

ADVANCED REVIEW

Science-state alliances and climate engineering: A ‘longue durée’ picture

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Abstract

Since the early 2000s, proposals to deliberately modify the Earth's climate have gained political traction as a controversial last resort measure against dangerous global warming. The article provides a ‘longue durée’ picture of such climate engineering proposals. It traces their historical trajectory from the late 1950s to their most recent arrival on mainstream climate policy agendas. This perspective suggests that the history of climate engineering unfolds not only along historically specific modes of understanding climatic change. It also corresponds to changing alliances between climate science and the state. By bringing together historical scholarship with contributions from sociology and science policy studies, the article sheds new light on the rise of climate engineering proposals. It recontextualizes these proposals within the bigger history of the political cultivation of climate science. This perspective highlights how deeply entwined efforts to understand and efforts to govern climatic change have always been.

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climate change, climate engineering, geoengineering, scientific expertise, weather modification, climate science

1 | INTRODUCTION

Spraying sulfuric aerosols into the stratosphere, seeding stratocumulus clouds with tiny droplets of seawater, installing artificial ‘trees,’ or fertilizing the oceans: since the early 2000s, a set of controversial proposals has arrived on international policy agendas to counteract climate change. Under umbrella terms like ‘climate engineering’ or ‘geo-engineering’ these proposal are usually sorted into two categories: on the one hand, there are measures to remove carbon dioxide from the atmosphere and store it for long periods of time underground or in the oceans

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(carbon dioxide removal or CDR). On the other hand, there are measures to reflect incoming sunlight back into space (solar radiation management or SRM).

Such climate engineering proposals have gained political traction in recent years as a kind of last resort option to halt increasingly dangerous global warming (Connor & Green, 2009; Fialka, 2020; Fagniere & Gardiner, 2016; Huttunen & Hildén, 2014; Kreuter, 2015; Lederer & Kreuter, 2018; Luokkanen et al., 2014; Oomen & Meiske, 2021; Pierrehumbert, 2019; Victor et al., 2009). Scientists, it seems, are finally stepping in to tackle a problem that politicians remain unable to solve. Climate engineering, in short, is explored as a controversial response to a dire crisis.

This prevailing narrative of climate engineering notably conflicts with a body of literature which has pointed to the longer-standing history of these measures (see, particularly, Baskin, 2019; Fleming, 1998, 2010; Keith, 2000, Oomen, 2021; Schubert, 2021; Stilgoe, 2015). Such accounts have dated the historical roots of climate engineering back to the first half of the twentieth century and beyond, suggesting that these proposals are, in fact, older than the very crisis they promise to address. This raises the question, then, of how crisis and remedy, action and reaction, precisely interrelate in this story of climate engineering. It points us to the joint roots and deep entanglements between efforts to understand and efforts to control human impacts on the climate. While some climate engineering scholars have begun to highlight the need to further explore these connections, it is primarily the notion of a “disjuncture” from “conventional” climate science and policy that defines our understanding of climate engineering today (Stilgoe, 2015, pp. 64–65). This narrative of disjuncture is rooted in the politics of climate engineering research. It caters to advocates who wish to emphasize the novelty of these measures, potentially revolutionizing previous climate policy approaches. But it also serves critics who seek to delegitimize climate engineering by removing it from mainstream science and policy discourses. Yet, as Jack Stilgoe (2015, p. 65) aptly put it, this narrative of disjuncture “obscures a more complicated history.” Taking into account the central role that hopes of climate control have played in the formation of the climate science field will be essential for a meaningful engagement with such proposals today. This is especially so, if climate engineering is deemed “barking mad” (Pierrehumbert, 2015).

Histories of climate engineering are necessarily manifold. This article seeks to add another layer to the picture. It tells the story of climate engineering as a story of historically changing alliances between climate science and the state. To do so, the text assesses scholarship on the historical emergence of climate engineering in light of historical, sociological, and political research on the relationship between climate science and the state. The notion of science-state alliances is meant to draw our attention to the reflexive relation between science and (governmental) politics (see, e.g., Allan, 2017; Baker, 2017; Jasanoff, 1987, 1990, 2004; Salter, 1988). This relation is reflexive in the sense that it is not linearly defined by either side. Nor does it imply a concerted effort by scientists and politicians to join forces in a common struggle. Instead, this relation is defined by historically contingent settings that link scientific and political interests. In reference to the work of Pierre Bourdieu, environmental sociologist Zeke Baker (2017, p. 2) speaks of “matched struggles” in a similar sense. That is, to describe how “scientific and government actors have linked conflicts” respectively.

To analyze such science-state alliances in the case of climate engineering, this article focuses on the context of U.S. climate science policy. From this perspective, climate engineering hardly emerged from the fringes of policy agendas. Instead, we will see how hopes of being able to intervene in, modify, and control atmospheric processes have provided a central motif in efforts to cultivate climate science for the state. Rather than providing a daunting last resort for this dire crisis, historically specific versions of climate engineering stood at the beginning and have remained a central driving force for our current knowledge and understanding of anthropogenic climate change.

After providing a short overview of the review’s methodology and literature corpus, the article distinguishes three critical episodes in the genesis of climate engineering, spanning the timeframe from the 1950s to the 2020s: During the afterwar years, it was hopes of control and visions of mastery that defined alliances between climate science and the state and shaped the then-emerging field of weather and climate modification (*Years of Mastery*). The subsequent politicization of global warming questioned these visions of mastery. Human impacts on the climate came to be understood as a problem, thereby fracturing established science-state alliances (*Years of Fracture*). With the turn of the new millennium, the crisis of climate change progressed. The notion of crisis now came to define political interest in climate science, effectively pushing climate engineering as a potential last resort option into the climate policy mainstream (*Years of Crisis*).

2 | METHODOLOGY

This review builds on three kinds of literature. First and foremost, it rests on a review of existing ‘histories’ of climate engineering. Such histories are not limited to historical scholarship, but include interdisciplinary accounts that seek to make sense of the historical emergence and trajectory of climate engineering proposals. It should be noted, that even after two decades of intensifying debate over climate engineering, this body of literature remains surprisingly small (see, e.g., Baskin, 2019; Fleming, 2010; Keith, 2000; Oomen, 2021; Schubert, 2021; Stilgoe, 2015; for the context of weather modification, see, e.g., Harper, 2017; Kwa in Miller & Edwards, 2001). The article contextualizes these histories of climate engineering, secondly, with the rich body of historical, sociological, and political research that has explored relations between climate science and the state. While much attention has been paid to essential conflicts between climate scientists and (party-)political interests, this article focuses in particular on the many ways in which climate science and politics have built on and shaped one another. Third and finally, the article considers a ‘gray’ kind of literature, namely U.S. science policy reports. These policy reports serve as empirical hinges that link the histories of climate engineering with the formation of the climate science field and its relation to state interests more broadly. In other words, they illustrate some of the essential points of connection between the two previously mentioned lines of inquiry and provide an important empirical foundation for the argument at hand.

3 | YEARS OF MASTERY: CLIMATE MODIFICATION

After the end of World War II, the field of weather and climate modification (WCM) emerged as nucleus for the debate over climate engineering today. This field of WCM provides a particularly meaningful starting point for historicizing the current debate in at least two respects. First, the field unites the roots both to what would later be understood as the problem (namely global warming) *and* to what would later be explored as the controversial response (namely climate engineering). It therefore suggests the contingent trajectory of the current climate engineering debate. Second, this field of WCM illustrates how early visions of climate modification have provided a central motif for state support of the atmospheric sciences, especially during the 1950s and 1960s. This episode thus demonstrates how immediately the history of climate engineering has intersected with the formation of the climate science field more broadly.

3.1 | Drawing connections between WCM and climate engineering

In one of the earliest efforts at historicizing climate engineering, David Keith (2000, p. 247) suggests to focus on two dimensions in particular, when exploring connections between early WCM programs and current climate engineering proposals: namely the scale and intent of the proposed measures.¹

Regarding the *scale* of WCM, it is the joint treatment of weather *and* climate that seems to differ most notably from current climate engineering debates. A national policy assessment of the WCM field, which Keith mobilized in this context, illustrates for example that WCM included the modification of “large-scale weather” as well as “local and regional climates” (U.S. National Research Council, 1966, p. 4); it was concerned with measures to modify rain, hail, lightning, hurricanes, cyclones or storms, but also sought to provide a “comprehensive theory of natural climate change” and the “theoretical simulation of global atmospheric behaviour” (U.S. National Research Council, 1966, pp. 8–9). This sweeping scope of the WCM field can be explained quite simply by the historical evolution of the used concepts. Historians of meteorology have pointed to the fact that climate science was part of meteorology for most of the twentieth century. That means that notions of climate and weather “were not just intimately connected, they were essentially identical” (Miller, 2004, p. 51; see also Baskin, 2019, p. 34; Fleming, 2010, p. 7). The joined treatment of weather and climate in the WCM programs of the 1950s and 1960s therefore does not categorically separate these endeavors from current climate engineering debates. Quite to the contrary, it points to a relevant development in the problematization of climate as aggregated weather phenomena. It was not until the 1980s really that climate and weather became differentiated into two objects and that the climate emerged as a global category (Edwards, 2006, 2010; Miller, 2004; Miller & Edwards, 2001). In what remains one of the most comprehensive and authoritative accounts on the history of climate engineering, historian Jim Fleming therefore expands in much detail on the rain-making and cloud seeding schemes of Cold War “weather warriors” as important precursors of today’s climate intervention proposals (Fleming, 2010).

Regarding the *intent and goal* of early WCM programs, it is particularly the distinction between “deliberate” and “inadvertent” weather and climate modification that sticks out in hindsight (U.S. National Research Council, 1966, p. 1; see also: U.S. National Science Foundation, 1965, p. 7). This distinction of deliberate versus inadvertent modification has been picked up not only by climate engineering scholars but also quite prominently by historians of meteorology (see, e.g., Fleming, 1998, 2010; Harper, 2017; Weart, 2010; Miller & Edwards, 2001). It points us to a historically specific problematization of human impacts on the climate, which differs substantially from the kind of problematization that would gain traction towards the end of the century and defines current climate engineering debates. WCM programs explored the human potential to alter the Earth’s weather and climate not primarily as a problem, but rather as challenge and opportunity (Schubert, 2021). This did not, however, imply a purely optimistic outlook (Keith, 2000). Quite to the contrary, these programs were driven by the realization that societies depend on and shape climatic conditions as part of their natural environment. Beginning in the 1960s, WCM increasingly included concerns over unintentional, unwanted, inadvertent modifications—addressing precisely the flipside of human control over the climate (Bonnheim, 2010; Keith, 2000; Oomen, 2021; Schubert, 2021; Stilgoe, 2015; Weart, 2010). Against this backdrop, research into WCM followed a twofold goal: On the one hand, it promised a better understanding of human modifications of the climate. What is discussed today as global warming emerged in this context as one kind of “inadvertent climate modification.” In his early history of the climate engineering debate, Keith (2000, p. 250) suggested that the 1966 report by the National Academy includes an “excellent summary of the CO₂-climate problem,” marking the “first extensive treatment” of the issue in the context of an Academy’s report. “Today,” the Academy’s Panel warns in the section quoted by Keith, “unintentional alteration of the atmosphere by man is a minor problem compared with what it will be one or two generations hence” (U.S. National Research Council, 1966, p. 10).

On the other hand, WCM programs promised the deliberate and beneficial use of atmospheric modifications. In his historization of the climate engineering debate, Jack Stilgoe (2015, p. 67) suggests how particularly a report by the U.S. National Science Foundation (1965) focused on the notion of “triggering opportunities.” The growing awareness of the complexity and instability of weather and climate events gave rise to the idea that this complexity could be used: “the idea of taking advantage of the instability of weather was central to the [NSF] report’s conclusions” (Stilgoe, 2015, p. 68).

Taken together, these historical analyses thus suggest how the field of WCM contained important roots, both to what is discussed today as global warming *and* to what is discussed today as climate engineering. Instead of relating these two as problem and response, however, WCM programs explored them as two sides of the same equation; as deliberate and inadvertent modification.

3.2 | Knowing and making the climate: Science-state alliances around WCM

In their efforts at historicizing current climate engineering debates, a number of science studies and science policy scholars have suggested paying attention to another, overarching, dimension of these WCM programs. In addition to exploring dis/continuities in the scope and intent of the proposed measures, these accounts have shed light on the alliances between climate science and the state that have defined the field of WCM (see in particular Baskin, 2019; Oomen, 2021; Schubert, 2021; Stilgoe, 2015). These accounts suggest that the field of WCM emerged during the 1950s and 1960s not only as a technological and ideational precursor to current climate engineering proposals. What might be even more significant is that these early notions of climate modification stood at the heart of climate science policy at the time—a point that Keith (2000, p. 249) has already alluded to more than 20 years ago. Put differently, it was a political vision for climate science that shaped this emerging field of WCM and linked the history of climate engineering to the history of climate science more broadly. Baskin (2019) has described this vision as a “Vision of Mastery,” which was held both by policymakers and scientists and entailed a belief that “any problem...could be fixed” by techno-scientific intervention (Baskin, 2019, p. 29; see also Bonnheim, 2010, p. 892). During the beginning of the Cold War, this vision united scientists and policymakers in a “triumphant marriage” (Balogh qtd. in Harper, 2017, p. 82).

This “triumphant marriage,” then, provides further context for explaining the broad scope and various goals of WCM programs as discussed above. These WCM programs bound together hitherto disparate lines of modification efforts, comprising commercial as well as scientific endeavors, extending from Irving Langmuir’s rain-making experiments all the way to meteorological interests in understanding, modeling, and predicting atmospheric behavior (see particularly Harper, 2017; Hart & Victor, 1993). For politics, this connection promised a powerful tool for the state. Policymakers hoped to rationalize and push forward thus far rather erratic and unsystematic rain-making attempts. For

meteorology, this “broad view” of WCM promised sustained political support (Hart & Victor, 1993, p. 658f). Historical and sociological scholarship has emphasized just how closely this formation of the climate science field had been linked to interests of the state (Baker, 2017; Edwards, 2006; Fleming, 2010; Harper, 2008, 2017; Hart & Victor, 1993). During World War II, the military challenges of an air-based war had directly “matched” the scientific challenges of understanding atmospheric circulation dynamics (Baker, 2017, p. 8). In effect, the War had turned meteorology and oceanography into a national priority in the United States. It thereby pushed scientific boundaries and fostered disciplinary formation and the professionalization of meteorology. Beginning in the 1950s, meteorologists were confronted with the challenge to sustain this vital support by the state. The scientists were “painfully aware” that the recognition and establishment of meteorology as “a real science” had been closely connected to military interests in weather forecasting (Harper, 2017, p. 131). Now, that the war had ended, they worried that their discipline would “fall back into being a practice of ‘amateurs’” (Baker, 2017, p. 10).

WCM promised help in this context. Although the notion of climate control had many meteorologists of the time “eye-rolling,” its sheer promise as a tool for the state catered to U.S.-national strategic concerns of the time (Harper, 2017, pp. 83–84). Spurred by the launch of Sputnik, concerns over the techno-scientific superiority of the Soviet Union incrementally moved WCM “to the top drawer of national science politics” in the United States (Keith, 2000, p. 252). “[P]romoting the benefits of weather prediction (and control)” thus allowed meteorologists to secure funds and the political support that would sustain the further professionalization and bounding of their discipline (Baker, 2017, p. 11; Baskin, 2019, p. 37; Harper, 2008, 2017; Hart & Victor, 1993). WCM effectively served to “implicat[e] ‘basic’ research in techniques of statecraft”; it turned progress in meteorology—and particularly in Numerical Weather Prediction—into a national priority (Baker, 2017, p. 19).

This historical perspective on the formation of the climate science field importantly complements existing histories of climate engineering. It suggests how—despite failures in concrete modification programs of the time—the notion of weather and climate modification played a central role in shaping the future development of meteorology (Baker, 2017, p. 11). The strong focus on Numerical Weather Prediction made the atmosphere into “a new kind of object for meteorologists,” as Baker explains, “a global physical system that could be rendered calculable, in addition to being observed and mapped” (Baker, 2017, p. 11; Edwards, 2010). During the 1960s, the field of climate science coalesced around climate models, integrating lines of meteorological, oceanographic, and atmospheric research (Allan, 2017, p. 146; Baker, 2017; Edwards, 1999, 2006, 2010; Hart & Victor, 1993). This new outlook, in turn, further fuelled hopes for control. Climate science later emerged as a bounded scientific field precisely based on its capacity to “shape the national security state”; it thrived because it was aligned with the continuing geopolitical challenges of the time (Baker, 2017, p. 14).

4 | YEARS OF FRACTURE: CLIMATE CHANGE

In 1965, the President’s Science Advisory Committee published a report entitled “Restoring the Quality of Our Environment” (1965). This report heralded a new stage in the history of climate engineering. And, again, this policy assessment provides a central hinge, linking the history of climate engineering to the history of climate change: The Advisory Committee not only presented “the first official government statement on global warming” (Bonnheim, 2010, p. 893), warning President Johnson that CO₂-induced climate change might be “deleterious” for humanity. It also advised the president to explore measures of climate modification as a potential response to address this very problem (The President’s Scientific Advisory Committee, 1965, p. 127; see also, e.g., Keith, 2000, p. 254, Stilgoe, 2015, p. 68; Weart, 2010, p. 71). Somewhat ahead of its time, this report thus prepared a momentous departure from the WCM programs of the 1950s and 1960s: instead of exploring human modifications to the climate in the form of inadvertent and deliberate modifications, the report related the two as *problem and response* for the first time (Schubert, 2021). In the following, we will see how this reconfiguration marked a more general shift in climate science-state alliances, which would unfold over the following decades and was driven by the politicization of anthropogenic climate change. This shift moved us from an era of “modification,” which problematized human-climate relations primarily through the lens of control or mastery, to an era of “change,” which looked at these relations through fears of a loss of control.

4.1 | The politicization of a problem ...

During the 1970s and 1980s, anthropogenic climate change emerged as an issue of global political significance (Edwards, 2010; Fleming, 1998; Edwards in: C. Miller & Edwards, 2001; Weart, 2008, 2010). One result of this politicization, which may seem somewhat surprising at first glance, was that political interest in WCM waned (Kwa in Miller & Edwards, 2001). Scholarship on climate engineering has grappled with this dynamic by declaring the advent of a putative “taboo”, a “hiatus” of climate engineering in the years that followed (Baskin, 2019; Keith, 2013, p. 92; Schelling, 1996; for critical voices on the notion of a taboo, see, e.g., Oomen, 2021; Stilgoe, 2015). Literature on the historical emergence of climate engineering has explained this particular development with a general shift in “the public and the scientific imagination” regarding the relation between humans and nature (Oomen, 2021, p. 55; see also Baskin, 2019, p. 43f). This “imagination” was defined by an awareness of the complexity and fragility of atmospheric phenomena. Anthropogenic climate change gained political traction against the backdrop of a spectacular rise of environmentalism which had raised its head in the 1960s already. Propelled by the atrocities of World War II and the Vietnam War, social movements of the time drew attention to the grim side of techno-scientific interventions. Awareness regarding the adverse consequences and vulnerability of societies vis-à-vis their own technological progress rose. Importantly, this awareness was fuelled in part by a backlash against covert weather modification operations by the U.S. military (e.g., Fleming, 2010, p. 179–186; Harper, 2017, p. 230f; Keith, 2000, p. 254; Kwa in: C. Miller & Edwards, 2001, p. 152f). In this particular setting, climate change became politicized as an issue of environmental safeguarding, a problem that marked the limits of human control over the climate. It emerged as a challenge to reduce, rather than expand techno-scientific intervention capacities; and this meant, it emerged as a challenge which precisely curbed earlier political excitement over the prospect of deliberate climate modification (Baskin, 2019, p. 43f.; Keith, 2000, p. 253; Kwa in: C. Miller & Edwards, 2001, p. 152).

A number of accounts by science studies scholars and political scientists have carved out how this particular politicization of anthropogenic climate change fundamentally redefined alliances between climate science and the state (see especially Baker, 2017; Hart & Victor, 1993; Lahsen, 2008; Schubert, 2021). Baker (2017, p. 19) even speaks of a “historical inversion of prior science-state relations” to mark the fracture imposed on established visions of atmospheric mastery and control. In contrast to the 1930s through 1960s, atmospheric research no longer seemed to promise a tool to expand control and state power. Quite to the contrary, the field began to establish itself around an issue, which seemed to question the very hopes of control that had defined the political cultivation of this research until then. Esteemed climate scientists, such as Stephen Schneider and William W. Kellogg, warned that progress in weather and climate prediction would not necessarily lead to options of control (Kellogg & Schneider, 1974, p. 1163). Like Jim Hansen or Rachel Carson, these researchers represented a “new breed” of scientists who “raised the alarm” about climate change and other environmental issues (Turner & Isenberg, 2018, p. 33). In this new role, climate science thus “came to haunt the politics of mastery,” which had defined the very grounds of this field (Baker, 2017, p. 19). During the 1980s, more and more funding was attributed to research that explored “the detrimental environmental effects of human actions” (Lahsen, 2008, p. 210).

The fact that established alliances between climate science and the state began to crumble during the 1970s, hardly implied that they were abandoned altogether. As suggested earlier, these alliances merely underwent a substantial shift. Political scientists have pointed to the crucial role that climate scientists played, not only in placing climate change on the political agenda, but also in defining the terms in which the issue was problematized and addressed (Allan, 2017; Hart & Victor, 1993; Pielke, 2000). As a result, during the 1970s and 1980s, climate change became assembled in the political realm as a geophysical object. It emerged as “the CO₂ problem” or “the greenhouse problem”; an issue of managing atmospheric chemistry and carbon dioxide pollution (Allan, 2017; Charney et al., 1979; MacDonald et al., 1979; Nierenberg et al., 2010, p. 219; Pielke, 2000, p. 13). Climate change was no longer conceptualized in its plural form—as climatic changes, concerning the meteorological conditions of individual places and geographic regions. Instead, it was now devised as a global category, “something more closely akin to the global environment: a natural object to be understood, investigated, and managed on planetary scales” (C. Miller & Edwards, 2001, p. 7; Edwards, 2010; Oomen & Meiske, 2021, p. 64).

4.2 | And the emergence of a potential response

In the context of this new role of climate science for the state, modification measures changed their shape and status. Keith (2000, p.53f) provides an initial overview of policy assessments by the National Academy of Sciences (NAS), that

were aimed at devising a research agenda for the atmospheric sciences. This overview is especially instructive in tracing this shift in the status of climate modification measures. Building on these policy assessments, Keith (2000, p. 255) traces how in the 1970s and 1980s, climate engineering became part of an agenda that envisioned climate science as catering to concerns over how to protect the climate as a fragile geophysical system.

One of these reports, the 1977 NAS assessment on “Energy and the Climate,” for example, raised the question of “[w]hat [...] the atmospheric carbon dioxide content [should] be over the next century or two to achieve an optimum global climate?” (U.S. National Academy of Sciences, 1977, p. ix, emphasis in original). Measures to modify the climate were envisioned here as a means for achieving this “optimum global climate”; they were seen as a potential approach to managing atmospheric chemistry and counteract CO₂ pollution. In this new setting and outlook, modification measures were of course hardly discussed as the only, let alone preferable option to respond to dangerous climate change. This must not necessarily be interpreted as implying a “taboo”. Rather, climate modification now stood in the context of a variety of different response measures that policy makers and expert bodies considered, each mobilizing different constituencies over how to effectively tackle anthropogenic climate change.

Together with the aforementioned “Energy and the Climate” volume from 1977, Keith (2000, p. 255) mobilizes two further reports from 1983 and 1992 in his overview, which he argues formed “a chain” of assessments on this issue, “linked by shared authorship, and explicit cross-references”. The 1983 assessment provides one of the earliest climate policy frameworks, a four-tiered taxonomy of policy options to address “CO₂-Induced Climatic Change” (U.S. National Research Council, 1983, pp. 58–59). In addition to “Reduc[ing] CO₂ Production (1)” and “Adapt[ing] to Increasing CO₂ and Changing Climate (4),” the framework suggests the option to “Remove CO₂ from Effluents or Atmosphere (2)” and to “Make Countervailing Modifications in Climate, Weather, Hydrology (3).” Around a decade later, the Academy presented its 1992 assessment of “Policy Implications of Greenhouse Warming,” which featured an entire chapter evaluating “Geoengineering” measures (U.S. National Academy of Sciences, 1992, pp. 437–464) and has become a central point of reference within histories of climate engineering to suggest early U.S. policy interest in such measures (see, e.g., Baskin, 2019; Fleming, 2010; Oomen, 2021; Stilgoe, 2015).

These three reports also indicate how the notion of climate modification incrementally became differentiated to comprise what is commonly referred to today as CDR or negative emissions approaches on the one hand and SRM on the other. In their promise to tackle the “greenhouse problem,” these two sets of fundamentally different techno-scientific concepts became part of one (climate) policy agenda (e.g., U.S. National Academy of Sciences, 1977; U.S. National Research Council, 1983, pp. 58–59; U.S. National Academy of Sciences, 1992, pp. 437–464). The two sets of techno-scientific concepts had been introduced respectively in two scientific contributions from 1977. In his book “Climatic Changes,” Russian geoscientist Mikhail Ivanovitch Budyko provided one of the first suggestion of what is discussed today as Solar Radiation Management (SRM) (Budyko, 1977; for the significance of this contribution to the history of climate engineering, see also Fleming, 2010, p. 241; Stilgoe, 2015, p. 162). That same year, Italian physicist Cesare Marchetti formally introduced the term “geoengineering” in the inaugural issue of *Climatic Change*—a term, which would increasingly replace the notion of climate modification over the following decades (Marchetti, 1977; see also Schneider, 1996, p. 292). To address “the problem of CO₂ control in the atmosphere,” Marchetti (1977, p. 59) proposed to collect and dispose CO₂ in the oceans.² Fuelled by increasing political interest in “managing” the CO₂ problem, a wave of Ocean Fertilization studies followed during the 1990s, marking the beginning of international studies on climate engineering measures (Lawrence and Crutzen in: Blackstock & Low, 2019, p. 90; see also Hamilton, 2013, p.31f).

5 | YEARS OF CRISIS: CLIMATE INTERVENTION

As we enter the first decades of the new millennium, climate modification measures incrementally gained more attention as a potential policy tool against dangerous global warming. What was now commonly referred to as geo-engineering, climate engineering, or climate intervention, became established as “a bad idea whose time has come”—a last resort in responding to a dire crisis (Baskin, 2019; Fleming, 2010; Hamilton, 2013; Kintisch, 2010; Morton, 2016; Oomen, 2021).

This status of climate engineering during the early 2000s has to be understood in the context of the continuing politicization of climate change as captured by a host of political, sociological, and historical analyses. Climate engineering took shape and gained traction during these years in response to a growing sense of urgency regarding the problem of climate change. Metaphors of “climate emergencies” and “tipping points,” from which there would be no return,

defined the scientific and political debate of the issue and “struck a cultural nerve” (Fleming, 2010 p. 227; see also Kintisch, 2010, p. 39; Lenton, 2011; Russill & Nyssa, 2009). Research on the politicization of the climate change issue has suggested how public concern for climate change reached a “historic high” in 2000 (Turner & Isenberg, 2018, p. 168; see also McCright & Dunlap, 2011). Climate change, in short, was increasingly made sense of as a crisis (Paglia, 2018). This notion of crisis corresponded to a growing concern by scientists and the public that global mitigation efforts would be not enough. Baskin (2019, pp. 76–81) observed a general disappointment of public hopes for a global solution to this and other environmental issues.

James Turner and Andrew Isenberg suggest how, in the United States, this continuing politicization of climate change entailed a growing division of policy agendas. While both the Democratic and Republican parties had been champions of environmental policies throughout the late 1980s, it was precisely the politicization of global warming which changed this (Turner & Isenberg, 2018). In 1997, Bill Clinton failed to sign the Kyoto Protocol due to opposition from the Senate (McCright & Dunlap, 2003); and the subsequent administration of George W. Bush stood decidedly against binding emissions reductions for the United States, which further fuelled political conflict and turned climate change into the quintessential partisan issue (Brechtin & Freeman, 2004). Science and technology emerged as a core battleground in this context (McCright & Dunlap, 2011). While scholarship on the politicization of climate change has particularly emphasized the role of science in either motivating or halting policy action on climate change (Farrell, 2015; Jacques et al., 2008; Oreskes & Conway, 2010), the fate of climate engineering during the early 2000s further complements this picture. Instead of standing “with” or “against” climate science, the case of climate engineering suggests that the lines of (political) conflict follow different visions for science and technology in the state.

5.1 | Climate engineering as techno-fix

In the first decade of the new millennium, climate engineering gained political traction as a highly controversial techno-fix (Baskin, 2019, pp. 129–133; Schubert, 2021, pp. 143–166). At the time, the Bush administration sought to expand the focus on technology in its climate science policy portfolio. Climate engineering emerged on the Congressional agenda in this context as part of an effort to redefine the role of climate science in the state and thereby fundamentally alter the politics of climate change. It became part of an agenda that sought to reinstate climate science—and particularly technology—as a tool of control at the hands of the state. In his historical sketch of the period, Baskin (2019, p. 85) suggests that we can find resounding “echoes of the mastery imaginary” here, which had defined the politics of climate modification during the first half of the twentieth century.

Climate engineering and climate change research more generally was invoked here as the solution itself: instead of questioning the economic and political status quo, this research was promoted as a means to trigger technological innovation in responding to the climate change issue; a kind of weaponry to tackle, combat, and ultimately “win” the climate change challenge (Schubert, 2021, p. 146). It was the promise to perpetuate the political and economic status quo that enticed a White House which was “officially skeptical” of global warming to explore climate intervention measures (Fleming, 2010, p. 253; for the case of CDR measures, see Carton et al., 2020, p. 7).

This entailed a vision for science that would cater to decidedly national interests. Climate engineering promised to expand national power and reinstate national agency in the face of a global challenge (Baskin, 2019, p. 76). For the case of carbon removal approaches, for example, Carton et al. (2020, p. 6) show that particularly those states which had generally opposed international policy agreements on climate change were the ones in favor of including carbon sinks in the Kyoto Protocol (for the international science controversy around carbon sinks, see also Lahsen 2009). In contrast to binding policy agreements on emissions reductions, CDR approaches in this sense seem to provide a techno-fix to the issue at hand, allowing for national independence in tackling climate change. Closely connected, climate engineering catered to corporate and economic interests in this context. U.S. Congressional exploration of climate engineering during these years rested particularly on economic analyses and expertise. Accounts on the more recent development of climate engineering within U.S. climate policy illustrate how Congress invited expert witnesses, such as David Schnare from the Heartland Institute or Lee Lane from the American Enterprise Institute, both of whom stand for “climate inactivist” voices (Baskin, 2019, pp. 85, 130–133; see also Schubert, 2021). Schnare and Lane built their testimonies substantially on analyses by economists like Thomas C. Schelling or William Nordhaus, two co-authors of the 1983 and 1992 Academy’s assessments. In their analyses, Schelling and Nordhaus propose that tackling climate change by means of climate engineering would hardly require questioning the status quo, but would “involve just spending money” (Schelling, 1996, p. 306; see also Nordhaus, 1990, 1992, p. 1317). In these accounts, climate engineering was mobilized

as offering a managerial gaze onto the climate change issue instead of challenging established economic infrastructures around the supply side of emissions. In a similar vein, US CDR research which was centered at the Department of Energy at the time and was driven by the goal to provide economical “solutions” to the climate change issue (Schubert, 2021).

Such hopes for a techno-fix, which would help to avoid confronting existing energy infrastructures and the corporate landscape that was built on it, thus explain much of the support for climate engineering research during the early 2000s. However, they also explain much of the controversy surrounding this debate since then. This techno-fix rationale proved unsuccessful as an official narrative that would move climate engineering further into the climate policy mainstream. It very much appeared like an “echo” from different times, as Baskin suggests (Baskin, 2019, p. 85, see also Stilgoe, 2015, p.69f). Accounts, which sought to promote climate engineering as an alternative to deep emissions cuts, were therefore “rarely found” in official policy assessments (a notable exception being the widely propagated argument that Solar Radiation Management will be cheaper than mitigating carbon emissions) (Baskin, 2019, p. 99). As an official “Plan A,” in other words, climate engineering did not become successful (Baskin, 2019, p. 85). This did not mean, however, that climate engineering measures were taken off the climate policy table.

5.2 | Climate engineering as last resort: A synthesis?

Oddly enough, it was precisely at the time of the incoming Obama administration in 2009, that climate engineering officially arrived on the climate policy agenda as a potential response against global warming. In a concerted effort with the UK parliament, U.S. Congress began establishing an official record on these measures, a first important step in any legislative process on newly emerging issues. This “official record” comprised a variety of documents, including Congressional hearings, Committee reports, legislative assessments and scientific reports (for an overview, see Schubert, 2021).

In contrast to the early 2000s, however, this official record on climate engineering did not establish these measures as a potential techno-fix. Quite to the contrary, climate engineering now gained traction as a daunting option of last resort, as we saw at the outset of this article—an unwanted, yet potentially necessary tool to avoid dangerous global warming (Bellamy et al., 2012; Connor & Green, 2009; Fialka, 2020; Fragniere & Gardiner, 2016; Huttunen & Hildén, 2014; Kreuter, 2015; Lederer & Kreuter, 2018; Luokkanen et al., 2014; Pierrehumbert, 2019; Victor et al., 2009).

This most recent stage in the political trajectory of climate engineering, then, can be understood as a kind of synthesis—one that reconciles two historically conflicting roles of climate science within the state. In this outlook of a last resort option, the call for climate engineering research promotes techno-scientific control over the climate all the while anticipating a critique of this proposition. It aligns visions of “mastery” which had defined political interest in meteorology during the 1950s and 1960s with the rather critical positions of climate scientists, which came to question these visions of mastery during the 1970s (Schubert, 2021, p. 175).

As a result, the political exploration of climate engineering followed a less blatantly techno-optimistic tone than during the height of the Bush years. Climate engineering evolved from controversial techno-fix to “just research.” To become “part of mainstream climate policy,” as Baskin observes, climate engineering “would need to be detached from climate inactivist thinking and attached to the mainstream scientific narrative” (Baskin, 2019, p. 85). Similarly, Stilgoe observes how “the rehabilitation” of climate engineering approaches “required scientists to create some distance between themselves and these Cold War characters” (Stilgoe, 2015, p.69). The literature particularly emphasizes the relevance of prestigious scientist and Nobel laureate Paul Crutzen in this context, who called for research into climate engineering in 2006 and thereby lifted the putative “taboo” on these measures (Keith, 2000, p. 92; see also Morton, 2016, pp. 152–156; Hulme, 2014, p. 4; Stilgoe, 2015, p. 133f).

In the United States climate engineering became formulated as part of a basic science agenda around 2009 (Schubert, 2021, p. 176f). Cast in this light, climate engineering hardly seemed to propose a politically controversial or radical approach, but rather appeared as the next logical step in developing a rational—i.e., science-based and research-driven—approach to tackling climate change. The U.S. policy documents that started to proliferate around 2009 suggest for example how exploring climate engineering in this sense directly translated into basic research in the atmospheric sciences. Efforts to determine the technological viability of the proposed measures or to devise appropriate monitoring and governance tools essentially depend on precise climatological modeling and measuring capacities (U.S. House of Representatives, Committee on Science and Technology, 2009, 2010; U.S. Senate, Committee on Environment and Public Works, 2013). Very much in line with the role of WCM for meteorology, climate engineering implied addressing

“the holy grail” of climate science—namely “using present observations to predict future climate states” (long in: U.S. House of Representatives, Committee on Science and Technology, 2009, p. 308).

6 | CONCLUSION

Historicizing societal objects, structures, or discourses does not merely amount to searching for continuity with earlier times. After all, it is particularly the shifts and fractures, the *discontinuities*, which question taken-for-granted assumptions and help us make sense of how we arrived at the present point in time. Historicizing climate engineering in this sense implies both working with a moving target and reflecting on its very essence. It is an exercise in understanding the historical conditions that made this idea of counteracting global warming by intervening in the Earth's climate possible. Fleming suggests that it is high time “to reflect on the precedents that brought us to this point” (Fleming, 2010, p. 227). But what exactly are the relevant precedents?

I suggested here to consider hopes for climate control as a historically important political motif for cultivating climate science: we saw how efforts to control the climate flourished during the 1950s and 1960s. The field of WCM emerged during these years as a result of the “triumphant marriage” between scientists and the state (Balogh qtd. in Harper, 2017, p. 82). This “marriage” made almost everything seem controllable by techno-scientific knowledge. As a result, climate modification was pursued during these years through the lens of control, that is, as a means to cultivate weather and climate according to human needs.

Around the 1970s through 1990s, global climate change became problematized and politicized as an environmental challenge. Climate scientists played a crucial role both in placing the issue on the political agenda and defining the terms with which it was problematized in policy contexts. This fundamentally redefined alliances between scientists and the state—and, respectively, the status of climate modification. Climate science emerged now as the problem defining authority on an issue that questioned the political and economic status quo, effectively “haunting” earlier hopes for mastery over nature (Baker, 2017, p. 19). Hopes for climate control did not vanish in this context but became substantially reformatted. What used to be explored as “deliberate” and “inadvertent” climate modification, as two sides of the same equation, was related now as problem (global warming) and response (climate engineering).

Around the first two decades of the new millennium, climate engineering changed its shape once again. Efforts to promote these measures as a techno-fix, which would allow addressing climate change all the while stabilizing status quo dynamics and support climate-inactivist thinking remained unsuccessful in pushing these measures into the mainstream. Only around 2009 and in the face of a “crisification” of climate change communication (Paglia, 2018), climate engineering successfully gained political traction as a last resort in facing a dire crisis. Framed as “a bad idea whose time has come” (Kintisch, 2010, p. 13), the current exploration of climate engineering appears as a kind of synthesis of two historically conflicting visions for climate science in the state. Climate engineering in this context builds on hopes for techno-scientific control over nature all the while catering to ‘green’ notions of environmental safeguarding. It aligns 1950s visions of science as a tool for the state with the 1970s critique thereof. Since the late teens of the new millennium, we can observe how climate engineering is becoming increasingly embedded in a basic research agenda for the atmospheric and oceanographic sciences. It is explored in this context as “just science,” concerning mere technicalities, or matters of fact.

“[M]odification plans,” as Jim Fleming aptly put it, have always been “couched in the pressing issues and available technologies of their eras” (Fleming, 2010, p. 265). This historical perspective suggested how such modification plans have provided a crucial, if shape shifting, node in linking scientific agendas to political agendas. From this angle, the history of climate engineering, then, is not just the history of a radical or even crazy idea, advanced by “rain fakers,” “weather warriors” and “charlatans” (Fleming, 2010); it is also part of the history of how politics sought to use and cultivate climate science for the state.

AUTHOR CONTRIBUTIONS

Julia Schubert: Conceptualization (lead); data curation (lead); formal analysis (lead); funding acquisition (lead); investigation (lead); methodology (lead); project administration (lead); resources (lead); validation (lead); visualization (lead); writing – original draft (lead); writing – review and editing (lead).

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Data sharing is not applicable to this article as no new data were created or analyzed in this study.

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ENDNOTES

¹ David Keith adds “the degree to which the action is a countervailing measure [to anthropogenic global warming]” as a separate “marker” of current climate engineering debates (Keith, 2000, p. 247). But we may also think of this dimension as part of the intent or goal of the proposed measures. For a critical perspective on the focus on goal and intent of climate engineering, see Fleming (2010, p. 228).

² The notion of “geoengineering” was thus originally coined here in the context of a proposal to remove carbon dioxide from the atmosphere. This seems noteworthy as much of the CDR debate has successfully distanced itself from this label and is currently discussed as a form of mitigating climate change.

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