THE RED DAWN OF GEOENGINEERING: FIRST STEP TOWARD AN EFFECTIVE GOVERNANCE FOR STRATOSPHERIC INJECTIONS

EDWARD J. LARSON†

ABSTRACT

A landmark report by the National Academy of Sciences (NAS) issued in 2015 is the latest in a series of scientific studies to assess the feasibility of geoengineering with stratospheric aerosols to offset anthropogenic global warming and to conclude that they offer a possibly viable supplement or back-up alternative to reducing carbon dioxide emissions. The known past effect of major explosive volcanic eruptions temporarily moderating average worldwide temperatures provides evidence in support of this once taboo form of climate intervention. In the most extensive study to date, an elite NAS committee now suggests that such processes for adjusting global temperature, while still uncertain, merit further research and field testing. Every study stresses the need for transparent international governance of stratospheric injections, especially given that the benefits of such interventions are certain to be unevenly distributed and the risks are not fully known. After examining the roadblocks to such governance, this paper explores the statutory and common law frameworks that could provide some stop-gap approaches until the needed regulatory regime emerges.

INTRODUCTION

Many commentators view climate change as the issue of our era – the most critical challenge that we face as a nation or a species. Even climate skeptics are gradually being won over. Some of those scientific skeptics, however, and a growing number of scientists most concerned about the problem have begun to discuss the possibility of using

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† Hugh and Hazel Darling Chair in Law and University Professor of History, Pepperdine University; J.D., Harvard Law School; Ph.D. University of Wisconsin-Madison. The author would like to thank the Yale Law School and Whitney Humanities Center for inviting him to present this paper and also for receiving comments at a symposium honoring Dan Kevles. An earlier version of this article appeared as "The Common Law of Geoengineering: Building an Effective Governance of Stratospheric Injections," 2 INDONESIAN J. INT. & COMP. L. 329-68 (2015). This version is printed with the permission of the editors of that journal.

stratospheric injections to counter or mask some of the harmful effects of climate change should other measures failed to address the problem. In the first two substantive sections below, this article briefly introduces the concept of geoengineering by means of stratospheric aerosols and the science of global warming. These sections show that past experience with explosive volcanic eruptions suggest that injecting sulfate aerosols into the stratosphere could, at least in gross terms but not without side effects, reduce the effect of CO_2 emissions on global temperature. A third substantive section examines the technology of geoengineering by stratospheric aerosols and the growing support for at least examining the prospects for employing it should efforts to curtail carbon emissions fail and catastrophic climate change occur. Even if successful in reducing overall global temperatures, injecting massive amounts of sulfate aerosols into the stratosphere will have adverse environmental side-effects, only some of which can be predicted in advance. There will be winners and losers from the process. This factor creates the imperative for some form of global governance for the procedure. The final substantive section of this article explores the lack of any current governance scheme for this form of geoengineering, the obstacles to adopting a governance scheme, and the possible use of the common law and existing statutes as stop-gap measures until appropriate mechanism are put in place.

I. NATURAL GEOENGINEERING

The great Indonesian volcano Krakatoa erupted at 10:02 A.M. local time on Monday, August 27, 1883, in an explosion heard thousands of miles away. From the Philippines in the north to Australia in the South and Sri Lanka in the West, it sounded as if a cannon were fired at sea. Similar accounts came from places around the Indian Ocean and the South China Sea.[1] An official on Rodriguez Island, nearly 3000 miles west of Krakatoa, noted that "reports were heard coming from the eastward, like the distant roars of heavy guns."[2] In Burma, the police dispatched a launch to look for a ship in distress. Imperial Dutch soldiers in western Sumatra feared their fort was under attack. The explosion was then, and remains today, the loudest (or at least most distantly heard) terrestrial noise – natural or human generated – in historical memory.[3]

While awesome, the sound was one of the explosion's less notable effects. The eruption of Krakatoa sent walls of water across the sea in every direction. These tsunamis crashed into the nearby shores at heights of up to

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[1] SIMON WINCHESTER, KRAKATAU: THE DAY THE WORLD EXPLODED 261–62 (2003).
[2] TOM SIMKIN & RICHARD S. FISKE, KRAKATAU 1883, THE VOLCANIC ERUPTION AND ITS EFFECTS 146 (1983).
[3] SIMKIN & FISKE, *supra* note 2, at 146; WINCHESTER, *supra* note 1, at 264.

135 feet, destroying 165 coastal villages and killing over 36,000 people.[4] The waves reached halfway around the globe, flooding low-lying regions in Sri Lanka and hitting the South African coast with four-foot-high breakers, before diminishing and rippling shores as far away as France and California.[5]

Although less destructive than the sea-waves, another effect of Krakatoa's eruption carries greater significance today. Krakatoa is the type of volcano formed at a geological subduction zone where a heavier oceanic tectonic plate collides with and sinks beneath a lighter continental tectonic plate. The massive, ongoing stress of one plate rubbing against another raises a mountainous ridge above the seam and builds pressure within. Seawater carried with and trapped in the descending rock and soil percolates upward into the lighter, overlaying rock, lowering its melting point and further decreasing its density. The combination of building pressure and reduced melting point causes the lower levels of the overlying rock to melt, which releases gas trapped in the rock. The resulting magma and gases collect in underground chambers that push up steep-sided volcanic cones. If the pressure building within the chamber overcomes the cone's structure, an explosive eruption occurs.[6] This type of steep-sided stratovolcano differs from the rounded shield volcanos that rise over geological hotspots or divergent boundaries between separating tectonic plates and erupt in non-explosive fluid lava flows.

Displacing more than six cubic miles of earth, Krakatoa's explosive eruption was one of the largest on record.[7] When it ended, only one-third of the formerly three-by-six mile island remained above sea level.[8] Lumps of pumice rained down onto the surrounding sea and, being lighter than seawater, floated in the ocean for months, drifting west with the currents as far as the African coast.[9] Visible ash from the eruption rose higher than the pumice and was carried with the winds, causing midday darkness in nearby regions. Over the ensuing days, the ash settled at sites up to 3775 miles away.[10] The force of the explosion was such, however, that much of the ejected matter was all-but vaporized into particles of a micron or less in diameter. These particles were shot over twenty-five miles into the atmosphere and had prolonged worldwide effects.[11] For future, would-be geoengineers, this was what mattered most.

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[4] SIMKIN & FISKE, *supra* note 2, at 15; WINCHESTER, *supra* note 1, at 140–50.
[5] WINCHESTER, *supra* note 1, at 276–78; SIMKIN & FISKE, *supra*, note 2, at 148.
[6] WINCHESTER, *supra* note 1, at 312–13.
[7] *Id.* at 308.
[8] SIMKIN & FISKE, *supra* note 2, at 15.
[9] *Id.* at 149–53.
[10] *Id.* at 37–39, 149.
[11] WINCHESTER, *supra* note 1, at 283; SIMKIN & FISKE, *supra* note 2, at 418.

Once lodged in the stratosphere, this volcanic cloud of sulfate aerosols, mineral dust, and gases remained aloft for up to three years, with the jet stream carrying it around the globe and dispersing it north and south.[12] Because gravity exerts little pull on such small particles in the stratosphere, they take months to descend even a few thousand feet, and the rains that wash them from the sky never reach that high.[13] Particularly in South Asia, Europe, and North America, the effect on sunlight was dramatic. Vivid sunsets, deep-red evening afterglows, blue and green colored moons, and whitish halos around the sun became commonplace and were widely noted for roughly three years.[14] In one poem, widely believed to have been inspired by this phenomenon, Alfred Lord Tennyson wrote of "many a blood-red eve."[15]

Krakatoa was the first major explosive volcanic eruption for which reliable before-and-after measurements exist for the intensity of solar radiation reaching the earth's surface.[16] These measurements were first studied two decades later, and the director of the Smithsonian Institution's Astrophysical Observatory, C.G. Abbot, and his assistant, F.E. Fowle, concluded that "very great departures from the usual intensity of solar radiation occurred from 1883 to 1887."[17] They attributed this to the reflective effect of Krakatoa's high altitude emissions and went on to write, "It seems to us in consideration of this, that there can be little question that the volcanic haze has very appreciably influenced the march of temperature in the United States." They estimated the impact at "perhaps as much as

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[12] SIMKIN & FISKE, *supra* note 2, at 154; WINCHESTER, *supra* note 1, at 286–87; Raymond S. Bradley, *The Explosive Volcanic Eruption Signal in Northern Hemisphere Temperature Records*, 12 CLIMATE CHANGE 221, 240 (1988) (finding that although fine ash may be an important added factor in the initial temperature depression caused by explosive eruptions, sulfate aerosols are more likely to cause the more prolonged effects); GILLEN D'ARCY WOOD, TAMBORA: THE ERUPTION THAT CHANGED THE WORLD 78 (2015) (listing components of the volcanic cloud).

[13] Particles one micron in diameter can take weeks to fall through one kilometer of stratosphere; particles one-half micron in diameter take months to do so. SIMKIN & FISKE, *supra* note 2, at 419.

[14] *Id.* at 154–59.

[15] WINCHESTER, *supra* note 1, at 284.

[16] *See* SIMKIN & FISKE, *supra* note 2, at 420. For a further discussion of the data limitations, see also Bradley, *supra* note 13, at 221–22.

[17] C.G. Abbot & F.E. Fowle, *Volcanoes and Climate*, 60:29 SMITHSONIAN MISCELLANEOUS COLLECTIONS, 15 (1913).

several degrees."[18] Later studies put the average worldwide drop in annual temperature from the Krakatoa eruption at over 0.5°C.[19]

Although similar scientific records do not exist for prior eruptions, the effect of this 1883 explosion on global temperatures was not unique. Less than seventy years earlier and 900 miles away, the 13,000-foot-high Mount Tambora erupted on the Indonesian island of Sumbawa with ten-times the force of Krakatoa and a proportionately greater impact.[20] Displacing twice as much matter as Krakatoa's 1883 eruption, the 1815 explosion of Tambora shot proportionately more sulfate aerosols into the stratosphere and cooled the earth dramatically.[21] Crops failed in much of Western Europe, eastern North America, and China, with poor harvests persisting for two additional years.[22] New England suffered its shortest growing season on record after experiencing snow in June and frosts in July and August.[23] From Virginia, former president Thomas Jefferson complained, "We have had the most extraordinary year of drought and cold ever known in the history of America."[24] Modern tree-ring studies indicate that 1816 was the coldest year in the Northern Hemisphere since 1601, and 1810–1820 was the coldest decade on record.[25] Across the impacted regions, people noted the persistently hazy sky and vivid sunsets.[26] A high-altitude sulfate cloud covered much of the earth, reflecting away sunlight and radiant heat.

At the time, however, observers did not attribute these far-off temperature changes and atmospheric phenomena to a volcano in

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[18] SIMKIN & FISKE, *supra* note 2, at 420–22.

[19] WINCHESTER, *supra* note 1, at 291. *See also* Bradley, *supra* note 12, at 229 (describing a statistically significant drop in average annual global temperature that occurred in 1884, after the 1883 eruption of Krakatau).

[20] Robert Evans, *Blast from the Past*, SMITHSONIAN MAGAZINE, July 2002, at 54; WINCHESTER, *supra* note 1, at 292.

[21] Evans, *supra* note 20, at 54; WINCHESTER, *supra* note 1, at 292. A smaller, but still significant, volcanic eruption in 1809 also apparently contributed to the overall effect. K. R. Briffa et al., *Influence of Volcanic Eruptions on North Hemisphere Summer Temperature Over the Past 600 Years*, 393 NATURE, 450, 452 (1998); WOOD, *supra* note 12, at 39.

[22] WOOD, *supra* note 12, at 61, 98, 203; Evans, supra note 21, at 54–56.

[23] WOOD, *supra* note 12, at 205.

[24] Letter from Thomas Jefferson to Albert Gallatin (Sept. 8, 1816), *in* 12 THE WORKS OF THOMAS JEFFERSON, 34 (Paul Leicester Ford ed., 1905).

[25] Briffa, *supra* note 21, at 452. *See also* WOOD, *supra* note 12, at 39, 205, 216.

[26] *E.g.*, WOOD, *supra* note 12, at 39–40, 107–08, 203. The yellow suns, overcast skies, and vivid sunsets in the paintings of British artist J. M. W. Turner probably reflect the influence of the Tambora eruption. WOOD, *supra* note 12, at 2–3; WINCHESTER, *supra* note 1, at 280.

Indonesia.[27] Mount Tambora had erupted on a remote island in an era when news traveled overseas by ship. Most people who did not see, hear, or feel its immediate effects probably never even knew that it happened.[28]

In contrast, Krakatoa erupted in the middle of a major international shipping channel at a time when telegraph wires girded the globe.[29] Its impact on atmospheric phenomena was both anticipated and widely noted. Based on their later study of contemporary accounts, Smithsonian Institution geologists Tom Simkin and Richard Fiske concluded:

> Of all of the geophysical phenomena related to Krakatau's 1883 eruption, those that affected the atmosphere received the most widespread attention. Surely at least three-quarters of the world's 1883 population of about 1,400 million must have been conscious of the gaudy sunrises and sunsets that decorated the sky in the months following the paroxysmal blasts. Many scholars chronicled their observations, scientific journals and even newspapers were filled with discussion, and fully two thirds of the Royal Society's 1888 report [on the eruption] was devoted to description and interpretation of the atmospheric effects.… There can be no doubt that the atmospheric effects of Krakatau's 1883 eruption helped to make it one of the most famous eruptions in history.[30]

Even though its visual atmospheric effects were widely recognized, Krakatoa's influence on global temperatures went unnoticed for years.[31]

Scientists only began recognizing and intensively studying the widespread impact of explosive eruptions on temperature during the twentieth century.[32] For example, they detected some global cooling from eruptions that occurred in 1963 and 1974 by using instruments developed during the Cold War to study nuclear fallout.[33] By the time the great

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[27] WOOD, *supra* note 12, at 3.
[28] Evans, *supra* note 20, at 54–55.
[29] WINCHESTER, *supra* note 1, at 194–95.
[30] SIMKIN & FISKE, *supra* note 2, at 395. In his book about the eruption's impact, Simon Winchester notes that the American painter Frederic Church traveled to good sites in western New York State for painting rich evening color in anticipation of the atmospheric effects caused by the explosion. WINCHESTER, *supra* note 1, at 280.
[31] WINCHESTER, *supra* note 1, at 290–91.
[32] While suffering an unusually cold summer in France following the eruption of an Icelandic volcano in 1783, the remarkably perceptive American natural philosopher Benjamin Franklin published the first scientific paper speculating a connection between volcanism and climate change, but no one seemed to take notice of it until the twentieth century. WOOD, *supra* note 12, at 1–4; SIMKIN & FISKE, *supra* note 2, at 419–20.
[33] SIMKIN & FISKE, *supra* note 2, at 422; WOOD, *supra* note 12, at 3.

Mexican volcano El Chichón exploded in 1982, American climatologist J. Murray Mitchell could write, "We know that volcanic veils like El Chichón's take something away from the warmth of the sun's rays and tend to cool the lower atmosphere."[34] He went on to note:

> A cooler atmosphere could well go on to have other weather effects too. It could slow the cycling of moisture between the oceans of the atmosphere, resulting for a time in slightly less rainfall over the world as a whole. It could also slow the global-scale atmospheric winds, thereby shifting the paths of weather systems and the distribution of weather, including rain or snow, associated with them.[35]

Even more dramatic than El Chichón, the 1991 eruption of Mount Pinatubo in the Philippines shot over a million tons of SO_2 into the stratosphere, roughly as much as Krakatoa, and caused the temperature on the Earth's surface to drop by an average of 0.5°C during the following year.[36]

Scientists sought to extend their research into the past by studying the effect of earlier eruptions on global temperature using historical weather data and climate-proxy records, such as those preserved in tree-rings and ice-cores.[37] They found a consistent pattern. Through ejecting sunlight-reflecting sulfate aerosols into the stratosphere, major eruptions can lower the average global temperature for up to three years, with the effect gradually decreasing as the airborne particles settle out of the atmosphere.[38] Researchers noted that explosive eruptions would have to recur at short intervals to sustain the effect.[39]

By 2000, climatologists accepted the correlation between temporary global cooling and large-scale volcanic eruptions releasing sulfate aerosols

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34 J. Murray Mitchell, *El Chichón: Weather-Maker of the Century*?, 35 WEATHERWISE 252, 252 (1982).
35 *Id.* at 253.
36 INTERGOVERNMENTAL PANEL ON CLIMATE CHANGE WORKING GROUP I, CLIMATE CHANGE 2013: THE PHYSICAL SCIENCE BASIS 634 (2013); Paul J. Crutzen, *Albedo Enhancement by Stratospheric Sulfur Injunctions: A Contribution to Resolve a Policy Dilemma*?, 77 CLIMATE CHANGE 211, 212, 215 (2006). Pinatubo and Krakatau were both ranked 6 on the volcanic explosivity index (VEI), which is the second highest ranking. In the past 500 years, only Tambora ranked 7. El Chichón ranked 5. *See* Briffa, *supra* note 21, at 453 (displaying a chart of the largest explosive volcanic eruptions since 1400).
37 *See* Bradley, *supra* note 12, at 222; Briffa, *supra* note 21, at 451; Shanaka L. de Silva & Gregory A. Zielinski, *Global Influence of the AD 1600 Eruption of Huaynaputina, Peru*, 393 NATURE 455, 455 (1998); *WINCHESTER*, *supra* note 1, at 293.
38 Bradley, *supra* note 12, at 240; Briffa, *supra* note 21, at 450–52.
39 Briffa, *supra* note 21, at 454; Bradley, *supra* note 13, at 240.

into the stratosphere.[40] They also agreed that the accumulation of carbon dioxide and other greenhouse gases in the atmosphere was causing significant global warming, building toward a tipping point with potentially disastrous consequences for humanity, a process discussed in the next section.[41] The opposite effects on climate of these two different types of chemical compounds prompted some scientists to propose countering the dire effects of rising greenhouse gases by intentionally injecting sulfate aerosols into the stratosphere.[42] The idea quickly became the most widely debated and seemingly plausible means of geoengineering.

II. Global Warming

The theory that carbon dioxide generated by the burning of fossil fuels causes global warming developed over the past century. During the mid-1800s, British physicist John Tyndall first showed that CO_2 and other so-called greenhouse gases trap radiant heat from the sun and emit it in the atmosphere.[43] Figuratively and literally, they blanket the earth. Early in the 1900s, Swedish researchers Svante Arrhenius and Nils Gustaf Ekholm found that atmospheric carbon dioxide has had more impact than any other greenhouse gas on changes in global temperature and that, going forward, increasing its concentration by burning fossil fuels should warm the climate.[44] Ekholm estimated that tripling the amount of CO_2 in the atmosphere could raise average temperatures by up to 9ºC.[45] Data collected by British engineer Guy Callendar in the 1930s showed that, since the dawn of the coal-fired Industrial Revolution in the late 1800s, the climate had in fact warmed about .5ºC as carbon-dioxide levels rose, and that both trends correlated with fossil fuel use.[46]

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[40] *E.g.*, Briffa, *supra* note 21, at 451.

[41] James Rodger Fleming, Fixing the Sky: The Checkered History of Weather and Climate Control 225–26 (2010).

[42] The 2015 NAS report on the subject observed, "[I]t was the observed cooling following large eruptions that provided much of the initial stimulus for the idea that albedo modification could help offset effects of warming due to anthropogenic CO_2 increase." Comm. on Geoengineering Climate, Climate Intervention: Reflecting Sunlight to Cool Earth 73 (2015) [hereinafter NAS Report]. In this context, "albedo modification" refers to stratospheric aerosol injection. *Id.* at 32. *See also* Fleming, *supra* note 41, at 236–49 (discussing the use of aerosols to modify the climate); Wood, *supra* note 12, at 230.

[43] Naomi Oreskes & Erik M. Conway, Merchants of Doubt 170 (2010). Carbon dioxide, methane, ozone, and water vapor are the four major greenhouse gases in the atmosphere of the earth.

[44] Fleming, *supra* note 41, at 4–5; Oreskes & Conway, *supra* note 43, at 170.

[45] Fleming, *supra* note 41, at 4.

[46] *Id.* at 5; Oreskes & Conway, *supra* note 43, at 170.

At the time, not everyone was concerned about these developments. Coming from Sweden, Arrhenius and Ekholm actually welcomed the prospect of global warming.[47] Ekholm even suggested accelerating the process by exposing and burning shallow seams of coal to release more CO_2 into the atmosphere.[48] During the mid-twentieth century, some Soviet scientists took up this cause as a means of geoengineering to thaw the Siberian permafrost for farming and melt the Arctic ice cap for shipping. Climate change, they believed, would help the Soviet Union win the Cold War.[49]

Over the century, however, researchers began expressing alarm over the impact of carbon dioxide emissions on the global climate. In 1961, Mikhail Budyko, a Russian who pioneered bringing the application of quantitative methods to climatology, warned that waste heat from energy generation could render the earth uninhabitable and, eleven years later, he released a model suggesting that the warming attributable to rising levels of atmospheric CO_2 would melt the Arctic ice cap and significantly raise sea levels by 2050.[50] In Hawaii during the 1950s, Scripps Institution of Oceanography chemist Charles David Keeling began systematically measuring atmospheric CO_2, finding a steady rise over time correlated with increased burning of fossil fuels.[51] Scripps Director Roger Revelle used this so-called Keeling Curve in a 1965 governmental report to predict that the amount of carbon dioxide in the atmosphere would increase 25 percent by 2000, potentially causing "marked changes in climate."[52] This report, which was the first U.S. governmental statement on global warming,[53] led President Lyndon Johnson to warn Congress in 1965 that "a steady increase in carbon dioxide from the burning of fossil fuels" was altering the composition of the atmosphere on a global scale.[54] Additionally, a 1969

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[47] David W. Keith, *Geoengineering the Climate: History and Prospect*, 25 ANN. REV. ENERGY & ENV'T 245, 249 (2000).

[48] FLEMING, *supra* note 41, at 4–5.

[49] *See id.* at 201–04 (describing Soviet discussion of the benefits and political implications of geoengineering in the Arctic).

[50] Mikhail I. Budyko, *The Future Climate*, 53 EOS, TRANSACTIONS, AM. GEOPHYSICAL UNION, 868, 874 (1972). Budyko initially focused on the effect of waste heat on climate and later extended his concerns to include the even more worrisome impact of CO_2 emissions. FLEMING, *supra* note 41, at 236, 241.

[51] ORESKES & CONWAY, *supra* note 43, at 170.

[52] Roger Revelle et al., *Atmospheric Carbon Dioxide*, *in* PRESIDENT'S SCIENCE ADVISORY COMM., RESTORING THE QUALITY OF OUR ENVIRONMENT app. Y4, at 120, 126–27 (1965).

[53] *See* Fleming, *supra* note 41, at 225 (discussing significance of Hansen's testimony).

[54] 1 LYNDON B. JOHNSON, *Special Message to Congress on Conservation and Restoration of Natural Beauty*, *in* PUB. PAPERS OF THE PRESIDENTS OF THE U.S.

RAND Corporation study projected that increased atmospheric carbon dioxide could raise global temperatures by an added 2ºC by the year 2000.[55]

The debate over climate change and its causes first gained widespread public attention during the sweltering summer of 1988, when NASA climate modeler James Hansen told a U.S. Senate committee that global warming has begun. The trend did not have natural causes, he said, but was caused by a buildup of carbon dioxide and other artificial gases in the atmosphere.[56] That same year, the World Meteorological Organization and the United Nations Environment Program created the Intergovernmental Panel on Climate Change (IPCC).[57] The IPCC issued a series of five increasingly stark Assessment Reports for which it received the Nobel Peace Prize.[58] The IPCC's 2014 Fifth Assessment Report stated that "[h]uman influence has been detected in warming of the atmosphere and the ocean, in changes in the global water cycle, in reductions in snow and ice, and in global mean sea-level rise," and the report also predicted that failure to reduce carbon dioxide emissions could lead to food shortages, refugee crises, the flooding of cities and islands, and the mass extinction of plant and animal species.[59] Indeed, a 2015 *New York Times* article suggests that, even if pledged national targets for reducing carbon are met – and none have been met so far – the earth's average surface temperature would still rise by 6.3 degrees Fahrenheit during the current century as opposed to 8.1 degrees if emissions continued on their present course.[60]

155, 161 (Feb. 8, 1965). For *Restoring the Quality of our Environment* as first government report warning of anthropogenic climate change, see FLEMING, *supra* note 41, at 238. *See also* Keith, *supra* note 47, at 254 (describing *Restoring the Quality of our Environment* as an "early and influential assessment").

[55] Joseph O. Fletcher, *Managing Climate Resources*, RAND Rep. (RAND Corp.) No. P-4000-1, at 2 (1969), https://www.rand.org/content/dam/rand/pubs/papers/2009/P4000-1.pdf.

[56] Philip Shabecoff, *Global Warming Has Begun, Expert Tells Senate*, N.Y. TIMES, June 24, 1988, http://www.nytimes.com/1988/06/24/us/global-warming-has-begun-expert-tells-senate.html?pagewanted=all. *See also* Fleming, *supra* note 41, at 225 (discussing significance of Hansen's testimony).

[57] Fleming, *supra* note 41, at 226.

[58] *See id.* (discussing the first four IPCC reports and their increasingly stark language); Justin Gillis, *U.N. Panel Issues Its Starkest Warning Yet on Global Warming*, N.Y. TIMES, Nov. 3, 2014, http://www.nytimes.com/2014/11/03/world/europe/global-warming-un-intergovernmental-panel-on-climate-change.html (describing the fifth IPCC report and noting that the IPCC was awarded the Nobel Peace Prize in 2007 with Al Gore).

[59] Gillis, *supra* note 58.

[60] Justin Gillis & Somini Sengupta, *Limited Progress Seen Even as More Nations Step Up on Climate*, N.Y. TIMES, Sept. 28, 2015, http://www.nytimes.com/2015/09/28/world/limited-progress-seen-even-as-more-nations-step-up-on-

In 2005, Hansen contributed the concept of "tipping points" to the discussion. This model projects that amplified feedback from the warming-caused loss of Arctic sea ice and collapse of ice sheets in Greenland and West Antarctica would accelerate climate change, making it irreversible.[61] Adopting this view, the influential English environmentalist James Lovelock concluded in 2006 that CO_2 emissions had already pushed the climate past its tipping point. Predicting that "before this century is over billions of us will die" from global warming, he wrote, "[t]he worst will happen and survivors will have to adapt to a hell of climate."[62] During the first decade of the twenty-first century, study after study found carbon dioxide emissions rising, atmospheric CO_2 levels increasing, and Arctic sea ice disappearing, all more rapidly than anticipated.[63]

Although skeptical at first, the scientific community has now overwhelmingly adopted the view that climate change has occurred, is accelerating, and has been primarily caused by humans.[64] A 2010 survey of climate researchers ranked by their publications found that 49 out of the top 50 support the IPCC's conclusion that human-caused greenhouse gases have caused significant global warming over the past fifty years, and the outlier accepted the evidence of climate change but simply was not certain of the cause.[65] The debate over climate change and its causes occurs among

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climate.html. *See also* NAS REPORT, *supra* note 42, at 13 ("[T]here is no substitute for dramatic reductions in CO2 emissions to mitigate the negative consequences of climate change at the lowest probability of risk to humanity."); Ken Caldeira & Lowell Wood, *Global and Arctic Climate Engineering: Numerical Model Studies*, 366 PHIL. TRANSACTIONS ROYAL SOC'Y A 4039, 4053 (2008) ("Regardless of what we might consider to be prudent or imprudent with respect to CO_2 emissions into the atmosphere, these emissions continue to increase and as a result atmospheric CO_2 concentrations also continue to increase.").

[61] Jim Hansen, *The Tipping Point?, Presentation to the American Geophysical Union* (Dec. 6, 2005), *in* N.Y. REV. BOOKS, Jan. 12, 2006, http://www.nybooks.com/articles/archives/2006/jan/12/the-tipping-point/.

[62] James Lovelock, *The Earth is About to Catch a Morbid Fever that May Last as Long as 100,000 Years*, THE INDEPENDENT (London), Jan. 16, 2006, http://www.jameslovelock.org/page10.html (discussing his new book, THE REVENGE OF GAIA (2006)).

[63] *See* Caldeira & Wood, *supra* note 60, at 4039–40 (listing several such studies).

[64] ORESKES & CONWAY, *supra* note 43, at 169 ("Today, all but a tiny handful of climate scientists are convinced that Earth's climate is heating up, and that human activities are the dominant cause."); Philip J. Rasch et al., *An Overview of Geoengineering of Climate Using Stratospheric Sulphate Aerosols*, 366 PHIL. TRANSACTIONS ROYAL SOC'Y A 4007, 4008 (2008) (referring to "the scientific consensus that reductions [in CO_2 emissions] must take place soon to avoid large and undesirable impacts"). *See also* NAS REPORT, *supra* note 42, at 15.

[65] William R.L. Anderegg et al., *Expert Credibility in Climate Change*, 107 PROCS. NAT'L ACAD. OF SCI. 12107, 12107 (2010).

the people and politicians, not within science. Instead, scientists debate what can and should be done about it, with some of the earliest and most vocal heralds of global warming calling for research into geoengineering responses.[66]

III. PLANNED GEOENGINEERING

In a 1996 article, Nobel Prize winning economist Thomas Schelling, a climate-change skeptic, observed, "'Geoengineering' is a new term, still seeking a definition. It seems to imply something global, intentional, and unnatural."[67] In its seminal report on the issue published thirteen years later, a blue-ribbon Working Group of Britain's prestigious Royal Society defined geoengineering "as the deliberate large-scale intervention in the Earth's climate system, in order to moderate global warming."[68] Unlike Schelling, this Working Group fully accepted the reality of anthropogenic (or human-caused) global warming and feared that it will get worse.[69] The Working Group's 2009 Report warned, "[i]t is likely that global warming will exceed 2ºC this century unless global greenhouse gas emissions are cut by at least 50% of 1990 levels by 2050, and by more thereafter," reductions that the Group did not expect to occur.[70] The serious predicted consequences of such severe climate change led the Working Group to assert, "[u]nless future efforts to reduce greenhouse gas emissions are much more successful then [sic] they have been so far, additional action may be required should it become necessary to cool the Earth this century."[71] Such action, the Group concluded, "might involve geoengineering."[72]

Although many different methods of geoengineering have been proposed, they fall into two main categories. One type attempts to remove carbon dioxide from the atmosphere. The other type aims at reducing the amount of heat-causing solar radiation entering or remaining in the

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[66] *E.g.*, Rasch et al., *supra* note 64, at 4008.
[67] Thomas C. Schelling, *The Economic Diplomacy of Geoengineering*, 33 CLIMATIC CHANGE 303, 303 (1996).
[68] ROYAL SOCIETY, GEOENGINEERING THE CLIMATE: SCIENCE, GOVERNANCE AND UNCERTAINTY ix (2009). In its report, the NAS committee assigned to study "geoengineering" proposed instead to use the term "climate intervention" with its connotation of "an action intended to improve a situation" rather than reengineer it. NAS REPORT, *supra* note 42, at viii, 1, 19–20.
[69] ROYAL SOCIETY, *supra* note 68, at 4.
[70] *Id.* at ix, 4.
[71] *Id.* at ix.
[72] *Id.* at ix, 57.

atmosphere.[73] The latter is significantly more controversial than the former.[74]

Carbon dioxide removal (CDR) methods use biological, chemical, or mechanical means to draw CO_2 from the atmosphere and sink it into the land or deep oceans.[75] These methods include reforestation, carbon capture from emissions or the ambient air, deep-water upwelling or downwelling, and ocean fertilization to increase algae growth.[76] While CDR methods have the advantage of dealing with the source of the problem, they are too slow, inefficient, costly, untested, or environmentally risky to provide more than a partial answer to global warming.[77] Proponents have given the most attention to fertilizing the Southern Ocean with iron filings to stimulate phytoplankton growth, but studies suggest that most of the absorbed CO_2 would quickly return to the atmosphere and the resulting algae blooms could create dead zones in the oceans.[78]

Solar radiation management (SRM) methods do not reduce atmospheric CO_2 but instead seek to counter its warming effect by reducing or reflecting incoming solar radiation.[79] While most of the proposed SRM

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[73] *Id.* at 1; Adam D.K. Abelkop & Jonathan C. Carlson, *Reining in Phaëthon's Chariot: Principles for the Governance of Geoengineering*, 21 TRANSNAT'L L. & CONTEMP. PROBS. 763, 772 (2013).

[74] Tracy D. Hester, *Remaking the World to Save It: Applying U.S. Environmental Laws to Climate Engineering Projects*, 38 ECOLOGY L.Q. 851, 866 (2011). *See* also NAS REPORT, *supra* note 42, at 1 (describing the latter method as "speculative").

[75] Abelkop & Carlson, *supra* note 73, at 772.

[76] *Id.* at 772–75.

[77] David P. Keller et al., *Potential Climate Engineering Effectiveness and Side Effects During a High Carbon Dioxide-Emission Scenario*, 5 NATURE COMM., Feb. 25, 2014, at 5 ("[C]arbon dioxide reduction (CDR) methods are thus, as expected from other studies, unable to prevent a 2.7–3.9°C mean temperature increase (temperature increases by 3.8°C with no climate engineering) in our model simulations under the RCP 8.5 emission scenario by the year 2100.") (citations omitted). *See also* NAS PANEL ON POLICY IMPLICATIONS OF GREENHOUSE WARMING, POLICY IMPLICATIONS OF GREENHOUSE WARMING, 458–59 (1992) [hereinafter NAS PANEL]; ROYAL SOCIETY, *supra* note 68, at 19–21.

[78] Abelkop & Carlson, *supra* note 73, at 773–75.

[79] ROYAL SOCIETY, *supra* note 68, at ix, 23. In its report, the NAS committee on geoengineering explained:

> The climate system can be compared to a heating system with two knobs, either of which can be used to set the global mean temperature. The first knob is the concentration of greenhouse gases such as CO_2 in the atmosphere . . . . As more greenhouse gases are added to the atmosphere, the system (if otherwise undisturbed) will warm up . . . . The other knob is the reflectance of the planet . . . . One could instead attempt to restore the balance at the original temperature by increasing the proportion of sunlight that Earth's surface and atmosphere reflect back to space . . . .

methods would either have limited effect, such as brightening surfaces and clouds, or are presently impractical, such as putting sun-shields in space, the known cooling caused by volcanic eruptions has drawn attention to the possibility of intentionally injecting sulfate aerosols into the stratosphere.[80] The following sections of this article, therefore, focus on this particular method of geoengineering.

A. The Promise of Sulfate Aerosols

Interest in sulfate aerosol injections has erupted over the past decade. For example, in its 2009 report, the Royal Society Working Group urged reduced CO_2 emissions by any method of geoengineering, while also singling out stratospheric aerosols as "the most promising" means of "reducing global temperatures rapidly should the need arise."[81] Four years later, the IPAA's Fifth Assessment Report, without endorsing geoengineering, expressed medium confidence "that stratospheric aerosol SRM could counteract some changes resulting from [greenhouse gas] increases."[82] Even more emphatically, a 2014 comparative study modeling the impact of various geoengineering methods found that *only* solar radiation management by stratospheric aerosols could prevent significant global warming during the current century.[83] As suggested in section II above, and discussed more fully below, these recent findings are built on prior research and earlier proposals.[84]

Reflecting his longstanding concern for the catastrophic consequences of climate change and faith in central planning, Soviet climatologist Mikhail Budyko was the first to advocate for intentionally injecting sulfate aerosols into the stratosphere to counter global warming.[85]

NAS REPORT, *supra* note 42, at 33–34.

[80] IPCC WORKING GROUP I, *supra* note 36, at 693; NAS REPORT, *supra* note 42, at 34–35; Abelkop & Carlson, *supra* note 73, 775–77. Similarly, Rasch et al. *supra* note 64, at 4030 ("Part of the attraction of using stratospheric aerosols arises because volcanic eruptions form a natural, but imperfect, analogue to geoengineering. Observations following major volcanic eruptions have demonstrated that sulphate aerosol, in sufficient amounts, will cool the planet, and that the Earth system can survive this kind of perturbation."). Even though the NAS committee studying geoengineering deemed marine cloud brightening as well as stratospheric aerosols to merit further research, it nevertheless conceded its more limited, local effect. NAS REPORT, *supra* note 42, at 82.

[81] ROYAL SOCIETY, *supra* note 68, at 36.

[82] IPCC WORKING GROUP I, *supra* note 36, at 635.

[83] Keller et al., *supra* note 77, at 5–6.

[84] *See supra*, Section II; *infra* III.A.

[85] Rasch et al., *supra* note 64, at 4008. Budyko had earlier endorsed an idea by Soviet academician M. Ye. Shvets to inject dust particles into the stratosphere to

In a 1974 book that has been widely cited by subsequent supporters of geoengineering, Budyko proposed using high-altitude flights by airplanes burning some 100,000 tons of sulfur per year to generate and deliver the aerosol.[86] Without fully working out the math, Budyko estimated that this would be enough to cool the Earth by several degrees and thereby fully offset the temperature effects of anthropogenic global warming.[87] Critics, including climate historian James Fleming and others, questioned the accuracy of Budyko's calculations, the feasibility of his delivery system, and the environmental side-effects of the procedure.[88]

Environmentalism had taken root by then, and the modernist faith in using technology to "fix" natural processes had given way to post-modern angst about such technological fixes.[89] Indeed, even the warmest proponents of using stratospheric injections to cool the climate acknowledge that the process would have serious side-effects and might not even be feasible.[90] Some worried that even raising the possibility of a technological response, no matter how speculative, might further undermine the already lagging efforts to reduce greenhouse gas emissions.[91] These commentators considered research into using stratospheric aerosols for geoengineering to pose a serious problem of moral hazard. As three American climate scientist explained in a 2013 article,

> The climate science community has been aware of the possibility of performing SRM for decades. However, most researchers have shied away from working in this area, in part because of a concern that the more that is known, the greater the chance that someone will try it.[92]

Consequently, field research was stalled.

Nevertheless, the prospect of using stratospheric aerosols to counter global warming retained a following among a subset of technologically-minded scientists that, although worried about adverse side-effect, were both concerned about climate change and pessimistic about reducing

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counter the climactic effects of the waste heat resulting from the generation of energy by humans, particularly in cities. FLEMING, *supra* note 41, at 236.

86 MIKHAIL IVANOVICH BUDYKO, CLIMATIC CHANGES 230–40 (1977) (English translation of 1974 book originally published in Russian).

87 FLEMING, *supra* note 41, at 241.

88 *See id.* at 241, 254–55.

89 KEITH, *supra* note 47, at 251, 277–80.

90 *See infra* Section IV.A.

91 *See* KEITH, *supra* note 47, at 276; NAS Report, *supra* note 42, at ix.

92 M. Granger Morgan et al., *Needed: Research Guidelines for Solar Radiation Management*, 29 ISSUES IN SCIENCE AND TECHNOLOGY 23, 30 (2013).

emissions.[93] Some of them saw it as a remedy of last resort worthy of study so as to be available should targets for reducing atmospheric CO_2 not be met and global temperatures surge rapidly.[94] Others saw it as either more realistic, or even preferable, to sharply curtailing the use of fossil fuels.[95] Taking the latter view, in a 1984 article, University of California-San Diego Engineering Professor Stanford S. Penner and two colleagues proposed that modifying the engines of commercial airplanes to emit more particulates at high altitude should solve the problem, although critics noted that such aircraft rarely fly high enough to perform this task.[96] Further, the prospect of using stratospheric sulfate injections to combat global warming attracted the attention of some climate-change skeptics, because that prospect reduced the imperative of mitigating CO_2 emissions and offered an escape hatch if catastrophic warming were to occur.[97]

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[93] *E.g.*, Rasch et al., *supra* note 64, at 4008; *see also* HESTER, *supra* note 74, at 852–54.

[94] *See* ROYAL SOCIETY, *supra* note 68, at 61; Caldeira & Wood, *supra* note 60, at 4040 (Caldiera was a member of the working group that produced the previously cited Royal Society report); Crutzen, *supra* note 36, at 216.

[95] *See, e.g.*, Thomas C. Schelling, *Climate Change: Implications for Welfare and Policy*, *in* CHANGING CLIMATE: REPORT OF THE CARBON DIOXIDE ASSESSMENTS COMMITTEE 449, 468-70 (1983). For more on Schelling, see Oreskes & Conway, *supra* note 43, at 174–80.

[96] S.S. Penner et al., *Active Measures for Reducing the Global Climate Impacts of Escalating CO_2 Concentrations*, 11 ACTA ASTRANAUTICA 345, 347–48 (1984). Criticism noted in NAS PANEL, *supra* note 76, at 453; FLEMING, *supra* note 41, at 243.

[97] In one of his last papers, the legendary theoretical physicist known for offering technological fixes to military, political, and social problems, Edward Teller (a climate-change skeptic) wrote with geoengineering proponent Lowell Wood:

> *[I]f* you're inclined to subscribe to the Rio Framework Convention's directive that mitigation of global warming should be effected in the "lowest possible cost" manner – *whether or not* you believe that the Earth is indeed warming significantly above-and-beyond natural rates, and *whether or not* you believe that human activities are largely responsible for such warming, and *whether or not* you believe that problems likely to have significant impacts only a century hence should be addressed with current technological ways-&-means rather than be deferred for obviating with more advanced means – then you will *necessarily* prefer active technical management of radiation forcing of the Earth to administrative management of greenhouse gas inputs to the Earth's atmosphere . . . .

Edward Teller, et al., *Active Climate Stabilization: Practical Physics-Based Approaches to Prevention of Climate Change* 6 (Lawrence Livermore Nat'l Laboratory, Preprint UCRL-JC-148012, 2002). Teller is considered the real-live model for Dr. Strangelove. FLEMING, *supra* note 41, at 243.

Sustained interest in solar radiation management was apparent in a series of reports on climate change issued by the National Academy of Science (NAS) from 1977 to 1992 that were linked by common authors and cross-references.[98] All of these reports warn of anthropogenic global warming and most of them suggest using geoengineering to counter it.[99] The final report was the most explicit. In a chapter titled "Geoengineering," the report gave greatest attention to the option of injecting volcanic dust or sulfate aerosols into the atmosphere on a continuous basis.[100] Drawing on Budyko's work, the report discussed delivering the material by aircraft, rockets, and high-altitude balloons but favored using artillery shells as the least expensive and most efficient means.[101] "A 16-inch naval rifle fired vertically could put a shell weighing about 1 t up to an altitude of 20 km," the report noted, with 10 million such shots needed per year at an estimated annual cost of about $125 billion.[102] Former NASA Administrator Robert Frosch, who shaped the report's geoengineering section, commented at the time, "I don't know why anybody should feel obligated to reduce carbon dioxide if there are better ways to do it."[103]

The professional scorn heaped on the geoengineering recommendations set forth in NAS's 1992 report, which included a cartoon in the *Geographical Magazine* depicting Frosch frantically loading skyward-pointed artillery with vacuum-cleaner dust, helped to quiet proponents for a time.[104] No IPCC assessment recommended geoengineering.[105] "Refereed publications that deal with such ideas are not numerous nor are they cited widely," NAS President Ralph Cicrone noted in 2006.[106] Yet that same year, the Nobel Prize winning Dutch atmospheric chemist, Paul Crutzen, shattered this silence with an editorial in the journal *Climate Change* on the use of stratospheric sulfur injections to offset global warming. Citing the known cooling effect of volcanic eruptions, Crutzen wrote, "[i]f sizeable reductions in greenhouse gas emissions will not happen and temperatures rise rapidly, then climate engineering, such as presented here, is the only option available to rapidly reduce temperature rises."[107] He

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[98] *See, e.g.*, KEITH, *supra* note 47, at 255.
[99] *See* FLEMING, *supra* note 41, at 243–46; KEITH, *supra* note 47, at 255–56.
[100] *See* NAS Panel, *supra* note 76, at 448–54. Describing it as one of "the most promising" options, the report concluded, "[t]he rifle system appears to be inexpensive, to be relatively easily managed, and to require few launch sites." *Id.* at 460.
[101] *See id.* at 451–54.
[102] *Id.* at 451. *See also* FLEMING, *supra* note 41, at 247.
[103] Dan Fagin, Tinkering with the Environment, NEWSDAY, Apr. 13, 1992, at 7.
[104] FLEMING, *supra* note 41, at 246–48; KEITH, *supra* note 47, at 245.
[105] KEITH, *supra* note 47, at 269.
[106] FLEMING, *supra* note 41, at 255.
[107] Crutzen, *supra* note 36, at 216.

stressed that at the very least research into its feasibility and environmental effects "should not be tabooed because of the presumed moral hazard of discussing it ."[108]

Discussion and research on SRM methods has been going on, even if somewhat under the radar, for a while.[109] Soon after George W. Bush became president in 2001, for example, the White House sponsored an invitation-only conference on how to address rapid global warming, and, in 2003, the U.S. Defense Department issued a report calling for research on geoengineering to deal with abrupt climate change.[110] Two years later, Russian science advisor Yuri Izreal urged his country to begin work on ways to inject sulfate aerosols into the stratosphere, which he later depicted as "an optimal option to compensate [for] warming."[111] Since 2000, Lawrence Livermore researchers Bala Govindasamy, Ken Caldeira, and Lowell Wood have modeled the impact of stratospheric albedo modification on the climate and have published a series of articles suggesting its effectiveness at offsetting increased atmospheric CO_2.[112] In 2005, Wood proposed the alternative delivery system of piping liquid sulfur dioxide to the stratosphere in hoses suspended from a high-altitude blimp of the type planned, but not yet built, by the Defense Department.[113]

By 2007, following Crutzen's editorial and a 2007 Carnegie Institution-sponsored conference on managing solar radiation, the issue had become hot enough for the *New York Times* to run an editorial cartoon showing two sweating polar bears on a small, unstable ice-flow feverishly pumping sulfur skyward as factories belched CO_2 in the background. The

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[108] *Id.* at 214.

[109] Discussing this apparent lull in the scientific debate over geoengineering even as work was quietly proceeding in his 2000 overview of the history of geoengineering, David Keith wrote:

> A casual look at the past few decades of debate about the CO_2-climate problem might lead one to view geoengineering as a passing aberration: an idea that originated with a few speculative papers in the 1970s; that reached a peak of public exposure with the NAS92 assessment and the cotemporaneous American Geophysical Union and American Association for the Advancement of Sciences colloquia of the early 1990s; and an idea that is now fading from view as international commitment to substantive action on climate grows ever stronger . . . However, I argue that this view is far too simplistic.

KEITH, *supra* note 47, at 278.

[110] FLEMING, *supra* note 41, at 253–54.

[111] *Id.* 254–55.

[112] *See* Crutzen, *supra* note 36, at 215; Caldeira & Wood, *supra* note 60, at 4045.

[113] *See* Caldeira & Wood, *supra* note 60, at 4052 (discussing and citing Wood's earlier proposals).

caption read, "Screwing (with) the Planet."[114] Political theorist David C. Victor commented a year later: "[f]ormerly a freak show in otherwise serious discussions of climate science and policy, geoengineering today is a bedfellow, albeit one of which we are wary. The option may be needed as a hedge against unexpectedly harsh changes in climate."[115]

B. The Royal Society and National Academy

A potential tipping point occurred in 2009 when the Royal Society Working Group issued its Report calling for more research into the feasibility of geoengineering, with "the highest priority" given to stratospheric aerosol injections.[116] This recommendation mirrored both the core message of a special issue on geoengineering in the Society's *Philosophical Transactions* a year earlier and a 2004 conference at the Oxbridge-backed Tyndall Centre for Climate Change Research in England.[117] Drawing on an earlier calculation that "a reduction of solar input by about 2% can balance the effect of global mean temperature of a doubling of CO_2,"[118] the Report asserted:

> It should therefore be feasible to balance the global radiative forcing from greenhouse gases as precisely as required, using SRM methods. However, it is important to note that the cancellation will not be exact at any given location, with likely residual net impacts on regional climates.[119]

While more cautious than positions taken in the *Philosophical Transactions* issue, the Report conveyed the same take-home message on geoengineering as expressed in the issue's Preface that "[w]hile such geoscale interventions may be risky, the time may well come when they are accepted as less risky than doing nothing."[120] The Royal Society's then President, England's Astronomer Royal Lord Rees, later articulated a similar position when he

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[114] FLEMING, *supra* note 41, at 257.
[115] David C. Victor, *On the Regulation of Geoengineering*, 24 OXFORD REVIEW. OF ECONOMIC POLICY 322, 323 (2008).
[116] ROYAL SOCIETY, *supra* note 68, at 61.
[117] FLEMING, *supra* note 41, at 258-61.
[118] ROYAL SOCIETY, *supra* note 68, at 39. This calculation came from a 2002 study co-authored by Ken Caldiera, who was the only American member of the Royal Society's Working Group.
[119] *Id.* at 34. *See also*, NAS REPORT, *supra* note 42, at 143 ("Feasibility studies suggest that it may be technically possible to introduce aerosols into the stratosphere that can produce significant cooling (on the order of 1 W/m^2 or larger) with little or no major technological innovations required.").
[120] Brian Launder & J. Michael T. Thompson, *Preface* to 366 PHILOSOPHICAL TRANSACTIONS OF THE ROYAL SOCIETY A 3841, 3841 (2008).

endorsed stratospheric aerosols as a back-up "Plan B" to combat anthropogenic global warming.[121]

The debate over geoengineering has intensified since the release of the Royal Society Report.[122] Some call for more studies and field research into the various options.[123] Others complain that no form of geoengineering beats mitigation and adaption for responsibly addressing climate change, and even studying them could further weaken resolve for cutting carbon emissions.[124] All agree that, other than computer modeling, inadequate research has been conducted into the feasibility of injecting aerosols into the stratosphere in adequate quantities to lower temperatures.[125] No one really knows if any of the proposed delivery system would work, or at what cost.[126]

All also agree that injecting chemical aerosols into the stratosphere would have side effects, with some areas benefiting at the expense of others.[127] Scientists warn that less rain might fall, the daytime sky could

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[121] Alok Jha, *Astronomer Royal Calls for "Plan B" to Prevent Runaway Climate Change*, THE GUARDIAN, Sept. 11, 2013, at 1.

[122] The noted international environmental-law professor Daniel Bodansky, who has followed this issue closely for two decades, noted in 2012 that the grim outlook for CO_2 mitigation "has led many to take a second look at geoengineering solutions to climate change" beginning with the 2009 Royal Society Report. Discussion Paper, Daniel Bodansky, *The Who, What, and Wherefore of Geoengineering Governance*, (Sept. 9, 2012), http://ssrn.com/abstract_id=2168850. *See also* IPCC WORKING GROUP III, CLIMATE CHANGE 2014: MITIGATION OF CLIMATE CHANGE 484 (2014) (discussing some of the research since the Royal Society Report); FLEMING, *supra* note 41, at 255 (critically commenting on this period).

[123] *See, e.g.*, Crutzen, *supra* note 36, at 217; ROYAL SOCIETY, *supra* note 68, at ix. In 2009, Russian climatologist Yuri Izreal conducted a limited, low-level, and largely inconclusive SRM field experiment using helicopters to deploy a reflective haze. FLEMING, *supra* note 41, at 256-57. In 2012, a planned British field trial of a SRM delivery system using a balloon and hose was cancelled when organizers discovered that some of the researchers had already patented parts of the process, which created a potential conflict of interest. Erin Hale, *Geoengineering Experiment Cancelled Due to Perceived Conflict of Interest*, THE GUARDIAN, May 16, 2012.

[124] *See* IPCC WORKING GROUP III, *supra* note 122, at 219; KEITH, *supra* note 47, at 276–77; FLEMING, *supra* note 41, at 263–64; Victor, *supra* note 115, at 323.

[125] See IPCC WORKING GROUP I, *supra* note 36, at 629; Crutzen, *supra* note 36, at 215; ROYAL SOCIETY, *supra* note 68, at xii; FLEMING, *supra* note 41, at 243–57; NAS REPORT, *supra* note 42, at 59.

[126] NAS REPORT, *supra* note 42, at 77. For skeptical commentary on proposed delivery systems, see FLEMING, *supra* note 41, at 241–34, 247–49, 254–57.

[127] Geoengineering proponents Ken Caldeira and Lowell Wood concede that "climate engineering is likely to result in relative winners and losers; all such circumstances are pregnant with political tensions." Caldeira & Wood, *supra* note

whiten and sunsets redden, the ozone hole could grow, and atmospheric CO_2 levels may continue to rise, causing more ocean acidification and, if injections ceased, dangerously rapid warming.[128] Furthermore, models suggest that stratospheric aerosol injections would have relatively less impact in Polar Regions, and thus be unlikely to slow the loss of Arctic sea ice.[129] Then there is the parade of imagined and unimagined horribles that might follow from such a large-scale tampering with nature.[130] Finally, all agree that no adequate international governance structure or legal framework exists for a process that, while potentially deployable by a single nation, organization, or wealthy individual, would have trans-boundary impacts.[131]

In 2013, after the IPCC's Fifth Assessment Report expressed medium confidence that stratospheric sulfate aerosols could counteract global warming but did not address the technical feasibility of injecting them, attention turned to the NAS.[132] It assembled a committee with experts

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60, at 4054. *See also* NAS REPORT, *supra* note 42, at 34 ("The geographical and seasonal distribution of radiative forcing due to albedo modification is substantially different from that arising from a decrease of CO_2."); *id.* at 143 ("Models also strongly suggest that the benefits and risks will not be uniformly distributed around the globe.").

[128] IPCC WORKING GROUP I, *supra* note 36, at 575, 627, 634; IPCC WORKING GROUP III, *supra* note 122, at 487; NAS Panel, *supra* note 76, at 450–51; ROYAL SOCIETY, *supra* note 68, at 31–32: NAS REPORT, *supra* note 42, at 34, 69, 75.

[129] NAS REPORT, *supra* note 42, at 70.

[130] *Id.* at 147, 155. Some call this the Frankenstein factor in geoengineering. *E.g.*, Bodansky (2012), *supra* note 122, at 3. By way of comparison, most of the actual side effects of nuclear weapons tests were not predicted in advance. Victor, *supra* note 115, at 328.

[131] *See, e.g.*, ROYAL SOCIETY, *supra* note 68, at 5; NAS REPORT, *supra* note 42, at 153–55; Caldeira & Wood, *supra* note 60, at 4054; Editorial, *A Charter for Geoengineering*, 485 NATURE, 415, 415 (2012); Abelkop & Carlson, *supra* note 73, at 788–90; IPCC WORKING GROUP III, *supra* note 122, at 488. Referring to a figure from an early James Bond movie, one commentator noted that "[a] lone Greenfinger, self-appointed protector of the planet and working with a small fraction of the Gates bank account, could force a lot of geoengineering on his own." Victor, *supra* note 115, at 324. Gates has in fact contributed a large portion of the funding for geoengineering research to date. Bodansky (2012), *supra* note 122, at 10.

[132] IPCC WORKING GROUP I, *supra* note 36, at 574, 627, 635. *See also* IPCC WORKING GROUP III, *supra* note 120, at 219, 484–489. Russia had called on the IPCC to endorse geoengineering. *See* Martin Lukaas et al., *Russia Urges UN Climate Report to Include Geoengineering*, THE GUARDIAN, Sept. 19, 2013; *Geoengineering Climate: Technical Evaluation of Selected Approaches*, at 2 (Jan. 2015), *available at* https://www8.nationalacademies.org/cp/projectview.aspx?key=49540.

from various sides and charged them with assessing the feasibility and risks of geoengineering.[133] Projected originally for release in 2014, the committee's report came out in 2015.[134] It continued the push toward opening the field for research.

The committee produced two reports.[135] The first focused on CDR techniques, which it viewed as mostly benign and beneficial but too slow, expensive, or ineffective to make much difference in combating climate change at this time. Still, the committee viewed them as ready for increased research and development.[136] The second report addressed SRM, which it called "albedo modification," with primary focus on stratospheric aerosol injections and secondary attention on marine cloud brightening.[137] The report dismissed other SRM methods as "either prohibitively expensive or difficult to scale to the point where they could offset a substantial amount of CO_2 radiative forcing."[138] With respect to the two more feasible SRM approaches, the committee concluded that, "as a society, we have reached the point where the severity of the potential risks from climate change appears to outweigh the potential risks from the moral hazard associated with a suitably designed and governed research program."[139] While favoring mitigation over any form of geoengineering or "climate intervention" and opposing the current large-scale deployment of SRM techniques, the committee called for the development of a research program into stratospheric aerosol injections that could include "some controlled emissions experiments" or field tests.[140] This report could open the floodgates for significant U.S. government funding for research into stratospheric aerosol injections.[141]

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[133] For a typical media comment about the NAS's pending report, see Graham Readfearn, *Failure to Deal with Ethics Will Make Climate Engineering "Unviable,"* THE GUARDIAN, July 31, 2014 (calling the report "a key report into the 'technical feasibility' of a number of proposed geoengineering methods." Members of the sixteen-person committee included Ken Caldeira and James Fleming); *Geoengineering Climate: Technical Evaluation of Selected Approaches*, at 2 (Jan. 2015), *available at* https://www8.nationalacademies.org/cp/projectview.aspx?key=49540.

[134] *Geoengineering Climate: Technical Evaluation of Selected Approaches*, at 2 (Jan. 2015), *available at* https://www8.nationalacademies.org/cp/projectview.aspx?key=49540.

[135] NAS REPORT, *supra* note 42, at 16.

[136] *Id.* at 4–5.

[137] *Id.* at 28, 82.

[138] *Id.* at 37.

[139] *Id.* at 147.

[140] *Id.* at 150–55.

[141] When interviewed about the reports, geoengineering researcher David Keith commented about the committee and its members: "I think it is terrific that they

IV. GOVERNING GEOENGINEERING

Despite its intended trans-boundary impacts and increasing prominence, no specific international law, treaty, or governance structure exists for geoengineering.[142] While some types of geoengineering are more-or-less covered by a patchwork of existing international regimes originally designed for other purposes, SRM methods in general, and stratospheric injections in particular, are largely regulated by local or national law. Yet proponents and opponents alike generally agree that there is more need for some form of global governance over stratospheric injections than over any other form of geoengineering.[143]

Comparing various geoengineering methods shows the special need for a coordinated response to stratospheric aerosols. Many CDR and SRM methods, from reforestation and carbon extraction to surface and cloud brightening, have such little effect that they would probably do no more than mitigate the carbon footprint of the nation implementing them.[144] Such benign efforts call for international encouragement rather than regulation.[145] Deploying a sun shield in outer space is both presently impractical and already governed by the Outer Space Treaty.[146] Ocean upwelling and downwelling are similarly speculative, likely ineffective, and probably regulated by the 1982 U.N. Convention on the Law of the Sea (UNCLOS).[147] Ocean fertilization is covered by the Antarctic Treaty

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made a stronger call than I expected for research, including field research," and added his hope that the report would "break the logjam" and "give program managers the confidence they need to begin funding." Henry Fountain, *Panel Urges Research on Geoengineering as a Tool Against Climate Change*, N.Y. TIMES, Feb. 11, 2015, at A17.

[142] Cinnamon P. Carlarne, *Arctic Dreams and Geoengineering Wishes: The Collateral Damage of Climate Change*, 49 COLUM. J. TRANSNAT'L L. 602, 642 (2011); Bodansky (2012), *supra* note 122, at 4: Abelkop & Carlson, *supra* note 73, at 788–90.

[143] *See* Jesse Reynolds, *The International Regulation of Climate Engineering: Lessons from Nuclear Power*, 26 J. ENVTL. L. 269, 273–74 (speaking of the "consensus" on this issue and then referring to "stratospheric aerosol injection[s]" in particular); Daniel Bodansky, *May We Engineer the Climate?*, 33 CLIMATIC CHANGE 309, 315 (1996); NAS REPORT, *supra* note 42, at 143 (comparing governance issues for CDR and SRM efforts).

[144] For the limited impact of such methods, see ROYAL SOCIETY, *supra* note 68, at 22, 35 (summarizing the small potential impact of all of these methods except carbon capture, which is presented as potentially scalable but still limited by cost and not yet proven on a large scale).

[145] See Bodansky (1996), *supra* note 143, at 316.

[146] ROYAL SOCIETY, *supra* note 68, at 33; Bodansky (1996), *supra* note 143, at 314.

[147] ROYAL SOCIETY, *supra* note 68, at 19–21; Bodansky (1996), *supra* note 143, at 314.

System if done in the Southern Ocean, likely covered by UNCLOS if done elsewhere, and already restricted by parties to both the London Convention and Protocol and the Convention on Biological Diversity.[148] Furthermore, studies suggest that ocean fertilization would have little net effect on atmospheric CO_2 levels.[149] These considerations leave stratospheric aerosols as the type of geoengineering in greatest need of immediate regulation.[150]

A. The Special Case of Stratospheric Injections

Foundational to the special case for regulation is the fact that stratospheric aerosols offer a plausible method of geoengineering that some scientists and policymakers find attractive, at least as a back-up plan in a case of extreme climate change.[151] From experience with explosive volcanic eruptions, climatologists know that a massive injection of sulfate aerosols into the stratosphere can quickly lower global temperatures for the year or so that they remain aloft.[152] Sustained reductions require sustained injections.[153] Despite a lack of study and testing of delivery systems, the IPCC has expressed "medium confidence" that deliberate injections can offset projected levels of warming, at least in rough terms.[154] In 2009, the Royal Society called both for more research and development in the field and for setting up international structures to govern it.[155] Without a

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[148] Bodansky (1996), *supra* note 143, at 314–15; David A. Wirth, *Engineering the Climate: Geoengineering as a Challenge to International Governance*, 40 B.C. ENVTL. AFF. L. REV., 413, 427–30 (2013); Carlarne, *supra* note 140, at 644–48.
[149] ROYAL SOCIETY, *supra* note 68, at 18.
[150] Addressing this matter in a report, the British House of Commons Science and Technology Committee wrote in 2010: We conclude that geoengineering techniques should be graded according to factors such as trans-boundary effect, the dispersal of potentially hazardous materials in the environment and the direct effect on ecosystems. The regulatory regimes for geoengineering should then be tailored accordingly. Those techniques scoring low against the criteria should be subject to no additional regulation to that already in place, while those scoring high would be subject to additional controls. So for example, at the low end of the scale are artificial trees and at the high end is the release of large quantities of aerosols into the atmosphere. SCIENCE AND TECH. COMM., THE REGULATION OF GEOENGINEERING: FIFTH REPORT OF THE SESSION, 2009-10, H.C. 221, at 18 (U.K.) [hereinafter HOUSE OF COMMONS REPORT].
[151] See Abelkop & Carlson, *supra* note 73, at 777; Bodansky (2012), *supra* note 122, at 2–3.
[152] Bradley, *supra* note 14, at 240; Briffa, *supra* note 22, at 451, 454; NAS REPORT, *supra* note 42, at 59.
[153] ROYAL SOCIETY, *supra* note 68, at 39.
[154] IPCC WORKING GROUP I, *supra* note 36, at 574; NAS REPORT, *supra* note 42, at 116.
[155] ROYAL SOCIETY, *supra* note 68, at ix–xii, 40, 57.

governance regime in place, a climate emergency could lead to rash, risky actions.[156]

The argument for multi-national regulation of deliberate SRM injections is bolstered by the possibility that, while having global impact, they can have a single source. At least in the short term, one country could proceed alone.[157] Yet, studies suggest that injected aerosols cannot be contained in one place in the stratosphere, such as only to cool the Arctic or any one region, but will inevitably spread so as to have a broad impact.[158] Other nations are not likely to accept one country unilaterally changing the world's climate, even if for the better, and no single nation may want to accept the risks associated with such a responsibility.[159] Even an avid proponent like Ken Caldeira readily concedes that "climate engineering is likely to result in relative winners and losers [and that] all such circumstances are pregnant with political tensions."[160] Equity demands shared governance; feasibility may require it.[161] As in every house, car, or shared office space, even more so in the world, people want to control the thermostat.[162]

Furthermore, scientists agree that any stratospheric aerosol injections large enough to combat global warming will have side effects, may impact various regions differently, and cannot simply create or restore an ideal climate.[163] Indeed, the Royal Society's Working Group on geoengineering warned in 2009:

> Although injecting sulphate aerosols into the upper atmosphere is designed to limit global average temperature increases, the actual benefits and drawbacks of doing this are unlikely to be evenly distributed across regions.[164]

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156 John Virgoe, *International Governance of a Possible Geoengineering Intervention to Combat Climate Change*, 95 CLIMATE CHANGE 103, 117 (2009).
157 Abelkop & Carlson, *supra* note 73, at 777; Caldeira & Wood, *supra* note 60, at 4054.
158 NAS REPORT, *supra* note 42, at 69.
159 See Bodansky (1996), *supra* note 143, at 310.
160 Caldeira & Wood, *supra* note 60, at 4054.
161 *Compare* Abelkop & Carlson, *supra* note 73, at 793–97, *with* Bodansky (1996), *supra* note 143, at 310. *See generally*, ROYAL SOCIETY, *supra* note 68, at 37–46. Caldeira stated that "it would be strongly preferable to obtain international consensus and cooperation before deployment and operation of any climate engineering system." Caldeira & Wood, *supra* note 60, at 4054.
162 See ROYAL SOCIETY, *supra* note 68, at 40; Victor, *supra* note 115, at 330 ("Bluntly, whose hand will be allowed on the thermostat?").
163 NAS REPORT, *supra* note 42, at 34.
164 ROYAL SOCIETY, *supra* note 68, at 39–40.

Studies suggest that, among other side effects, injections will reduce global precipitation, change regional rainfall patterns, modify the Asian and African summer monsoons, cause atmospheric ozone loss, increase photosynthesis, change sky color and clarity, and contribute to ocean acidification.[165] Added side effects would result from the delivery system.[166] Because many such effects are subtle and hard to document, people are likely to blame aerosol injections for all sorts of bad weather and unfavorable climate changes even if the injections did not cause them. Since atmospheric CO_2 lasts for centuries while sulfate aerosols remain in the stratosphere only months, any program offsetting the temperature impact of one with another must be sustained or a very rapid warming would result that could prove catastrophic to living systems.[167]

Despite these risks, no international governance system now exists for geoengineering.[168] Laws are necessary both to act in an orderly fashion and to limit unwanted action. In an early article on the topic, environmental law professor Daniel Bodansky predicted that "[t]he absence of an effective process for making international decisions is far more likely to frustrate proposals for climate engineering" than to facilitate it.[169] However, the absence of a governance system would logically impose greater constraints on more responsible actors than on less responsible ones.[170] Taking a balanced view, Bodansky recently observed that international regulation can cut either way:

> If we are concerned to keep the geoengineering option open, international governance might aim to facilitate or even promote geoengineering research, so that we have a better understanding of the feasibility, costs, and benefits of different geoengineering techniques. In contrast, if we are concerned about the potential risks of geoengineering, then geoengineering governance might aim to impose limits on geoengineering or to collectivize the decision-making process, in order to prevent actors from making decisions that might

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165 IPCC WORKING GROUP I, *supra* note 36, at 627, 629–34; ROYAL SOCIETY, *supra* note 68, at 31–32; Victor, *supra* note 115, at 326–28; Rasch, *supra* note 64, at 4030–33; Caldeira & Wood, *supra* note 60, at 4053–54.
166 FLEMING, *supra* note 41, at 247–49.
167 IPCC WORKING GROUP I, *supra* note 36, at 631; Victor, *supra* note 115, at 324; NAS REPORT, *supra* note 42, at 13, 36 ("[S]tratospheric aerosols dissipate within 1-2 years . . . as evidenced by the lifetime of volcanic forcing . . . . In contrast the climate forcing due to CO_2 persists for millennia even if emissions cease.").
168 Virgoe, *supra* note 156, at 109; NAS REPORT, *supra* note 42, at 121, 140; Bodansky (1996), *supra* note 143, at 310 ("The absence of an effective process for making international decisions is far more likely to frustrate proposals for climate engineering.").
169 Bodansky (1996), *supra* note 143, at 310.
170 See Victor, *supra* note 115, at 325.

> have serious, even catastrophic, consequence for others. Governance is needed, in the first case, to ensure sufficient geoengineering and, in the second, to avoid too much.[171]

Yet back-up legal systems inevitably exist and can point the way toward further regulation should anyone actually try to fix the climate using stratospheric aerosols.

B. From Common Law to International Governance

The arguments for international regulation of using stratospheric injections to lower global temperatures have led scientists, policy makers, and legal commentators to call for new, and sometimes sweeping, multinational treaties and governance regimes.[172] In 2015, NAS's geoengineering committee observed that any future treaty governing SRM would need to address the following three issues, which are similar to the questions raised in negligence actions:

> 1. How is it decided when the benefit to albedo modification will outweigh the harm? What metric is used?
> 2. What obligations do the acting parties have to compensate others for damages, anticipated or otherwise, caused by albedo modification? Who decides causality and how is it determined?
> 3. Who decides what is benefit versus harm, and on what time and space scales are such determinations made?[173]

To forge an international governance regime for SRM, some commentators suggest working through the United Nations or its agencies while others

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[171] Bodansky (2012), *supra* note 122, at 4.
[172] *E.g.*, *Charter for Geoengineering*, *supra* note 129, at 415; Reynolds, *supra* note 143, at 285 (calling support for international regulation "the unanimous opinion of those who advocate for consideration of, and research into climate engineering"); ROYAL SOCIETY, *supra* note 68, at xi ("It would be highly undesirable for geoengineering methods that involve activities or effects (other than simply the removal of greenhouse gases from the atmosphere) that extend beyond national boundaries to be subject to large-scale research or deployment before appropriate governance mechanisms are in place."). For a partial summary of such calls, see Carlarne, *supra* note 140, at 636–58.
[173] NAS REPORT, *supra* note 42, at 121.

favor using new or existing arrangements involving a voluntary consortium of key nations.[174]

In its 2009 study, the Royal Society concluded that governance issues raise greater obstacles to geoengineering than scientific or technical ones and noted that stratospheric injections "require some level of consensus among governments."[175] Yet nothing has been done to create an international governance regime for SRM methods. A legal expert recently termed it a "multilateral failure," but one that was predictable in light of past experiences with international management of the global commons.[176] Given national self-interest, uncertainty over methods, and public concerns, many expect little to change, at least in the near term.[177] If a treaty were attempted now, one policy analysis noted, "[m]ost countries would push for a ban, and most of the possible geoengineers would balk."[178]

The choice is not between international governance of stratospheric aerosol injections and no regulation of them at all. National sovereignty extends upward to the bounds of earth's atmosphere, which includes the regions where the injections would lodge.[179] Nations have jurisdiction over this space, or can assert it should they choose to do so. Furthermore, should injected aerosols have adverse impacts within its territory, any country would have jurisdiction to address those impacts and seek redress for them. In a 2011 law review article, for example, Tracy D. Hester noted that geoengineering projects launched from or impacting United States territory, and those directed by American citizens, would be subject to federal environmental protection laws.[180] In particular, he argued that stratospheric injections would be subject to the Clean Air Act.[181] Similar reasoning would apply to invoking the environmental protection laws of other nations and of individual American states, though Hester makes the point that "early climate engineering projects will likely be directed by U.S. citizens or

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[174] HOUSE OF COMMONS REPORT, *supra* note 148, at 40 (urging working through United Nations); Abelkop & Carlson, *supra* note 73, at 802–03 (favoring a consortium approach weighed according to stake in the enterprise or each participating nation). *See generally*, Virgoe, *supra* note 156, at 112–17.
[175] ROYAL SOCIETY, *supra* note 68, at xi, 40; NAS REPORT, *supra* note 42, at ix.
[176] Wirth, *supra* note 148, at 430 (quote), 434.
[177] *E.g.*, Reynolds, *supra* note 143, at 284-86.
[178] Victor, *supra* note 115, at 331.
[179] Bodansky (1996), *supra* note 143, at 315 (stating that the United States currently has no federal laws specifically addressing SRM efforts). NAS REPORT, *supra* note 42, at 140, 157.
[180] Hester, *supra* note 74, at 872–73. *See also*, NAS REPORT, *supra* note 42, at 136.
[181] *Id.* at 876.

within U.S. territory," which would favor using American environmental law.[182]

Drawing on the analogy that commentators frequently make between mid-twentieth century weather modification programs and possible future geoengineering,[183] state common law offers another back-up legal remedy for harms caused by stratospheric aerosol injections. The science of weather modification burst on the scene in 1946, when, using technology developed during World War Two, the General Electric Company (GE) announced the first successful cloud-seeding experiment.[184] Soon GE was claiming the ability to use dry ice and silver iodide crystals to create snowfall for ski resorts, make rain for farmers and water reservoirs, disperse fog at airports, and suppress or divert hail, thunderstorms, and possibly even hurricanes.[185] Almost as quickly, the threat of lawsuits from people damaged by the loss of rainfall or diversion of storms all but squelched the project, especially after a seeded hurricane off the Carolina coast in 1947 made a sharp turn and blasted ashore near Savannah, causing $23 million in damage.[186] No one ever proved that cloud seeding had any appreciable impact at all, and no liability resulted for any seeding-related injuries, but the threat of legal action under state common law served as an effective deterrent for GE.[187]

While the risk of liability could deter a deep-pocket developer like GE, it could not stop a fleet of enterprising, underfunded commercial cloud-seeders.[188] With faith in the power of science to transform the world riding high after World War Two and a seemingly simple technology that required little more than a plane capable of flying over clouds, a release system for dry ice, and a glut of decommissioned military pilots available for service, cloud-seeding took off. By 1951, up to a fifth of the nation's total land area

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[182] *Id.* at 872.
[183] *E.g*, Bodansky (1996), *supra* note 143, at 310–12; FLEMING, *supra* note 41, at 3, 12–14; NAS REPORT, *supra* note 42, at 209.
[184] Stanley Brooks, *The Legal Aspects of Rainmaking*, 37 CAL. L. REV. 114, 114–15 (1949); FLEMING, *supra* note 41, at 137–47.
[185] Vaughn C. Ball, *Shaping the Law of Weather Control*, 58 YALE L.J., 213, 214–24 (1948); FLEMING, *supra* note 41, at 154–55. For a listing of such claims by a key scientific promoter, see Louis J. Battan, *The Scientific Aspects of Weather Modification*, *in* CONTROLLING THE WEATHER: A STUDY OF LAW AND REGULATORY PROCEDURES 33–43 (Howard J. Taubenfeld ed., 1970).
[186] FLEMING, *supra* note 41, at 148–53; Ball, *supra* note 185, at 227; NAS REPORT, *supra* note 42, at 184.
[187] Ball, *supra* note 185, at 227. *See also*, NAS REPORT, *supra* note 42, at 27 (stating there is "'no convincing proof' that cloud seeding is effective"), 205.
[188] *See* Donald D. Stark, *Weather Modification: Water—Three Cents per Acre-Foot?*, 45 CAL. L. REV. 698, 708–09 (1957).

was targeted for seeding operations.[189] It did not matter at first that no scientific study could show that cloud-seeding worked. Farmers in drought-stricken areas were desperate for rain, promoters were boundless in their promises, and many people simply saw what they wanted to see in rainfall patterns. Stories mattered more than statistics.[190] Lawsuits followed but the only resulting deluge was a flood of law-review articles from academics eager to extend existing legal theories to a hot new topic.[191] Many of these articles analyzed various common-law claims in tort and property law that could be brought against cloud-seeders and proposed statutory schemes to govern the field.[192]

Most of the plaintiffs who made it to trial in weather-modification cases lost for failing to prove causation, but some secured injunctions against cloud-seeding.[193] Perhaps the best known of these decisions is *Southwest Weather Research, Inc. v. Rounsaville*,[194] in which a Texas appeals court affirmed an injunction issued by a trial court on behalf of West Texas ranchers who objected to hail suppression operations over their property. In its 1958 opinion, the court wrote:

> We believe that under our system of government the landowner is entitled to such precipitation as Nature deigns to bestow. We believe that the landowner is entitled, therefore and thereby, to such rainfall as may come from clouds over his own property that Nature, in her caprice, may provide. It follows, therefore, that this enjoyment of or entitlement to the benefits of Nature should be protected by the courts if interfered with improperly and unlawfully.[195]

The court concluded that modifying weather over another's property, done without the landowner's consent or official authorization, was illegal.[196]

Concerns over such rulings and their impact on weather control efforts led many states to enact regulatory regimes.[197] A Pennsylvania law,

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[189] *Id.* at 699. *See also*, Robert C. Fleagle, *Background and Present Status of Weather Modification*, *in* WEATHER MODIFICATION: SCIENCE AND PUBLIC POLICY 11 (Robert C. Fleagle ed., 1969) (putting this figure at 10% for the early 1950's).
[190] FLEMING, *supra* note 41, at 158–64.
[191] Robert W. Hunt, *Weather Modification and the Law*, *in* Fleagle, *supra* note 189, at 118–19 (footnote 2 includes a helpful listing of these law-review articles).
[192] *E.g.*, Ball, *supra* note 185, at 226–29, 237, 244; Brooks, *supra* note 184, at 116–21; Stark, *supra* note 188, at 704–6, 710–11; Note, *Who Owns the Clouds?*, 1 STAN. L. REV. 43, 46–63 (1948).
[193] *See* Hunt, *supra* note 191, at 125–28.
[194] Sw. Weather Research, Inc. v. Rounsaville, 320 S.W.2d 211, 213 (Tex. Civ. App. 1958).
[195] *Id.* at 216.
[196] *Id.*

for example, imposed licensing requirements on persons engaged in weather modification, urged research in the field, and provided compensation from the state for injured landowners.[198] The existence of this statutory scheme led a Pennsylvania court to deny relief to a local environmental organization seeking to stop a cloud-seeding program in 1968.[199] The federal government later added its own regulatory oversight in what became a classic case of bottom-up governance nudged along by the common law.[200]

The widening regulation of weather modification did not stop at the national level. While commercial cloud-seeding operations declined sharply in the United States during the late 1950s due to the lack of proven results, the American military continued to study weather modification systems for use in warfare.[201] For five years during the Vietnam War, the Air Force used clandestine rain-making operations to disrupt the flow of soldiers and supplies from north to south. Disclosure of these covert operations in 1971 led directly to the Environmental Modification Convention (ENMOD) barring the hostile use of weather modification. Signed by both the United States and the Soviet Union in 1977, the Convention took effect a year later after twenty countries ratified it.[202] Furthermore, in 1980, the U.N. Environment Programme (UNEP) adopted guidelines for international cooperation in weather modification programs having trans-boundary effects. Scarcely two decades after the development and initial deployment of scientific weather-modification methods, state, national, and international legal regimes had evolved in a bottom-up manner to govern the process. Something similar is likely to happen for the regulation of stratospheric injections, should they become an imminent possibility or common practice.

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[197] *Report of the Task Group on the Legal Implications of Weather Modification*, in TAUBENFELD, *supra* note 183, at 3 (By 1970, twenty-nine states had enacted statutes addressing weather modification) [hereinafter "*Report of the Task Group*"].
[198] Pa. Natural Weather Ass'n v. Blue Ridge Weather Modification Ass'n, 44 Pa. D. & C. 2d 749, 763 (1968).
[199] *Id*.
[200] For discussion of the federal regulatory role in weather modification, see Gordon J. F. MacDonald, *Federal Government Programs in Weather Modification*, *in* Fleagle, *supra* note 189, at 69–89; Ralph W. Johnson, *Federal Organization for Control of Weather Modification*, in TAUBENFELD, *supra* note 183, at 143–58; NAS REPORT, *supra* note 42, at 206. Bodansky, *supra* note 143, at 310 (One legal observer of the resulting regime later observed that, in contrast with the situation for geo-engineering, "at least for … local weather modification, we have a system of governance commensurate with the scale of the intended effects").
[201] Fleagle, *supra* note 189, at 11 (by the late 1950s, commercial cloud-seeding operations were a tenth or less than a decade earlier); FLEMING, *supra* note 41, at 170–79.
[202] FLEMING, *supra* note 41, at 179–86; NAS REPORT, *supra* note 42, at 206.

This is not to suggest that statutes and legal regimes governing weather modification cover geoengineering. Despite their superficial similarities, weather modification differs from geoengineering in fundamental ways. Weather is not climate: the former is the state of the atmosphere at a given place and time, the latter is the aggregate of such conditions over time.[203] Weather modification involves attempting to alter local atmospheric conditions, such as rain, snow, fog, wind, or heat.[204] Geoengineering refers to the deliberate, large-scale manipulation of the earth's climate in order to mitigate the effects of global warming.[205] Laws crafted to govern weather modification programs do not inevitably apply to geoengineering. This is clearly true for the sole international convention specifically addressing weather modification, ENDOC, because it restricts the hostile use of weather modification while, whatever its ultimate impact, geoengineering is designed for peaceful purposes.[206] Even the UNEP Weather Modification Guidelines focus on regional modification of atmospheric conditions, not global climate.[207]

The common-law principles that helped to spawn these statutes and legal regimes for weather modification, however, should apply to stratospheric injections designed to offset global warning. By their very nature, those injections cover the earth and affect the entire world. No place is exempt; every place is impacted. Even their warmest supporters concede that stratospheric injections will have adverse side effects and that their intended effect will harm some people and regions.[208] Overall global precipitation may decrease, for example, rainfall patterns could change and sunlight may become more diffuse.[209] "While ecosystems can survive occasional volcanic eruptions, it is not clear whether the consequences to

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[203] FLEMING, *supra* note 41, at 6–7.

[204] *See* W.T. EDMUNDSON, ECOLOGY AND WEATHER MODIFICATION, in Fleagle, *supra* note 189, at 89 ("weather modification actually seems to center on the rain-making problem"); *Report of the Task Group*, *supra* note 195, at 3 (describes weather-modification effects are "local").

[205] *See* ROYAL SOCIETY, *supra* note 68, at ix; NAS, *Geoengineering Climate: Technical Evaluation of Selected Approaches*, at 2 (Jan. 2015), *available at* https://www8.nationalacademies.org/cp/projectview.aspx?key=49540; Wirth, *supra* note 148, at 415.

[206] Bodansky, *supra* note 143, at 311 (noting further that ENMOD expressly exempts modification techniques done for peaceful purposes).

[207] *Id.*

[208] *E.g.*, Rasch et al., *supra* note 64, at 4030–33; Crutzen, *supra* note 36, at 213, 215.

[209] ROYAL SOCIETY, *supra* note 68 at 31; Keller et al., *supra* note 77, at 8–9; Victor, *supra* note 115, at 326.

ecosystems would be from long-term changes in direct/diffuse energy, or increases in UV radiation," one assessment team cautioned.[210]

The legal issues raised by adverse changes in local weather conditions, if caused by geoengineering, are similar to those raised by cloud-seeding. The reasoning in *Southwest Weather Research*, that "the landowner is entitled to such precipitation as Nature deigns to bestow," applies as much to rains reduced by stratospheric injections as to rains diverted by cloud-seeding, especially if the particles causing the effect are injected into the landowner's airspace.[211] Rights granted to protect access to sunlight might also apply.[212] As in cases involving cloud-seeding, the possible legal theories include water rights, nuisance, negligence, strict liability for ultra-hazardous activities, and trespass.[213] Admittedly, like cases involving cloud-seeding, [214] most suits would probably fail, but the mere risk of liability for cloud-seeding was enough to deter GE and spawn regulation, and the same could be true for geoengineering. Any stratospheric injection effort would likely be conducted or sponsored by a government or organization with deep-pockets.[215] Furthermore, much of the activity occurs in the United States or is funded by Americans, making it responsive to American courts.[216] Finally, foreign geoengineering activities could be subject to the law of various American states to the extent that they caused actionable injury in those states.

While the Royal Society's 2009 Report called for top-down international governance of geoengineering, an increasing number of legal

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[210] Rasch et al., *supra* note 64, at 4032.

[211] Sw. Weather Research, Inc. v. Rounsaville, 320 S.W.2d 211, 216 (Tex. Civ. App. 1958).

[212] *See, e.g.*, Prah v. Maretti, 321 N.W.2d 182 (Wis. 1982) (speaking of the equitable right to access to sunlight for solar power).

[213] Reviewing the use of many of these theories in cases brought against cloud-seeding, one exasperated legal commentator noted:

> [T]here is no agreement as to what theory or theories the courts should impose here. Litigation generally has followed a shotgun approach. Counsel for claimants has asserted every possible theory they could think of. The problem is that there are too many theories in the lawyer's bag of tricks.

Ray J. Davis, *Strategies for State Regulation of Weather Modification*, *in* Taubenfeld, at 185–92. *See also* Brooks, *supra* note 184, at 116–21; Ball, *supra* note 185, at 226–38; Hunt, *supra* note 191, at 119–25.

[214] *See* Hunt, *supra* note 191, at 125–28.

[215] For more information regarding weather modification on these matters, see Davis, *supra* note 211, at 193–96; FLEMING, *supra* note 41, at 148–49, 160.

[216] Victor, *supra* note 115, at 330. Bodansky, *supra* note 122, at 10. Most of the funding for geoengineering research to date has come from one American donor, Bill Gates.

commentators counter that such a treaty approach either is unlikely to happen soon or would be premature if done now.[217] Comprehensive treaty-making should wait, they say. Not enough is known about stratospheric injections and too much is at stake to proceed rashly. Nations either lacking the ability to conduct geoengineering or with strong environmental movements would likely favor a broad ban while those with power to control the process or strong business interests would want maximum flexibility, and nothing would result at this time.[218] Instead, these commentators call for a bottom-up approach utilizing case-by-case decision-making on a country-by-country basis or through a voluntary consortium of nations.[219] That approach could draw on and experiment with emerging norms of international governance, such as the precautionary principle, the duty to prevent significant trans-boundary harm, and the use of environmental assessments, which may not emerge from a treaty-making process.[220] Such an approach is compatible with the NAS committee's suggestion that the needed governance for SRM should be transparent and have input from a broad set of stakeholders, could build from diverse sources including existing or new norms, and may not initially involve formal regulation or an international treaty. "Governance," the committee wrote, "is not a synonym for 'regulation.'"[221]

Faced with a new technology filled with promise but fraught with danger, American courts can offer such a process and invoke such norms in cases brought by landowners or organizations seeking to use, stop, or limit geoengineering.[222] At the very least, judicial intervention can help prod and

[217] *Compare* ROYAL SOCIETY, *supra* note 68, at x, 40, 60–61, *with* Victor, *supra* note 115, at 325, 331–33. *See generally* HOUSE OF COMMONS REPORT, at 27–30.
[218] Victor, *supra* note 115, at 331; Virgoe, *supra* note 156, at 116–17; HOUSE OF COMMONS REPORT, at 27 (Explaining that the experts who gave us oral evidence favored a 'bottom-up generation of norms' rather than a 'top-down' approach from an organization such as the U.N."). *See also*, Bodansky, *supra* note 122, at 7–8, 11.
[219] Bodansky, *supra* note 122, at 7–8; Virgoe, *supra* note 156, at 116. Such an approach is also suggested in NAS REPORT, *supra* note 42, at 154.
[220] Victor, *supra* note 115, at 330–33; Bodansky, *supra* note 143, at 312–13.
[221] NAS REPORT, *supra* note 42, at 153–54 (internal quotation marks omitted); *see id.* ("[A]ppropriate governance of albedo modification research could take a wide variety of forms ranging from the direct application of existing scientific research norms to the development of new norms, to mechanisms that are highly structured and extensive."). This language leaves open options ranging from self-regulation by scientists and science funding organizations through common-law norms to formal treaties and new international agencies.
[222] For a discussion of this use of courts in the analogous situation of early weather modification operations, see Hunt, *supra* note 191, at 119–32; Ball, *supra* note 185, at 225–29. Some state Supreme Courts might use this opportunity to take a lead in developing law in this field. For an example of such a court**,** see, e.g., Adam

guide legislation and treaty making while at the same time offering a forum for parties to make their arguments, similar to what happened when weather modification operations began.[223] While the common law cannot produce a suitable end point for geoengineering governance, it can offer a serviceable starting point.

CONCLUSION

Earth's climate is a global commons that humans can and do significantly impact. Over the past century, we have impacted it unintentionally by burning enough fossil fuel to cause global warming. For humans and many other species, the result may be disastrous; it certainly will be serious. Geoengineering with stratospheric aerosols offers the promise of intentionally altering the climate to offset global warming. At this time, not enough is known to assess whether it is feasible to inject aerosols into the stratosphere in ways that will effectively offset global warming or what adverse side effects would result. Many experts worry that we can never know those side effects without irrevocably committing ourselves to pursue a potentially catastrophic course. Other experts believed that our current course of anthropogenic climate change is so risky that every option must at least be assessed, if not tried. In the absence of a rational international governance regime, which appears unattainable at present, existing national environmental statutes and state common law may offer our only starting point for regulation. We must work with what we have, even as we hope for more.

Nagourney, *Jerry Brown, Governor of California, Takes Second Chance to Shape Court*, N.Y. TIMES, Dec. 25, 2014, at A1.

[223] *See generally* the comments of John Virgoe to the House of Commons committee examining the issue of geoengineering governance in 2010:

> [I]f this is put on the table of some sort of UN forum, you could end up with a decision … to make geo-engineering a taboo, to outlaw it, and that would be a mistake …. What we need is an open process which builds on some of the principles that are already out there around similar issues; for example, principles developed to deal with long-range air pollution or weather modification: principles around openness, transparency in research, notifying a neighboring country or countries which might be affected. We probably develop these through maybe a slightly messier process than an international negation. Individual countries will have a role; communities of scientists will certainly have a role.

HOUSE OF COMMONS Report, *supra* note 148, at 27 (emphasis added).