these dynamics with regard to an environmental management proposal put forth by China).

348. *See* Wolfrum, *supra* note 34, at 148 (discussing state maneuvering around asserting exclusive economic zones in the Southern Ocean).

349. *Cf.* Kevin A. Hughes & Susie M. Grant, *The Spatial Distribution of Antarctica's Protected Areas A Product of Pragmatism, Geopolitics or C Conservation Need?*, 72 ENVTL. SCI. & POL'Y 41, 44 fig.2, 48 (2017) (depicting correspondence between locations of territorial claims and locations of research stations by claimant states).

350. *See* Nevitt & Percival, *supra* note 31, at 1679; Dodds & Colis at 66.

351. Joyner, *supra* note 134, at 75; *see also* John C. Behrendt, *Are There Petroleum Resources in Antarctica?*, *in* PETROLEUM AND MINERAL RESOURCES OF ANTARCTICA, GEOLOGICAL SURVEY CIRCULAR 909, at 3, 18–20 (John C. Behrendt ed., U.S. Dep't of the Interior 1984) (summarizing research from 1970s and 1980s regarding possible locations of petroleum deposits near Antarctica); *see also id.* at 22 ("A number of countries are actively carrying out multichannel seismic reflection surveys of the Antarctic continental margin, . . . which are obviously focused on petroleum resource studies.").

Worries over territory and resources thus could pressure the Antarctic Treaty System from within and without.[352] There is, however, one small favorable factor: Pine Island Glacier and Thwaites Glacier both lie in the only unclaimed part of Antarctica. The potential complications and jealousies associated with developing a large project within a state's claimed area hence might be avoided.[353] The bad news, though, is that this region is unclaimed largely because it is particularly difficult to reach.[354] As a result, gaining access may require supporting infrastructure in other parts of the continent that are claimed. Moreover, the ice systems that radical adaptation would seek to modify may in turn affect areas claimed by Chile, Argentina, and the United Kingdom.[355] Enthusiastic buy-in from these countries, and, indeed, from as many other countries as possible, may be necessary; the broader the support for research, the less that activities can be attributed to a hostile bloc. Other states meanwhile may need assurances that involvement of claimant states does not reaffirm those states' territorial claims or establish new ones. Negotiations on radical adaptation may have to develop delicate balancing language that allows states "to agree to disagree over sovereignty," much as Article IV already does.[356]

If such support does not materialize from states with implicated claims, a more assertive posture could be taken. There are very few territorial claims recognized by non-claimant parties. Even the United States and Russia do not formally recognize such claims, despite their own well-developed interests in the continent.[357] Recognition of claims is even rarer among states not party to the Antarctic Treaty.[358] The territorial claims may moreover be of dubious legal value, even supposing Article IV were not in force. They are a remnant of a twentieth-century land grab that is sharply at odds with how the international community now understands and governs itself.[359] With the area having been collectively governed for more than half a century with traditional sovereign

352. *See* Subpart I.B, *supra*.

353. *Compare* Subpart I.A fig.1, *supra*, *with* Moore et al., *supra* note 271, at 305 (figure detailing glacier locations).

354. Headland, *supra* note 43, at 171–72 ("Even during summer the [area's] 'Phantom Coast' is usually beset by persistent pack-ice extending hundreds of kilometres from its shores making them some of the most inaccessible of Antarctica. In this roughly 70 sector only one coastal station . . . has been established . . .[and] only [one] winter station in its interior," neither of which is still in operation. "Summer stations are also very sparse and of brief duration in this sector.").

355. *See Reform the Antarctic Treaty*, *supra* note 45, at 161 (noting overlapping territorial claims); Vigni & Francioni, *supra* note 64, at 241; *see also* Hodgson-Johnston & Jabour, *supra* note 84 (mapping claims and points of conflict).

356. *See The United States and Antarctica in the 21st Century Hearing Before the H. Comm. on Sci.*, 105th Cong. 16–17 (1997) (Memorandum from William J. Burns, Exec. Sec'y, U.S. Dep't of State, to Andrew D. Sens, Exec. Sec'y, Nat'l Sec. Council (March 9, 1996)).

357. *See id.* at 16–17; *but see id.* at 17 ("At the same time, the United States has a solid basis of claim in Antarctica, resulting from its activities there prior to 1959.").

358. Malone, *supra* note 118, at 80–81.

359. *See, e.g.*, Triggs, *supra* note 34, at 217–18 (reporting popularity of rival legal conceptions of Antarctica as the common heritage of mankind).

claims held in abeyance,[360] it is questionable that these claims would be respected as they might have been in 1955.[361]

This is not to say that claimant states are prepared to abandon their claims.[362] It does suggest, though, that claimants may seek a face-saving way to preserve their nominal interests while avoiding a conflict that would bring those very interests into question. The geographic location of the crucial glaciers being outside any territorial claim is helpful in this regard. Assurances of continued adherence to the provisions of Article IV and the Madrid Protocol could also help. Another simple and likely necessary step would be to educate interested and implicated parties about the nature of ice-sheet stabilization and the scope of an initial research program. Opening up the process of research design to states, expert groups, environmentalists, and other stakeholders may help build trust around the program.[363]

The second structural problem is veto power. While the ATCM does not require universal approval to adopt a measure, a single objection can scuttle a proposal.[364] Unanimity requirements have sunk efforts to enact new environmental rules under the Madrid Protocol that presented issues far less complex and disruptive than the prospect of radical adaptation.[365] Similar veto provisions in the CCAMLR's Commission have thwarted attempts to designate new marine protected areas.[366]

Yet there is reason to believe that widespread participation in research is possible, even probable, at least over the long term. Support for this view comes partly from the factors discussed above. States' interests in protecting their low-lying coastal regions might make them willing to explore even controversial measures to avoid ice-sheet destabilization. And as the large Antarctica programming investments made by the United States, China, Australia, and others suggest, states' geopolitical ambitions and anxieties may dispose them favorably toward even high-cost Antarctic interventions. The expense, scale, and difficulty may be a feature of Antarctic programs, not a bug.[367] To the extent such states' early initiatives make radical adaptation a prominent focus of activity in the Treaty Area,[368] it could generate a herding effect, with more states supporting the project to avoid being left out. Supporting ice-sheet stabilization

360. *See* Hemmings, *supra* note 68, at 37 (describing regime as "de facto condominium").

361. *See* Scott, *supra* note 42, at 38.

362. Hemmings, *supra* note 59, at 516.

363. *See generally* SHUCHI TALATI & PETER C. FRUMHOFF, UNION OF CONCERNED SCIENTISTS, ISSUE BRIEF: STRENGTHENING PUBLIC INPUT ON SOLAR GEOENGINEERING RESEARCH (2020), https://www.ucsusa.org/sites/default/files/2020-06/Solar%20Geo_WEB_New.pdf (analyzing the relationship between public engagement and good governance on geoengineering research).

364. *See* Subpart I.B, *supra*.

365. *See* Rupert Summerson & Tina Tin, *Twenty Years of Protection of Wilderness Values in Antarctica*, 8 POLAR J. 265, 282–83 (2018).

366. *See, e.g.*, Brooks, *supra* note 194.

367. *See* discussion at Part I, *supra*.

368. McGee, *supra* note 29, at 67–70.

projects would allow states to take part in shaping new strategic priorities of Antarctic governance.[369]

C. Rules

States wishing to investigate ice-sheet stabilization need not wait for consensus to form to begin research activities. Many related research activities—observation, surveying, modeling, even pilot ice-drilling—are legal under the Antarctic Treaty System and can be adequately regulated under existing law. This Subpart outlines what a radical adaptation research program might look like and how it could be brought into compliance with the Madrid Protocol and relevant domestic laws.[370]

The first step could be forming a multinational team to oversee the research program. Ideally, this would take place under the auspices of an expert institution already integrated into the Antarctic Treaty System, such as SCAR or the Committee on Environmental Protection.[371] The latter has previously developed climate change research agendas[372] and has both institutional expertise and a formal mandate to advise on areas of scientific research needed.[373] SCAR has also marshalled international scientific teams to produce reports synthesizing climate knowledge about Antarctica.[374] Even more on point, SCAR has recently established a subsidiary research group to study Antarctica's contribution to global sea-level rise.[375] Since radical adaptation research would rely on and extend this same body of research, this group would be well positioned to provide either a good home or a model for research on ice-sheet stabilization.

369. *See, e.g.*, YOUNG, *supra* note 87, at 1–6 (Australian foreign policy analysis embodying this mindset); Klaus Dodds & Cassandra Brooks, *Antarctic Geopolitics and the Ross Sea Marine Protected Area*, E-INTERNATIONAL RELS. (Feb. 20, 2018), https://www.e-ir.info/2018/02/20/antarctic-geopolitics-and-the-ross-sea-marine-protected-area/.

370. *See, e.g.*, Antarctic Conservation Act of 1978, 16 U.S.C. §§ 2401–2413 (internalizing Madrid Protocol requirements via U.S. law). U.S. law is used below as an illustrative example and to help ground analysis.

371. *See* Subpart I. C, *supra*.

372. *See generally* CLIMATE CHANGE RESPONSE WORK PROGRAMME, *supra* note 181.

373. Secretariat of the Antarctic Treaty, Committee for Environmental Protection, *25 Years of the Protocol on Environmental Protection to the Antarctic Treaty* 13 (2016) (reporting the Committee's interpretation of its responsibilities under article 12 of the Madrid Protocol).

374. *See, e.g.*, SCI. COMM. ON ANTARCTIC RSCH., THE INT'L COUNCIL FOR SCI., ANTARCTIC CLIMATE CHANGE AND THE ENVIRONMENT i–ii, ix–xi, xiii–xxvii (John Turner et al. eds., 2009); *see also* Colin P. Summerhayes, *International Collaboration in Antarctica The International Polar Years, the International Geophysical Year, and the Scientific Committee on Antarctic Research*, 44 POLAR REC. 321, 327–30 (2008) (describing SCAR's functions and numerous program subgroups and giving examples of research consortium it has helped coordinate).

375. *See* SCI. COMM. ON ANTARCTIC RSCH., INSTANT FINAL SCIENCE AND IMPLEMENTATION PLAN 1–2 (2020), https://www.scar.org/library/science-4/research-programmes/instant/5567-instant-sip-14jun/ (organizing multidisciplinary research activities to quantify past and future sea-level rise caused by Antarctica).

If standing bodies within the Treaty System are resistant to organizing research on the topic,[376] there are other options. The simplest route would be for a state to establish its own national research initiative, with provisions for researchers and organizations from other countries to participate.[377] Alternatively, a group of Contracting Parties could develop a collaborative research initiative outside Treaty System bodies.[378] These states could negotiate among themselves an agreement on objectives, responsibilities, and research plans, then undergo the environmental review procedures of the Madrid Protocol.[379] Contracting Parties could then assess the need to construct research stations close to the threatened glaciers to facilitate in-depth study.[380]

The research agenda to inform radical adaptation and to advance understanding of marine ice-sheet instability would be closely aligned for at least several years.[381] During this period, the most significant divergence between the two research agendas would be in modeling. Radical adaptation research would probably include continued modeling of the relationship between diverted warm-water ocean currents and ice melt; the effect of altered subglacial water on ice flows; and, if the program is considering regional solar radiation modification, modeling the effect of such solar geoengineering deployments on surface melting and hydrofracturing.[382] This modeling would not, however, present the environmental impacts and risks associated with field facilities.[383] And because this modeling would be conducted predominantly or entirely in laboratories outside the Treaty Area, it would not implicate the interests protected by the Madrid Protocol or associated constraints.[384] Other early research activities, such as *in situ* observations of the Amundsen Sea and the West Antarctic Ice Sheet, would not carry significant physical impacts, nor would they differ significantly from current research activities already permitted.[385] Moreover, the

376. *Cf.* Moon et al., *supra* note 274, at 436 (implying opposition within Antarctic scientific research communities to ice-sheet stabilization).

377. *See, e.g.*, INT'L POLAR FOUND., ANNUAL REPORT 2019, at 8, 10–14 (2020) (Belgian-led and funded Antarctic research organization reporting collaboration with international partners).

378. *Cf.* Madrid Protocol, *supra* note 32, art. 6, para. 1 (calling for cooperation on scientific research activities between the parties); *cf. also*, *e.g.*, Hemmings, *supra* note 96, at 7, 9–10 (reporting a joint research station operated by Italy and France, another operated by Australia and Romania, and an emerging pattern of research stations being built close to one another in clusters by different countries).

379. *See* FINAL REPORT OF THE THIRTY-NINTH ANTARCTIC CONSULTATIVE MEETING, *supra* note 334, at 317–354.

380. *See* Moore et al., *supra* note 271, at 305 (proposing same).

381. *See* discussion at Subpart III.A, *supra*.

382. *See generally* Lockley et al., *supra* note 20.

383. *Cf.* Corbett, *supra* note 340, at 255–58 (analyzing outdoor solar geoengineering experiments with de minimus physical impacts under NEPA).

384. *See* Madrid Protocol, *supra* note 32, annex I, art. 2, para. 1 (excusing activities clearly without "minor and transitory impacts" from environmental assessment procedures); *see also* FINAL REPORT OF THE THIRTY-NINTH ANTARCTIC TREATY CONSULTATIVE MEETING, *supra* note 334, at 321–22 (clarifying the focus of environmental assessment is on activities in Antarctica).

385. *See, e.g.*, AMES RSCH. CTR., NAT'L AERONAUTICS & SPACE ADMIN., ENVIRONMENTAL DOCUMENT AND FINDING OF NO SIGNIFICANT AND NOT MORE THAN MINOR OR TRANSITORY

Antarctic Treaty System encourages freedom of scientific inquiry. It thus tends to protect Parties' ability to pursue research even in the face of others' objections based on symbolism, linkage with policy controversies, or other concerns that are not directly related to environmental risk.[386]

The Madrid Protocol does require comprehensive environmental evaluation for activities that risk more than "minor or transitory" physical impacts to the environment.[387] A proposal undergoing that in-depth review must conduct a thorough environmental assessment in advance of the activity and propose mitigation and remediation commitments to reduce physical impacts as necessary.[388] The proponent state must then submit the draft assessment to the Committee on Environmental Protection for review, which delivers a recommendation to the ATCM.[389] The proponent must also circulate the draft to other parties and hold open a ninety-day comment period.[390] The ATCM then considers the plan and may present recommendations to the project proponent.[391] Finally, the proponent state must produce a final assessment, including responses to comments by the Committee, the ATCM, and individual parties.[392] After this environmental review process is completed, however, the authority to decide whether to proceed with the activity lies with the project

ENVIRONMENTAL IMPACT: AIRCRAFT OVER-FLIGHTS OF THE ANTARCTIC SEA ICE OF THE WEDDELL, BELLINGSHAUSEN AND AMUNDSEN SEAS AND LAND-ICE OF THE ANTARCTIC PENINSULA AND THWAITES, PINE ISLAND AND ABBOT GLACIERS 2–3 (2012) (U.S. Initial Environmental Evaluation [IEE] on file with Antarctic Secretariat describing low-altitude sea and ice flights studying Pine Island and Thwaites Glaciers, among other activities); *see also* SECRETARIAT OF THE ANTARCTIC TREATY: EIA DATABASE, GERMANY, IEE, A SURVEY ON THE EVOLUTION OF GLACIAL-MARINE SEDIMENTATION IN AMUNDSEN SEA AND SOUTH PACIFIC IN ORDER TO QUANTIFY GLACIAL-INTERGLACIAL CYCLES (2005–06) (database entry accessed August 2021) [hereinafter 2005 SEDIMENT IEE]; *see also* K. Gohl et al., *Expedition 379 Summary*, 379 PROC. INT'L OCEAN DISCOVERY PROGRAM 1–2 (2021) (findings from sediment drilling in Amundsen Sea regarding ice-sheet instability).

386. Reynolds, *supra* note 30, at 463–64.

387. *See* Madrid Protocol, *supra* note 32, annex I, arts. 1–3; *see also* 40 C.F.R. § 8.4(b) (2021) (environmental review rules for Antarctic activities by nongovernmental under U.S. authority, listing factors informing assessment of physical impacts).

388. Madrid Protocol, *supra* note 32, annex I, art. 3, para. 2; FINAL REPORT OF THE THIRTY-NINTH ANTARCTIC TREATY CONSULTATIVE MEETING, *supra* note 334, at 333–34.

389. Madrid Protocol, *supra* note 32, annex I, art. 3, para. 4; FINAL REPORT OF THE THIRTY-NINTH ANTARCTIC TREATY CONSULTATIVE MEETING, *supra* note 334, at 320 fig.1 (illustrating drafting and comment process).

390. FINAL REPORT OF THE THIRTY-NINTH ANTARCTIC TREATY CONSULTATIVE MEETING, *supra* note 334, at 320 fig 1, 342–43.

391. Madrid Protocol, *supra* note 32, annex I, art. 3, paras. 3–5.

392. *Id.* annex I, art. 3, para. 6.

proponent, not the ATCM or any other Treaty body.[393] In short, the project proponent and authorizing authority are one and the same.[394]

Thus far, most activities that have prompted comprehensive environmental evaluation have been of two types: proposals to build permanent structures in the Treaty Area, such as wharfs, runways, or research stations;[395] and deep ice drilling.[396] This suggests that radical adaptation research would be most likely to merit heightened review if it involved building research stations or runways near the targeted glaciers, or proposed conducting pilot ice-drilling experiments.[397] By the same token, the similarity in impacts between ice-drilling experiments already authorized and implemented, and those likely to be required for radical adaptation research, provides a clear precedent for the legality of the latter.[398] Although, as we discuss below, the Madrid Protocol would very likely prohibit construction without an amendment adopted and in force, environmental assessment of research is likely to be, and arguably should be, separate from consideration of potential future intervention projects. The progression from research to potential implementation would require multiple additional decisions, a vast increase in investment and deployment of technology and equipment, and distinct legal and political authorizations. None of these could happen quietly, thoughtlessly, or without adequate notice to all relevant parties.[399] In addition, early research may well show the entire ice stabilization

393. *See* 40 C.F.R. § 8.8(c) (2021) (stating proponents of nongovernmental Antarctic activities under U.S. jurisdiction are ultimately authorized to decide, based on the final comprehensive environmental evaluation, whether to proceed with the activity); *see also id.* § 8.5(a) (clarifying such nongovernmental activities are still subject to approval by EPA, in consultation with the National Science Foundation); 45 C.F.R. §§ 641.12, 641.18 (2020) (authorizing National Science Foundation officials to decide whether and how to proceed with proposed Antarctic research activities of the U.S. government, based on the final comprehensive environmental evaluation); *see also* Madrid Protocol, *supra* note 32, annex I, art. 3, paras. 3–4 (drafted so as to leave the identity of the deciding authority ambiguous); *id.* annex I, art. 4 (same).

394. *See*, *e.g.,* U.S. NAT'L SCI. FOUND., WHILLANS ICE STREAM SUBGLACIAL ACCESS RESEARCH DRILLING PROJECTS *1–*2 [hereinafter 2012 WHILLANS IEE].

395. *See generally, e.g.*, REPUBLIC OF TURKEY, DRAFT COMPREHENSIVE ENVIRONMENTAL EVALUATION (CEE) FOR THE CONSTRUCTION AND OPERATION OF THE TURKISH ANTARCTIC RESEARCH STATION (TARS) AT HORSESHOE ISLAND, ANTARCTICA (2021); ENV'T OFF., BRITISH ANTARCTIC SURVEY, ROTHERA WHARF RECONSTRUCTION & COASTAL STABILISATION: FINAL COMPREHENSIVE ENVIRONMENTAL EVALUATION (2018); ITALIAN NAT'L PROGRAM FOR RSCH. IN ANTARCTICA, FINAL COMPREHENSIVE ENVIRONMENTAL EVALUATION: PROPOSED CONSTRUCTION AND OPERATION OF A GRAVEL RUNWAY IN THE AREA OF MARIO ZUCCHELI STATION, TERRA NOVA BAY, VICTORIA LAND, ANTARCTICA (2017).

396. *See generally* U.S. ANTARCTIC PROGRAM, NAT'L SCI. FOUND., PROJECT ICECUBE COMPREHENSIVE ENVIRONMENTAL EVALUATION (2004) [hereinafter 2004 ICECUBE CEE]; 2010 LAKE VOSTOK CEE, *supra* note 287.

397. *But see* 2005 SEDIMENT IEE (proposal to extract sediment cores in the Amundsen Sea to study past retreat of the West Antarctic Ice Sheet prompted lower-level environmental review).

398. *Compare* 2004 ICECUBE CEE, *supra* note 396, at 3-3, 3-5 fig.3-2, 3-11 (describing drilling activities), *with* Lockley et al., *supra* note 20, at 405–07 (describing ice-sheet stabilizing techniques that would require deep ice drilling).

399. *See* FINAL REPORT OF THE THIRTY-NINTH ANTARCTIC TREATY CONSULTATIVE MEETING, *supra* note 334, at 322 (limiting scope of environmental analysis to the proposed activity itself and "previous, current or reasonably foreseeable activities").

approach to be technically infeasible, economically impracticable, or otherwise inadvisable.[400]

Although decision-making authority lies with the proponent state, the mandated comment process creates opportunities for opposition and procedural obstacles to proposed field research.[401] In view of this risk, one alternative for research proponents would be to avoid raising the issue at all. Interested states could simply fund conventional cryosphere and ocean science research relating to ice sheets, then separately use the data from those activities to improve modeling for radical adaptation.[402] Given the information-sharing requirements of the Antarctic Treaty System, teams modeling radical adaptation interventions may not require much formal coordination with groups conducting field observations.[403]

A more confrontational tactic would be to disregard or downplay a skeptical assessment by the Committee on Environmental Protection or the ATCM. A Russian project took this approach for an experiment that drilled into subglacial Lake Vostok, which proceeded despite more than a decade of protests from members of the scientific community.[404] It was able to do so because research activities can proceed as set forth in the final comprehensive environmental evaluation, despite continuing objections.[405] It would be an unfortunate way to launch research governance for radical adaptation. Open conflict at the start of a research program would tend to harm prospects for future cooperation, whereas engaging seriously with comments may improve research design.[406] Still,

400. *See, e.g.*, Gürses et al., *supra* note 275**Error! Bookmark not defined.**, at 2321 (modeling indicating proposed ice-sheet stabilization intervention would worsen ice-sheet retreat in other parts of western Antarctica).

401. *See, e.g.*, 2010 LAKE VOSTOK CEE, *supra* note 287, at 72–74; *see also, e.g.*, Brendan Gogarty et al., Correspondence, *Glacier Engineering Must Mind the Law*, 560 NATURE 167, 167 (2018)

402. *See* Wolovick & Moore, *supra* note 239, at 2957–60 (drawing on conventional climate science and glaciology to model radical adaptation proposals).

403. *See* Antarctic Treaty, *supra* note 49, art. III, para. 1(c) ("[T]o the greatest extent feasible and practicable . . . scientific observations and results from Antarctica shall be exchanged and made freely available."); *see also* SCI. COMM. ON ANTARCTIC RSCH., THE INT'L COUNCIL FOR SCI., ISSN 1755-9030, SCAR DATA POLICY 1–4 (2011) (summarizing ATS policy and infrastructure for sharing data produced by SCAR-sponsored scientific research).

404. *See* 2010 LAKE VOSTOK CEE, *supra* note 287, at 72–74 (minimizing environmental concerns raised during comment period by the Committee on Environmental Protection and others); *see also* Rebecca Boyle, *With 30 Meters Left to Drill, Scientists Leave Subterranean Lake Vostok for the Winter, Amid Controversy*, POPULAR SCI. (Feb. 10, 2011, 3:46 AM), https://www.popsci.com/science/article/2011-02/winter-ices-lake-vostok-drilling-effort-sending-scientists-packing-another-year/.

405. Jim Giles, *Russian Bid to Drill Antarctic Lake Gets Chilly Response*, 430 NATURE 494, 494 (2004) ("There is no law to stop [the Russian researchers from] doing what they want." (quoting Antarctic scientist Jean-Robert Petit)).

406. *Compare* Irina Alekhina et al., *Chemical Characteristics of the Ice Cores Obtained After the First Unsealing of Subglacial Lake Vostok*, 461 GEOLOGICAL SOC'Y, LONDON, SPECIAL PUBS. 187, 187–88, 193–195 (arguing ice core extracted by Russian researchers at Lake Vostok was significantly contaminated by drill fluid). In comparison, a U.S. research mission studying subglacial Lake Whillans was able to produce good data. Brent C. Christner et al., Letter, *A Microbial Ecosystem Beneath the West Antarctic Ice Sheet*, 512 NATURE 310, 310, 312–13 (2014).

rapidly accelerating climate impacts may make this tactic attractive to proponents.[407] Skeptics of radical adaptation should therefore consider whether forcing a confrontation over proposed research would be an effective strategy to protect Antarctica's environment.[408] It may be more prudent to let controversial research proceed and push for strong environmental compliance and international participation, thereby limiting strain on Antarctic governance.[409] And of course, research may well show that ice-sheet stabilization is infeasible.

Opponents could also take comfort that the text of the Madrid Protocol almost certainly prohibits implementing ice-sheet stabilization interventions. The Protocol generally prohibits taking[410] or harmful interference[411] of local wildlife, except by permit.[412] Harmful interference is defined to include "any activity that results in the significant adverse modification of habitats of any species or population of native mammal, bird, plant or invertebrate."[413] This definition would very likely include radical adaptation proposals, given the size of their construction footprints and the vast scale of the ice sheets they seek to modify.[414] Annex II provides that national authorities may grant permits where takings or harmful interference with wildlife are an "unavoidable consequence[] of *scientific* activities . . . or of the construction and operation of *scientific* support facilities."[415] But while this provision could allow permitting of radical adaptation interventions through research and demonstration phases, which could arguably be deemed "scientific activit[y],"[416] project development would clearly cross the line from scientific research to application and exceed the reach

407. *Cf.*, *e.g.*, 2012 WHILLANS IEE at *1–*2 (NSF officials authorizing U.S. experiment to proceed based on NSF's own analysis).

408. At the very least, it might have low likelihood of success. *See* ANTARCTICA & S. OCEAN COAL., XXX ATCM INFORMATION PAPER 84, at 3–4 (2007) (analyzing all CEEs then on file with the Antarctic Secretariat to conclude that "not one of the 26 CEE processes appears to have led to substantial modification of the activity as first elaborated by the proponent, nor to a single decision not to proceed with the activity, despite this being a mandatory consideration").

409. *See* Antarctic Treaty, *supra* note 49, art. VII (creating right for Contracting Parties to inspect each others' facilities, ships, and aircraft in Antarctica); Madrid Protocol, *supra* note 32, art. 14 (same); *cf.* 2010 LAKE VOSTOK CEE, *supra* note 287, at 72–74 (disregarding mitigation measures proposed).

410. *See* Madrid Protocol, *supra* note 32, annex II, art. 1(g) (defining "take" to include killing, injuring, capture, handling, or otherwise harming "a native mammal or bird," as well as significant damage or harm to their sources of food).

411. *See id.* annex II, art. 1(h) (including disruptive, disturbing, or harmfully intrusive use of aircraft, vehicles, vessels, or by other means).

412. *Id.* annex II, art. 3, para. 1.

413. *Id.* annex II, art. 1(h)(vi).

414. *See* Moore et al., *supra* note 271, at 305 (admitting some interventions risk accelerating loss of the glacier).

415. Madrid Protocol, *supra* note 32, annex II, art. 3, para. 2(d) (emphasis added). A further condition for permitting is that no more animals are taken or disturbed than "strictly necessary . . . and in no case more are killed . . . than can . . . normally be replaced by naturally reproduction in the following season." *Id.* annex II, art. 3, paras. 3(a)–(b).

416. Madrid Protocol, *supra* note 32, annex II, art. 3, para. 2(d); *see also* Antarctic Treaty, *supra* note 49, art. IX, para. 1(b) (recognizing "facilitation of scientific research" as an objective of the treaty); *Science*, OXFORD ENGLISH DICTIONARY (3d ed. 2021).

of this permitting exception.[417] There is thus no clear path to permitting construction of ice-sheet stabilization interventions under the Madrid Protocol.

The Protocol separately prohibits "[a]ny activity relating to mineral resources," once again excepting those that qualify as scientific research.[418] While initial exploration of ice-sheet stabilization would qualify as research, project development and construction would not. There are instances where the difference between research and application is unclear, but building a giant underwater berm is not one of them. This language would therefore seem to prohibit dredging the seabed to construct artificial pinpoints for glaciers, assuming seabed sediment is a "mineral resource."[419] Alternatively, importing millions of tons of earthen material from outside the Treaty Area would risk introduction of non-sterile soil or non-native microorganisms, violating requirements of Annex II.[420]

Another substantial legal obstacle to radical adaptation arises from the explicit purpose and values of the Madrid Protocol.[421] The Protocol's language recognizes Antarctica "as a natural reserve," with "[t]he Parties committ[ing] themselves to the comprehensive protection" of Antarctica, its environment and its ecosystems.[422] In doing so, the Parties recognize "the intrinsic value of Antarctica, including its wilderness and aesthetic values."[423] Activities in the Treaty Area must therefore "be planned and conducted so as to limit adverse impacts" on Antarctica's environment and ecosystems, working "to avoid . . . significant changes in the atmospheric, terrestrial . . . , glacial or marine

417. Though construction would rely on science and advance scientific understanding of ice sheet stabilization, it should not be considered a "scientific activity" for purposes of the Protocol. If that were true, any number of mineral exploration and extraction projects could also be classified as a "scientific activity" because they draw on geology, oceanography, and other sciences. Such an overbroad reading of the exception for scientific activities would conflict with the Protocol's explicit prohibition on mineral activities and undermine the Antarctic regime of environmental protection more broadly. For further discussion of disputes over the proper use of exceptions for scientific activities under international law, *see* Marc Mangel, *Whales, Science, and Scientific Whaling in the International Court of Justice*, 51 PRO. NAT'L ACAD. SCI. 14,523, 14,524-26 (2016) (analyzing Whaling in the Antarctic (Australia v. Japan: New Zealand Intervening), Judgment, 2014 I.C.J. 226 (March 31)).

418. Madrid Protocol, *supra* note 32, art. 7.

419. *Id.* art. 4. The prohibition may also present a problem for other proposals that involve drilling into the subglacial bedrock. *Cf.* Lockley et al., *supra* note 20, at 404–05, 412 (discussing anchoring techniques).

420. *See* Madrid Protocol, *supra* note 32, annex II, art. 4, para. 9 ("The deliberate introduction of non-sterile soil into the Antarctic Treaty area is prohibited."); *see also id.* annex II, art. 4, para. 7 ("requir[ing] . . . precautions are taken to prevent the accidental introduction of [non-native] micro-organisms").

421. *See* Vienna Convention on the Law of Treaties art. 31, May 23, 1969, 1155 U.N.T.S. 331 (1980) (instructing that interpretation of treaty language shall be informed by context of agreement, including preamble, annexes, subsequent agreements, and subsequent practice).

422. Madrid Protocol, *supra* note 32, art. 2; *see also* Antarctic Treaty, *supra* note 49, art. IX, para. 1(f) (recognizing "preservation and conservation of living resources in Antarctica" as a principle and objective of Antarctic Treaty System).

423. Madrid Protocol, *supra* note 32, art. 3; *see also* CCAMLR, *supra* note 131, pmbl. ("recognising the importance of safeguarding the environment and protecting the integrity of the ecosystem of the seas surrounding Antarctica").

environments."[424] Projects must also seek to avoid "degradation of, or substantial risk" to significant areas.[425]

These provisions are sometimes vague: *natural reserve*, *comprehensive protection*, *significant impacts*. But together they convey a strong presumption against large or intensive construction activities within the Treaty Area.[426] Construction of radical adaptation projects—say a large field of water pumps across the top of a glacier—could cause significant harm to local ecosystems,[427] introduce large amounts of pollution into the Treaty Area,[428] and create risks of even greater future disruption to the glacier.[429] Building the housing and supply chains needed to support a project of such scale would risk additional serious physical impacts.[430] Radical adaptation proposals would build public works sufficient to slow the movement of ice formations extending over half a continent; the physical impacts and environmental risks would be of an entirely different order than those of a research station, a runway, or drilling into a subglacial lake. Allowing any such megaproject to be built in the Treaty Area would thus very likely require amending the Madrid Protocol.

These clear legal obstacles to construction represent strong benefits for effective governance of radical adaptation. By preventing the most environmentally damaging activities from creeping into reality without ATS authorization, these obstacles would assure stakeholders that development will not race ahead of scientific justification or legitimate oversight. The Madrid Protocol's rules are binding on Parties and developed through decades of practice, making them sturdier than mere voluntary promises of scientists and institutions. As discussed above, the United States has incorporated the requirements of the Madrid Protocol via domestic law, providing controls that bind itself as well as U.S. nationals.[431] This approach, adopted by the United States and other ATS members, has created guardrails for Antarctic project development and related environmental assessments. U.S. domestic statutes may

424. Madrid Protocol, *supra* note 32, art. 3, para. 2.

425. Madrid Protocol, *supra* note 32, art. 3, para. (2)(b)(vi); *see also* CCAMLR, *supra* note 131, art. II, para. 3(c) (identifying principles of conservation in Antarctica include "prevention of changes or minimisation of the risk of changes in the marine ecosystem which are not potentially reversible over two or three decades").

426. Past practice of Contracting Parties to minimize environmental impacts provide further support for this interpretation. *See* FINAL REPORT OF THE THIRTY-NINTH ANTARCTIC TREATY CONSULTATIVE MEETING, *supra* note 334, at 323–25, 333–34; *see also, e.g.*, ICECUBE CEE, *supra* note 396.

427. *See* Moore et al., *supra* note 271, at 305 (flagging such risks).

428. *See, e.g.*, Lockley et al., *supra* note 20, at 405–07 (describing coolants and substantial wastewater associated with some interventions).

429. *see* Moore et al., *supra* note 271, at 305; *see also* Madrid Protocol, *supra* note 32, art. 3, para. 2(b)(iii) ("[A]ctivities in the Antarctic Treaty area shall be planned and conducted so as to avoid significant changes in the . . . glacial . . . environments.").

430. *See, e.g.*, U.S. ANTARCTIC PROGRAM, NAT'L SCI. FOUND., FINAL COMPREHENSIVE ENVIRONMENTAL EVALUATION FOR CONTINUATION AND MODERNIZATION OF MCMURDO STATION AREA ACTIVITIES 5-16 to 5-25 (2019) (detailing physical impacts).

431. *See* Antarctic Protection Act of 1990, 16 U.S.C. §§ 2461–2466; Antarctic Conservation Act of 1978, 16 U.S.C. §§ 2401–2413.

also provide an additional means of enforcement, by allowing stakeholders with standing to use the U.S. federal court system to enforce Protocol obligations against federal agencies.[432]

Given the potential progression of climate change, there may come a need to consider amending the Antarctic Treaty System to facilitate radical adaptation. Such consideration would require, as preconditions, research showing the possibility of some proposed interventions being practicable, and diplomatic momentum favoring such intervention—neither of which is assured. If such consideration does occur, a crucial provision to focus on will be the scope of Antarctica's "dependent and associated ecosystems" protected under the Madrid Protocol.[433] Clarifying that Parties could consider Antarctica's global earth-system impacts, including places far from the Treaty Area, would provide a clearer path toward legality. Amendment could also support risk-balancing analysis, which is not included in present environmental review practices. Even within the Treaty area, risk-balancing analysis would allow consideration of tradeoffs between an intervention's direct environmental impact and the benefits of stabilizing ice sheets. More broadly, such a risk balancing approach would be required to coherently integrate consideration of environmental impacts in Antarctica, with the aggregate benefits of slowing sea-level rise, both for coastal ecosystems worldwide and for human welfare.[434]

Other considerations specific to radical adaptation construction, such as cost sharing, monitoring, liability, and project-specific environmental requirements, could be developed along similar lines to the approach CRAMRA took for oil and gas activities.[435] Additional rulemaking under CCAMLR may also be undertaken to plan for marine-related impacts beyond the ice shelves. Depending on future political conditions, it may also be possible to enact more sweeping reforms to the Antarctic Treaty System via amendment, such as lowering voting thresholds to pass measures and authorizing the ATCM to enact binding rules applying to the Treaty Area. Alternatively, the Parties could designate parts of western Antarctica a special governance area, perhaps with more open membership and majority-rule voting requirements. Doing so could allow for more vigorous and democratic governance, commensurate with the region's rising importance in world affairs.

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432. *See* Env't Def. Fund v. Massey, 986 F.2d 528, 529, 532, 536–37 (D.C. Cir. 1993) (holding NEPA applied to U.S. agency's decision to incinerate trash at U.S. McMurdo Station in Antarctica and remanding to lower court to determine whether the agency's planning process complied with NEPA). Recent developments in doctrine regarding extraterritorial application of general federal statutes may limit such means of enforcement, however. *See generally* Nestlè USA, Inc. v. Doe, 141 S. Ct. 1931 (2021).

433. Madrid Protocol, supra note 32, arts. 2–3, 6, 8, 10.

434. *See* Antarctic Treaty, *supra* note 49, pmbl. (declaring Antarctica should be governed for progress and benefit of humanity as a whole); *see also* John C. Moore et al., *Targeted Geoengineering Local Interventions with Global Implications*, 12 GLOB. POL'Y 108, 114–15 (exploring these tradeoffs for proposed interventions under Antarctic Treaty System).

435. *See, e.g.*, CRAMRA, *supra* note 140, arts. 4, 8, 21, 26.

CONCLUSION

This Article has discussed several radical adaptation interventions for slowing ice-sheet retreat and, by extension, global sea-level rise. Under extreme climate change scenarios, states might seriously pursue these ideas, and research may indicate some of them are worth implementing. Today the Antarctic Treaty System appears incompatible with radical adaptation. But the system embeds a complex web of interests and relationships more mutable than it might first seem. Indeed, its history shows that Antarctic governance can evolve and transform with changing circumstances.

Early-stage research on radical adaptation would be relatively simple to plan and oversee using the tools of present Antarctic law. With time, the Antarctic Treaty System could adjust to support project development and even construction. Though some of the required governance changes would be difficult and uncertain—such as voting requirements or rulemaking authority—they would benefit the regime beyond the context of radical adaptation. Global warming has initiated changes in Antarctica's environment that are of profound consequence to the rest of the world. The scope and ambition of the continent's governance will need to grow to meet the associated challenges. Radical adaptation may prove to be the catalyst for improving the Antarctic Treaty System, providing a basis for greater cooperation in Antarctica and a model for climate politics everywhere else.