2 Dreaming the designer climate

Introduction

In June 1988, Dr. James Hansen of NASA famously told reporters it was 'time to stop waffling so much and say that the evidence is pretty strong that the greenhouse effect is here' (Shabecoff, 1988). Asked to testify at the U.S. Senate committee on Energy and Natural Resources Hansen insisted that it was '99 percent certain that the warming trend was not a natural variation but was caused by a build-up of carbon dioxide and other artificial gases in the atmosphere'.[1] Aided by widespread unease about a smouldering heatwave and prolonged drought in the western parts of the United States, Hansen definitively brought global warming into the public imagination. In 1988, global warming became a major political concern. George Bush Sr., the Republican vice-president running for the presidency, even vowed that he would be 'the environmental president' if elected. To Bush, 'successful economic development and environmental protection go hand in hand, and you can't have one without the other'. For many, including Bush, '1988, in a sense, is the year that the Earth spoke back'. Confronted with issues such as pollution, ozone depletion, and anthropogenic global warming, he urged his fellow Americans to treat the environment 'not as given, but as a gift' (Bush, 1988). Coinciding with the immanent end of the Cold War and subsequent implosion of the USSR, the 'Summer of '88' seemed a watershed moment for global environmentalism. The United Nations Environmental Programme (UNEP) and the World Meteorological Organization (WMO) collaboratively established the IPCC in November 1988, signifying global concern about climate change. Effective climate policy, it seemed, might be just around the corner.

Nothing could have been further from the truth. Optimism about international environmental collaboration, boosted in the 1990s by the quick resolution of the hole in the ozone layer in the late 1980s,[2] soon dissipated as climate change became a political battleground. In the 1990s, the mood around climate change shifted. A public concern in the late 1980s, it quickly became politicised and partisan issue, especially in the United States and Europe. Reacting to private and economic interests, the U.S. Republican Party increasingly disparaged climate change, pulling neoliberal and conservative movements across the world with them. By the 2000s, belief in climate change and support for climate policy had become an accurate predictor for political conviction (Kahan *et al.*, 2012; Kahan, Jenkins-Smith and Braman, 2011). Decades of international negotiations yielded little or no progress in combating climate change. Global greenhouse gas emissions only decrease significantly as the result of recessions, such as those following the financial crash in 2007/2008 and the recent COVID-19 pandemic—and then only temporarily. The Kyoto Protocol, the first binding agreement on greenhouse gas mitigation adopted in 1997, has proved ineffective (Prins and Rayner, 2007). Despite high expectations, the climate summit in Copenhagen in 2009 failed to provide a new impetus to climate change action. Only in 2015, 18 years after the Kyoto Protocol, did the UNFCCC deliver a firm commitment from its 195 participating countries to keep global warming at least below 2°C and to aim to keep it below 1.5°C. The efficacy of this agreement remains to be seen. For climate engineering researchers, this is the resonant environment in which they do their research. If climate policy does not deliver meaningful changes, it is time to take suboptimal solutions such as climate engineering seriously. In their eyes, increasing interest in climate engineering is a stinging rebuke of political inadequacy. It is a scientific response to climate change in absence of a political one.

This climate lethargy and political inaction is certainly a part of the story of climate engineering. But it is not the whole story. The ‘real’ history of climate engineering is a matter of perspective. Some, such as Jim Fleming (2010) and Jeremy Baskin (2019), argue for a long view of history. The story of climate and weather intervention, they insist, is a problematic story about pathological scientists, hacks, and Cold War warriors. Climate engineering is the manifestation of a human-centred ideology about dominating the natural world. It is a story full of scientific hubris and colourful characters: James Espy, ‘storm king’ and rainmaker in the 1800s; Irvin Langmuir, Nobel Prize winner in Chemistry, rainmaker for General Electric, and consultant to the U.S. army in the late 1940s and 1950s; John von Neumann, Cold War enthusiast and climate and weather control hopeful; Edward Teller, the father of the hydrogen bomb, who favoured dropping nuclear bombs on hurricanes in the hope they would dissolve or change course.[3] This longer history of climate and weather engineering is often told as an institutional story. During the Cold War, two military superpowers saw in weather and climate modification a new battleground. Clearly, traces of this hubristic and militaristic history still linger in contemporary dreams about controlling both weather and climate. Yet to many climate engineering researchers, excessive focus on the legacy of the Cold War and ideological continuities hampers critical discussion of *contemporary* climate modification research. To them, climate engineering represents the search for partial fixes for climate change. Excessive focus on earlier transgressions can be detrimental, because it carries unreasonable ‘taboos’ on climate intervention research (Keith, 2013). Implicitly, their view is that climate engineering should be seen as a *reactive* development of technological fixes for the unintended consequences of industrialisation rather than as a proactive search for the control of nature. Rather a military arms race, it is a civilian attempt to minimise the damage of climate change. Both these views have merit. Climate engineering has a long and troubling history. It is a legacy it still carries in its institutions and in the ways climate interventions are imagined and discussed.[4] And yet, imagining climate engineering as a temporary technological response to climate change instead of as a military frontier *does* matter.

The development of climate engineering does not happen in a vacuum. Scientific and technological developments are always part of a larger socioscientific and cultural reality. Culturally, politically, and scientifically, societies develop particular ways to imagine their relationship to their environment and, correspondingly, their capacity to influence it. The summer of 1988 *did* turn out to be a watershed moment for both climate engineering and climate change. It marked the beginning of a political story of climate change as part of the mainstream social imagination. It also confirmed the long-expected end of the Cold War histories of dreams of climate control. No longer were scientists merely curious about 'Man's vast geophysical experiment' of climate change. Now, officially, they were alarmed. With the summer of climate, both climate change and climate engineering had to renegotiate their part of scientific and public discourse. In this chapter, however, I address the longer history, the history that ended—or at least shifted—with the climate summer of 1988. During this period, dreams of climate and weather control and military competition play lead roles, while a slowly emerging conception of the Earth as a global, complex, and fragile system and fears about climate change are the supporting cast. In Chapter 3, I treat the post-1988 history of climate change and climate engineering. Here, climate change is a culturally defining concern, while dreams about climate engineering are controversial, even 'taboo'.

Dreams of climate intervention are constituted of various aspects of political, cultural, and scientific life. As science and culture at large change, so too do imaginations of environmental intervention. After the Second World War, ideologies based on the mastery over nature combined with scientific advances to popularise climate and weather interventions after. Cultural and scientific views of nature as fragile likewise contributed to the disappearance of climate interventionist dreams in the 1970s. As fears over climate change grew in the 1990s and 2000s, these imaginations changed again, increasingly seeing climate interventions as possible solutions to climate change. Central to these changing attitudes around climate intervention was the development of a *global* view of the climate. Through the development of a 'global gaze' (Ashley, 1983; Edwards, 2013; Jasanoff, 2001; Miller, 2004), it became possible to imagine the climate as manageable. Climate science as a holistic, numerical science, informed by satellite imagery and increasing computational power, decisively shaped this global view (Edwards, 2001, 2010). Satellites and increasing computational power solidified a view of the global climate by making it *computable*.

But this holistic view of the climate, seeing it as a 'unitary whole' (Ashley, 1983), also had political consequences. It changed the institutional set-up of climate science, and it changed imaginations of the climate and climate control that could be entertained. Political entanglements, moreover, deeply shaped the material conditions of climate research (Edwards, 2010; Hecht and Edwards, 2010). The modelling turn that would shape the understanding of the Earth's systems, for example, was always also political (Ashley, 1983; Edwards, 1996; Wynne, 1984). Scientific multilateralism too had a political aim in safeguarding openness of the international political system as well as maintaining American dominance (Burley, 1993). In this chapter, I ask how these trends have influenced dreams of climate modification. Here, then, I am interested in how the longer history of climate engineering created a particular 'possibility space' for contemporary research. Why was climate and weather control one of the foremost dreams of the early Cold War? How did the 'climate' become something that could be manipulated by humans? Why did dreams of climate control start to dissipate right as climate change became a mainstream scientific concern? What scientific and societal changes allowed climate change to become a major political concern by the late 1980s? How did climate engineering become a 'tabooed' topic in the climate change debate?

Science, technology, and politics after the Second World War

On 6 and 9 August 1945, the United States dropped Little Boy and Fat Man on Hiroshima and Nagasaki, respectively. Bringing the Second World War to a close and killing upwards of 100,000 people (Hiroshima Day Committee, 2018; Sklar, 1984), the bombs signified a changed world. Militarily, the bombs foreshadowed an era dominated by the 'mutual assured destruction' doctrine. Geopolitically, they heralded the start of the Cold War. The 'old powers' in Europe had lost their dominance in the geopolitical arena, and two new superpowers had arisen. This bipolar world redistributed political, cultural, and economic power (Guston and Keniston, 1994; Krige, 2006). The Second World War shook European intellectuals such as Hannah Arendt (1951, 1961), Theodor Adorno, and Max Horkheimer (Horkheimer and Adorno, 1972), who saw in its systematic destruction of human life and dignity a fundamental severance between past and future. To Arendt, humanity had forsaken all hope of a 'human future' (Andersson, 2018). Many European intellectuals shared this view. But in the United States and the USSR, clear victors of the war, the war's entanglement between science, technology, economy, and the military brought dreams of progress. The Second World War had institutionalised previously tenuous relationships between the 'state' and 'science'. Scientific discovery and technological development, such as code-cracking computers, radio, increased meteorological understanding leading to preliminary weather predictions, and nuclear weapons, were central to the Second World War warfare (Geiger, 2004). Many came to see science and technology as integral to both human welfare and political power. To Vannevar Bush,[5] MIT professor and science advisor to the highest layers of government, scientific progress was 'one essential key to our security as a nation, to our better health, to more jobs, to a higher standard of living, and to our cultural progress' (Bush, 1945). Increasingly, science and technology were imagined to be the key to wealth and welfare. In the United States, it was, after the closing of the Great Frontier, a new 'Endless Frontier', via which economic and political progress could be made indefinitely.

After the Second World War, both the United States and the USSR saw scientific and technological progress as a way to legitimise their political system (e.g. Ings, 2016, for the USSR; Chomsky *et al.*, 1997; Ezrahi, 1990, for the United States). Science was increasingly thought of not only as a means to compete politically but also as a means to shape the international arena. Scientific expertise became, more than before the war, a means to justify political and moral action. In the United States, scientific expertise had already been used to justify the invasive and expensive political measures of the 'New Deal Regulatory state' (Burley, 1993).[6] When the United States were faced with the challenge of rebuilding an international order and a global economy ravaged by war after the Second World War, they again looked for scientific and legal justifications. Global scientific cooperation, on U.S. terms, was to be an important scaffold of their imagined multilateral *liberal* world order (Burley, 1993; Miller, 2001). Over the previous centuries, Western countries had developed specific discourses that 'use scientific knowledge and skills… to ideologically defend and legitimate uniquely liberal democratic modes of public action, of presenting, defending, and criticising the uses of political power' (Ezrahi, 1990, p. 1). During and after the Second World War, this discourse became further institutionalised. Cold War considerations shaped the organisation of the academies' of the United States, the USSR, and their respective spheres of influence. It solidified the notion of 'science' and 'technology' as a moral beacon. In the West, science and technology defended the moral order of liberal democracy and capitalism (Chomsky *et al.*, 1997). In the USSR, they supported the moral superiority of communism (Baskin, 2019; Ings, 2016; Ivanov, 2002; Oldfield, 2013).

As a result, the role of science in society was comprehensively reimagined. This reimagining of the role of science in politics and society went hand in hand with a reimagining of nature. Technoscientific success in the war contributed to a solemn belief in the capacity of science to understand and subjugate nature. As Jeremy Baskin sees it,

> in the United States… what emerged was a belief that almost any problem, natural or man-made, could be fixed. Almost identical views could be found in the Soviet Union, underpinned in that case by the Stalinist belief in the power of the socialist order to overcome all obstacles to "progress". In hindsight what is most striking is that, after the most destructive and technologically sophisticated war (and genocide) in history, both East and West embraced a highly hubristic vision of "progress",

> science and technology. Indeed, this seemed to be a central component of the early Cold War *zeitgeist*.
>
> (Baskin, 2019, p. 29)

Today's conceptions of climate, anthropogenic climate change, *and* climate engineering still carry the political, cultural, and technological legacy of those post-Second World War dreams. The reimagining of the role of science in society after the Second World War had several important consequences for both climate science and the ambition to control and modify the weather and the climate. For one, the development of the digital computer during the war—still unwieldy yet much quicker in its calculations than the human mind and its previous tools—introduced the possibility of numerical prediction and calculation of weather and climate circumstances into meteorology and climatology. Eventually, numerical projections of climate behaviour became the core of today's climate modelling (Edwards, 2010)—and correspondingly the way climate change presents itself as a political concern. Secondly, meteorology became an important pillar of the U.S. attempt to shape the international (scientific) arena. The United States came out of the war as the world leader in climatology and meteorology. The centre of gravity of climatology had moved to the United States (and to a lesser extent the Soviet Union) as part of the general redistribution of scientific expertise during the war *and* as a consequence of deliberate U.S. policy (Fleming, 2016). By the end of the war, the United States was the global centre for meteorological and climatological research. The meteorological and geophysical sciences themselves had always sought after international cooperation. Increasingly, scientists believed that meteorology (like its close cousins geophysics, oceanology, and geology) could not achieve its scientific aims without international collaboration. Realising the climate system's global interconnectedness, meteorologists and climatologists believed that without access to data and observations from all over the globe, they could not find the answers they were looking for.

Large observational systems had been set up during the war, in order to provide weather and climate data to the military. Even more observational networks, such as information that could provide meteorological data at high altitudes, were now needed to provide meteorological for increasing aviation. The rise of aviation in particular demanded increasingly accurate weather and climate information. Weather forecasting had been central to the war, if notoriously unreliable. An anecdote told by Ken Arrow, Nobel Laureate in Economics, is telling. During the Second World War,

> some officers [including Arrow] had been assigned the task of forecasting the weather a month ahead, but Arrow and his statisticians were no better than number pulled out of a hat. The forecasters agreed and asked their superiors to be relieved of this duty. The reply was: "The Commanding General is well aware that the forecasts are no good. However, he needs them for planning purposes.
>
> (as recounted by Bernstein, 1996, p. 203)

Scientific internationalism was also needed to maintain access to cutting-edge technology and the political clout that would bring. Meteorology and related sciences' desires for more international collaboration converged with the political desire for liberal scientific modes of multilateral cooperation. American foreign policy planners in the State Department asserted 'greater control over America's cultural and intellectual exchanges with other countries' (Miller, 2001, p. 183). This convergence culminated in the creation of the WMO in 1947. The WMO aimed to create binding international standards for meteorological cooperation, as part of a larger (political) endeavour to create norms and standards of liberal multilateral cooperation.

The post-war institutional set-up of climatology and meteorology decisively influenced the development of climate science, the 'discovery' of climate change, and dreams of climate control. Climatologists and related scientists increasingly operated in a bipolar world, where scientific collaboration was possible, even encouraged, but always political. Weather and climate modification, which had been niche fields of research before the Second World War (at least in the United States), increasingly became subject to political and military imaginations. Both climate and weather control became fashionable research topics. In the next section, we will see how weather and climate modification moved from a niche position into the centre of political interest. Although anthropogenic climate change wasn't gaining immediate traction, climate and weather control *were*.

Dreams of environmental control

After the Second World War, interest in weather modification in both the United States and the USSR spiked. Such interest was not new. Ever since scientists had started to develop working theories about weather and climate systems, they speculated about methods to control it (Fleming, 2010). In the 19th century, this had manifested through an interest in 'rainmaking' throughout the Western world, particularly in the United States. By the early 20th century, these attempts had lost much of their allure, but after the Second World War weather modification returned to the attention of the scientific mainstream. In the success of the Manhattan project, state-run science had proven its potential for the military. It had also brought up a well-connected generation of scientists, mostly physicists, supremely confident in the human ability to manipulate and control nature. In the United States, physicists, chemists, and mathematicians like Edward Teller, Lowell Wood, John von Neumann, and Irving Langmuir all thought it must be possible to control natural systems—including the weather and possibly the climate. Vladimir Zworykin, a research director at Princeton, wrote *Outline of Weather Proposal*, published in October 1945. In it, Zworykin suggested that more and better data combined with digital computing, would make accurate weather prediction possible. If the weather could be predicted, he insisted, it could also be manipulated and controlled. Zworykin even imagined a future in which 'long-term climatic changes' could be engineered. Zworykin's proposal was picked up on by several scientists, most notably John von Neumann. Von Neumann, an American-Hungarian polymath connected to the highest levels of the U.S. government and military, enthusiastically endorsed Zworykin's idea. Von Neumann, who was pioneering weather prediction using numerical models, claimed that 'all stable processes we shall predict. All unstable processes we shall control' (von Neumann, as quoted in Fleming, 2010, p. 94). In the United States, Zworykin's and von Neumann's were highly influential. In the Soviet Union likewise many dreamed of weather climate control—as the 1932 establishment of the Leningrad Institute for Rainmaking illustrates. There too, important climate scientists such as Mikhail Budyko expressed an interest in controlling the weather and the climate. In both the United States and the USSR, this interest combined with a sustained faith in scientific and political capacities to subjugate and control nature.

Weather modification in the United States

In the United States, post-war weather modification research began in earnest when Irving Langmuir, a Nobel laureate in chemistry, started to champion the use of dry ice to induce rain in the late 1940s. At the time, Langmuir (1881–1957), famous for his work in surface chemistry, worked as a researcher for General Electric (GE). In this capacity, Langmuir led a team of excellent scientists. The team included Vincent Schaefer (1906–1993), who joined him at GE in 1932, and Bernard Vonnegut (1914–1997), who joined Langmuir's team in 1945, and had researched gas warfare and aircraft icing at an MIT laboratory during the war. In 1946, Schaefer serendipitously discovered that supercooled clouds could be induced to release their precipitation if they were seeded with dry ice particles. Because precipitation only forms when the moisture has a nucleus to form around, providing these nuclei, even in small doses, could trigger a chain reaction leading to rain, hail, or snow. Introducing dry ice to a cloud could lead to the generation of millions of tiny ice crystals. As Schaefer described it,

> in the experiments… a supercooled cloud is formed by introducing moist air into a small, commercial freezing unit… Under typical laboratory conditions with a room temperature of 27°C, the temperature of the air in the center of the chamber is maintained at about −15°C.
>
> (Schaefer, 1946, p. 457)

These clouds, according to Schaefer, never developed ice crystals, unless an agent was introduced to create ice nuclei. From these nuclei, spreading through the cloud, ice crystals would grow. To Schaefer and Langmuir, to whom he showed his discovery, the implication of this discovery was clear. Seeding supercooled clouds in the atmosphere with dry ice could lead to a chain reaction. The dry ice would provide the nuclei around which tiny droplets form, causing it to rain. Langmuir's claims that he could make it rain attracted attention (Fleming, 2010; Kwa, 2001). Cloud seeding was a scientifically sound claim, and to some extent it does lead to rainfall. Langmuir and Schaefer's idea of weather modification also fit well within the post-war conception of science and nature. In many ways, Langmuir was a precursor to 'weather warriors', in Jim Fleming's words (2010), such as John von Neumann, Edward Teller, and Lowell Wood who saw military applications for both weather and climate modification. Langmuir's experience working with the government, his close ties to the military, and his confidence in his ability to control nature exemplify the type of interventionist scientist of the post-war era. Langmuir and Schaeffer's interest in weather modification was part of a larger socioscientific interest in the manipulation of natural systems. As such, their experiments were well received by the American government and military, who were more than interested in the results. By the late 1940s, the U.S. military even took over GE's weather modification research project in 'Project Cirrus', using Langmuir and Schaefer as consultants.[7] According to the *Harvard Law Record School Record*, Project Cirrus had 'an annual budget of $750,000 from military and naval funds because of its war implications—bogging down enemy troops in snow and rain, clearing airfields of fog at lowest cost, and infecting induced storms with bacteriological and radiological materials' (Harvard Law Record, as quoted in Fleming, 2010, p. 150).

This interest in rainmaking fit into a larger faith in and desire for human control over natural systems. As part of the 1955 Advisory Committee on Weather Control, John von Neumann expressed his belief that deliberate human intervention in the climate could happen within a few decades (Kwa, 2001). Scientific knowledge of atmospheric processes was progressing so rapidly, he thought, that within a few decades it should be possible to reliably intervene in atmospheric and climatic processes.[8] Weather and climate control research were important Cold War interests. As the USSR might develop weather and climate control capabilities too, it was crucial for the United States to develop it first (Kwa, 2001). Edward Teller even stated that 'conflict over weather control is the likely cause of the "last war on earth"' (recounted by Stone, 1988), adding later that 'we would be unfaithful to the tradition of Western civilization if we shied away from exploring what man can accomplish, if we failed to increase man's control over nature' (Teller, 1962, p. 56). Teller also told the Military Preparedness Committee that he was 'more confident of getting to the moon than changing the weather, but the latter is a possibility. I would not be surprised if (the Russians) accomplished it in 5 years or failed to do so in the next 50' (Teller, 1958, p. 50). Military and agricultural interest in weather and climate intervention created sustained political support for weather and climate modification research. By 1953, a President's Advisory Committee on Weather Control was established. In 1958, the National Research Foundation (NSF) established a research programme on weather modification. Inevitably, weather and climate modification research were closely connected to the space race. As U.S. Senate majority leader (and later president) Lyndon Johnson asserted in 1958,

> control of space means control of the world… From space, the masters of infinity would have the power to control the earth's weather, to cause drought and flood, to change the tides and raise the levels of the sea, to divert the Gulf Stream and change temperate climates to frigid… If, out in space, there is the ultimate position—from which total control of the earth may be exercised – then our national goal and the goal of all free men must be to win and hold that position.
>
> (Johnson, 1958)

The launch of Sputnik by the USSR in 1957 even fuelled the fears for a 'new race with the Reds' over a 'weather weapon' (Newsweek, 1958: cover).

In the 1960s, weather modification research reached its zenith. In 1960, the first designated weather satellite, TIROS I, launched, after a prolonged advocacy for the use of weather satellites by Harry Wexler and Francis Reichelfelder, two prominent meteorologists. Politicians, such as Stewart Udall, the Secretary of Interior, expressed their excitement about the 'water resources in the sky' and the possibility of making rain at will (Udall, 1966). The National Science Foundation (NSF) published a report expressing optimism about the possibility of weather control, later to be followed by the National Research Council (NRC) (National Research Council, 1983; National Science Foundation, 1965). After 1966, multiple research initiatives existed, fundamental research at the Weather Bureau and the NSF and operational research under the supervision of the Interior Department's Bureau of Reclamation (Kwa, 2001). Rapid developments in satellites and computing raised scientific hopes that accurate weather data would soon improve weather prediction (Malone, 1967). Between the late 1940s and the early 1970s, a multitude of weather modification schemes were active in the United States. Some, such as Project Climax (1960–1970), aimed to increase the snowpack in Colorado, and the National Hail Research Experiment started in 1972 were large or politically important. Many others were small and regional. A particularly influential project was Project Stormfury, which investigated ways to forecast hurricane trajectories and the possibility of modifying storm behaviour. This successor to the National Hurricane Research Project that had started in 1955 aimed to increase the scientific understanding of hurricane formation. As part of the project, Jules Charney and Arnt Eliassen, pioneers in climate and weather modelling, developed a model of hurricanes that would become the basis for subsequent hurricane models in the project (Charney and Eliassen, 1964). Project Stormfury operated during the 1960s, continually improving its hurricane models. Occasionally, it also seeded hurricanes in an attempt to change their trajectory.

2.3.2 Weather and climate control in the Soviet Union

The United States was not the only country after the Second World War with a long-standing interest in climate modification.[9] After the Second World War, many aspects of the political imagination of science and nature in the Soviet Union were comparable to the dreams about environmental control in the United States. Nature, to Joseph Stalin's USSR, was a resource to be used and exploited. Here too, there was a sustained interest in large-scale interventions—such as the damming of rivers, the digging of canals, the planting of forests, and, if possible, altering weather and climate patterns.[10] Often, these interventions had disastrous environmental results (Brain, 2010; Zikeev and Doumani, 1967). By the 1960s, for example, many rivers in the western part of Russia had been dammed, seriously disrupting country's water systems (Ings, 2016). Like in the United States, the Cold War also intensified pre-existing scientific and political interest in climate modification in the USSR. As the United States used science to legitimise its liberal world order, the Communist Party co-opted science to prove communism and progress would go hand in hand. Joseph Stalin, in particular, used science to legitimise the communist ideology and his own power[11] (Ings, 2016). As Pollock (2006) describes it, in the USSR science for the people was science for the Party. This political status of science in the Soviet Union had paradoxical effects. On the one hand, Soviet scientists were well funded, to the envy (and apprehension) of Western scientific observers. At the same time, however, scientific freedom, as it was understood in the West, was not present.[12]

Meteorology was a well-funded part of this Soviet scientific system as it tied into these imaginations of power and technological progress. Scientific Soviet interest in rainmaking had predated the Second World War. As early as 1932, the USSR had founded the Leningrad Institute of Rainmaking. From 1934 to 1939, this institute had conducted cloud seeding experiments based on similar insights to those of Langmuir and Schaefer. After the war, Soviet interest in climate and weather control also turned to experiments using dry ice (1947) and silver iodide (1949). In the 1950s and 1960s, Soviet interest in climate and weather modification grew strongly. Soviet interest in weather and climate modification peaked around the same time as it did in the United States in the 1960s. The Soviets, however, were more interested in *climate* modification than their American counterparts were. At the time, American scientists were, despite mentions of albedo modification and possible climate control in the future, focused on weather modification. In the USSR, climate modification research played a much larger role. Partially, this had to do with their climate. In the 1950s and 1960s, various Soviet scientists proposed to warm the climate.[13] At the 22nd Congress of the Soviet Communist Party in 1961, the development of climate control was listed as one of the most urgent problems of Soviet Science:

> The progress of science and technology under the conditions of the Socialist system of economy is making it possible to most effectively utilize

> the wealth and forces of nature for the interests of the people, make available new forms of energy and create new materials, develop methods for the modification of climatic conditions and master space.
>
> (as noted by Rusin and Flit, 1964, p. 3)

Tying into Stalin's 'Great Transformation of Nature', climate modification was a serious research topic in the USSR. According to Fletcher, 'governmental and scientific interest [in weather and climate modification] has been more evident' in the Soviet Union than in the United States (Fletcher, 1968, p. 16).

In 1961, Leningrad hosted a conference on climate modification organised under 'the sponsorship of the three institutions most closely concerned with the problem—The Main Geophysical Observatory, The Institute of Applied Geophysics, Moscow, and the Institute of Geography, Moscow' (Fletcher, 1968, p. 16). At the conference, Michael Budyko, a leading climatologist whose legacy remains important, presided over research programmes into the Earth's heat balance and surface atmosphere interactions.[14] Clearly, 'interest in climate and the functioning of climate systems at a range of scales has a long history in Russia and simultaneously finds strong representation in Russian geographical thought and practice' (Oldfield, 2013, p. 521). According to David Keith, currently the most visible climate engineering researcher, sustained Russian interest in climate and weather modification seems to have three major causes:

> (*a*) a social climate in which demonstration of technological power expressed in rapid industrial expansion and in the space race was central to state ideology, (*b*) a climate that is harsh by European standards, and finally, (*c*) the existence of relevant scientific expertise.
>
> (Keith, 2000, p. 251)

Waking up to uncertainty and controversy

By the end of the 1960s, people started to question the desirability of climate and weather modification in both the USSR and the United States. In both countries, belief in the feasibility and desirability of climate and weather schemes started to wane (Baskin, 2019; Ivanov, 2002). Not all scientists had been equally thrilled by the idea of weather modification in the first place. Harry Wexler, one of the foremost meteorologists in the United States, for example, was consistently sceptical about weather and climate control. As chief of scientific services at the U.S. Weather Bureau, Wexler was the first to conduct a systematic assessment of climate and weather control (Fleming, 2007, 2010). Among other things, he found that it would be possible to intentionally destroy the ozone layer—a result that further informed his apprehension about and opposition against climate modification. Even John von Neumann was apprehensive. Although he believed in the possibility of weather and climate control, von Neumann was torn about the desirability of weather and climate control. In a 1955 article titled 'Can We Survive Technology?', he warned that climate modification would have 'rather fantastic effects'. Referring to Charney's idea of albedo modification, von Neumann agreed it was possible to consciously alter the climate. Moreover, by releasing carbon dioxide into the atmosphere, humanity might already 'have changed the atmosphere's composition sufficiently to account for a general warming of the world by about one degree Fahrenheit' (von Neumann, 1955, p. 106). 'Probably intervention in atmospheric and climatic matters will come in a few decades,' he asserted, 'and will unfold on a scale difficult to imagine at present' (p. 108). Von Neumann presciently argued that tampering with the Earth's climatic systems 'will merge each nation's affairs with those of every other more thoroughly than the threat of nuclear war or any other war may already have done' (p. 151). Believing that 'technology—like science—is neutral all through, providing only means of control applicable to any purpose indifferent to all' (p. 151), von Neumann argued against prohibition, but *for* caution, 'the more powerful [technologies] they could be, the more unstabilizing their effect could also be' (p. 151). USSR climate scientists, such as Mikhail Budyko, Y.K. Fedorov, and A.A. Grigor'ev, also contributed to this increasing awareness of anthropogenic climate change. Fedorov and other influential scientists expressed their doubts about invasive environmental modification, including climate and weather schemes (Fedorov, 1974). In 1971, Budyko, torn between dreams of human climate control and an increasing apprehension of anthropogenic climate change, published the book *Climate and Life*.[15] In the book, he 'proposed that if global warming ever became a serious threat, society could counter it with airplane flights in the stratosphere burning sulphur to make aerosols (small particles), similar to those found after a volcanic eruption' (IPCC, 2012, p. 20). Already in the early 1960s' USSR, 'climate' had become resource that had to be treated with care[16] (Oldfield, 2013). Internationally, Budyko was one of the first scientists to raise serious concerns about global warming. His work on the 'heat balance of the Earth's surface' was 'of great significance because of its underlying methodology and use of data at the global level' (Oldfield, 2013, p. 518). Budyko saw the climate as a complex global system. His book *Climate and Life* contributed to spread this view widely among climate scientists, which in turn helped to create a concern for global climate change. Slowly, an apprehension of climate change grew on both sides of the iron curtain—and certainty and optimism about weather and climate modification dissipated.

To a large extent, the hype around climate and weather modification schemes in between the early 1950s and the early 1970s was fuelled by competition between the communist and the capitalist bloc. It was a competition of 'weather warriors' (Fleming, 2010) imagining 'mastery' (Baskin, 2019) over nature. But this belief and confidence was never absolute. Even quintessential 'weather warriors' John von Neumann and Edward Teller expressed their concerns. As new scientific insights and a changing cultural imagination of nature tempered confidence in the possibility of mastering nature in the 1960s and 1970s, enthusiasm over weather and climate modification waned. In the period after the war, a climate science increasingly based on computer models had developed in parallel to the dreams of climate control. This brought new insights and contributed to a shifting conception of the relationship between humans and their environment. Slowly, nature was becoming redefined not as a risk to be tamed and control, but rather something that was *at risk* from human industrial society (Kwa, 2001). At the same time, computer modelling and satellite imagery increasingly made it possible to imagine the Earth as a globally unitary *whole* (Höhler, 2015; Jasanoff, 2001; Miller, 2004). In the short run, this reconceptualisation of the Earth and the environment led to the (temporary) disappearance of weather and climate modification from the mainstream. In the long run, however, it would make the current generation of climate engineering possible through providing *global* epistemological and political tools.

Making data computable

Enthusiasm for climate and weather prediction and modification in the 1950s and 1960s had much to do with the increasing availability of processing power in computing and better meteorological data. The Second World War had left an unprecedented amount of climatological and weather data. Wartime had stretched the limits of meteorological and climatological observations. According to Paul Edwards, 'between 1941 and 1945, the Air Force climatology program recorded 26,000 station-months of records on about 20 million cards' (Edwards, 2010, p. 101). As such, 'according to a 1948 US military manual, World War II created a genuine crisis for climatological data processing' (ibid.). Digital computing, however, would fundamentally change climate science and meteorology. It made ever large data sets workable, making real-time weather predictions possible. Where in the early years of the 20th century it had taken several weeks to calculate a one-day weather prediction—hardly a useful skill but a worthwhile proof of concept nonetheless—computing made it possible to calculate weather events in real time. As a result, ever more data was required. Satellites and other observational networks, developed as part of the military framework of the Cold War, delivered. Increasingly, scientists believed that enough data could be collected and computed to make accurate weather predictions—and potentially even climate projections.

The belief that both the weather and the climate could be calculated and predicted had grown out of 19th- and early 20th-century meteorology and climatology. Prior to these developments, climatology had largely been a geological affair, while meteorology lacked the fundamental equations to describe weather patterns and behaviours accurately. In climatology, this changed in 1895, when Svante Arrhenius provided the first calculation of the effect of carbon dioxide on the Earth's temperature, suggesting that the climate (and its changes) could be calculated. In the 1800s, the scientific conception of nature and the climate had already started to shift from inherently stable to variable on geological timescales (Fleming, 1998; Glacken, 1996). Arrhenius' calculation provided a climatological explanation for this variability.[17] Reinforcing Arrhenius' mathematical descriptions in climatology, Wilhelm Bjerknes first described *meteorological* behaviour with a set of physical equations based on seven variables around the turn of the 19th century (Bjerknes, 2009). Later Carl Gustaf Rossby, influenced by Bjerknes, constructed a model of the atmosphere as a process that could be described accurately with physics (Fleming, 2016). The works of Bjerknes, Rossby, and Arrhenius played a decisive role in shaping the contemporary cultural imagination of the climate. Arrhenius made climate into a primarily atmospheric phenomenon, rather than a geological one. Bjerknes and Rossby showed that atmospheric behaviour could be mathematically modelled. The implication of these scientific breakthroughs was that given enough climatological and meteorological data and resources, weather and climate should be *calculable*—and hence predictable. This conviction contributed to the scientific belief that climate and weather control might be possible (Malone, 1967).

Calculating the weather

In 1950, Jule Charney and John von Neumann ran the first real-time weather simulation. Four years earlier, von Neumann had given an interview to the *New York Times Magazine*, in which he had 'announced the intention of designing and building a large stored program machine for the purpose of predicting weather and of calculating the consequences of human intervention in the atmosphere' (as recounted by Thompson in an interview with William Aspray, 1986). Using a vastly simplified model of Bjerknes' equations, Charney and von Neumann's team tried to use the emerging digital computers to make numerical weather predictions. In 1955, Norman Phillips, a member of their team, tried to create a 30-day forecast. In the forecast, Phillips managed to reproduce patterns of atmospheric circulation. Phillips' experiment was revolutionary. His forecast 'showed that computer-based simulation could serve to simulate atmospheric phenomena' (Heymann, Grabelsberger and Mahony, 2017, p. 26). In doing so, the 'numerical integrations of the kind Dr. Phillips has carried out give us a unique opportunity to study large-scale meteorology as an experimental science', the British meteorologist Eric Eady thought (as quoted in Lewis, 1998, p. 52). Phillips' experiment opened up a host of modelling possibilities, including—two decades later—climate simulations. Eventually, general circulation models (GCMs), not unlike Phillips' became an important pillar for climate models.

At the same time, there was also a slowly increasing awareness that human industrial society might unwittingly have started to influence climate on a global scale. In the 1930s and 1940s, the British engineer John Stewart Callendar had warned that industrial societies already *were* heating up the Earth.

By 'throwing some 9,000 tons of carbon dioxide into the air each minute' (Callendar, 1949, p. 310), 'man is now changing the composition of the atmosphere at a rate which much be very exceptional on the geological time scale' (Callendar, as quoted in Fleming, 1998, p. 107). Although the Second World War had directed his warnings to the background, in the 1950s and 1960s they slowly started to find fertile soil. Deliberate weather and climate modification certainly received more attention, but various high-profile scientists had woken up to the possibility of *unintentional* anthropogenic climate change. Hans Suess, at the University of Chicago, and Roger Revelle, at the Scripps Institution of Oceanology, in particular, were intrigued. Despite Callendar's claim that human societies were increasing atmospheric carbon dioxide levels through emissions, no one knew for certain whether this was true because it was unclear what happened to the carbon dioxide once it was emitted. It was clear that it was emitted *into* the atmosphere, but if unclear whether it *stayed* there. Without accurate measurements of carbon dioxide in the atmosphere levels in the atmosphere, this question would never be solved.

These various trends converged in the International Geophysical Year (IGY), held in 1957/1958. Revelle and Suess saw an opportunity to get the funding they needed to set up measurements of the CO_2 levels in the atmosphere. And international collaboration around measurement and satellites would also provide the data necessary for improving climate and weather modelling.

Building a multilateral science, a liberal world order, and facilitating climate science

The IGY was both a scientific endeavour and a political intervention. Held in 1957/1958, it aimed to celebrate and institutionalise international scientific culture. As a corollary aim, it also intended to set up knowledge structures that improve meteorology and climatology—knowledge structures that would lastingly impact imaginations of climate and human interventions. The IGY resulted from a unique confluence of scientific and political developments. Although scientific merit was certainly an important aim, several other aspects contributed to the timing and the form of the event (Bulkeley, 2010). The return of peace to the advanced industrial societies had brought a 'revival of technological optimism' (Bulkeley, 2010, p. 235), which meant an increasing desire for (and belief in the feasibility of) artificial earth satellites and other large-scale research technologies. At the same time, political and scientific concerns converged around the need for such an international scientific event. International collaboration was seen as a geopolitical means for integration and institutionalisation, as well as an opportunity to discuss political conflicts—such as over claims over the territorial sovereignty of Antarctica—by other means. For scientists, the IGY was a great opportunity to safeguard funding. At the time, most funding for geophysical research in the United States came from the U.S. military. Because President Truman aimed to reduce the military budget, geophysicists were uncertain about their future funding. So, in the IGY, which was to be 'a comprehensive series of global geophysical activities to span the period July 1957–December 1958' (National Academy of the Sciences, 2005) coinciding with a period of high solar activity, geopolitical and scientific interests met.

For both meteorology and climatology, the IGY was deeply important. The scientific wish for better meteorological collaboration was clear (Miller, 2001). In the 1950s, this wish came to be shared by the Eisenhower administration, who believed that scientific research and its international exchange could help forge the idea of internationally shared interests (Adler, 1992). For the WMO, the governing body of meteorological research, the IGY was an opportunity to set up a distinct scientific agenda, particularly a global observation network. As 'the history of meteorological progress is inseparable from the history of successful development in the observation network' (van Mieghem, as quoted in Miller, 2001, p. 167), the WMO saw an opportunity in the IGY to develop such a network. The scientific aims of the WMO tied into a more broadly shared political aim. According to Clark Miller, meteorological internationalism in American foreign policy depended on

> three modes of interaction that emerged to characterize the deployment of meteorological science in postwar American foreign policy specifically and international politics more generally: (1) the coordination and standardization of government practices through technical cooperation, (2) the building of state capacity to promote economic development and its attendant securing of social stability; and (3) the raising of concern about problems of a transnational and often global character.
>
> (Miller, 2001, p. 207)

The IGY was important for the development of climate science too. In creating international research networks, exchanging meteorological information, and providing extensive funding, it helped change the material conditions of climate research in various ways. Both the increasing meteorological measurements and the prominence of satellite imagery excited climate scientists. The launch of Sputnik satellite led scientists to hope that satellites could provide data for accurate forecasts. These satellites and their measurements made it possible to view weather and climate as one globally interconnected whole. Early climate and weather models had mostly been regional or hemispheric (typically modelling segments of the Northern Hemisphere) due both to computational and observational limits. Satellite imagery, however, helped fashion a more *global* view of the Earth (Edwards, 2010).

The IGY also shaped climate science through providing funding for new atmospheric measurements. Hans Suess and Roger Revelle obtained the funding they sought to measure the possible increase of CO_2 in the atmosphere. Charles Keeling, the postdoc they hired, conducted continuous measurements of CO_2 concentrations at Mauna Loa, Hawaii, and on the South

Pole. Keeling quickly concluded that the carbon dioxide concentrations in the atmosphere were rising (Keeling, 1960; Keeling *et al.*, 1976). Instead of the 20 years Suess and Revelle had expected, it took Keeling only 18 months. Keeling's proof provided the first clear indication that carbon dioxide emissions might be influencing the global climate and was a crucial moment in the 'discovery of climate change'. By providing conclusive evidence that CO_2 levels were rising, Keeling's measurements started the journey of anthropogenic global warming from scientific niche interest to mainstream scientific and political concern. At first, global warming was no more than a footnote to presidential politics. A telling example is its treatment in appendix Y4 of 'Restoring the Quality of Our Environment', a 1965 report on environmental pollution of the U.S. president's Science Advisory Committee.[18] In a famous sentence, the report states that 'through his worldwide industrial civilization, Man is unwittingly conducting a vast geophysical experiment. Within a few generations he is burning the fossil fuels that slowly accumulated in the earth over the past 500 million years' (The White House, 1965, p. 126). In a striking example of the technological optimism of the time, the report goes on to add that 'the climatic changes that may be produced by the increased CO_2 content could be deleterious from the point of view of human beings. The possibilities of deliberately bringing about countervailing climatic change therefore need to be thoroughly explored' (p. 127). Clearly, the report connects the inadvertently changing climate to *deliberate* countervailing climate modification. The report also sees no need for the limitation of greenhouse gas emissions. Instead, it wholeheartedly embraces an imagination of technoscientific progress as a solution to environmental problems. Anthropogenic climate change remained a curiosity, while the confidence in future weather and climate control was peaking. Even Roger Revelle, the self-proclaimed granddaddy of climate change, saw climate change as something of scientific interest rather than as a reason to be alarmed:

> Our attitude toward the changing content of carbon dioxide in the atmosphere that is being brought about by our own actions should probably contain more curiosity than apprehension. Human beings are now carrying out a large-scale geophysical experiment which, if adequately documented, may yield far-reaching insight into the processes determining weather and climate. We must not forget, however, that even a relatively small rise in the average annual temperature of the atmosphere might be accompanied by other more serious changes, for example, shifts in the position or the width of belts of low rainfall. The possible future changes in climate that may be brought about by increases in atmospheric carbon dioxide give a unique justification to research and development on ways modifying climate by deliberate human action. Man-made climate modifications could be deleterious to others, and this raises serious ethical and legal objections to projects for carrying out such modifications. But these objections do not apply to attempts to bring about climatic changes

> that would counteract those that might be produced by an increase in the amount of atmospheric carbon dioxide. For example, a change in the radiation balance in the opposite direction could be produced by raising the albedo, or reflectivity, of the earth.
>
> (Revelle, 1966, p. 41)

By the late 1960s, however, the changes that would disrupt this technological optimism and put environmental concerns at the centre of science and politics were already afoot. Weather satellites became common. Scientists could monitor the weather and the climate *globally*, often in real time. The gradual discovery of human influence on the global atmosphere and climate was altering the way people experienced nature—and the climate. In the first few decades after the Second World War, both climate and weather were still inherently local and regional phenomena. The *globe*, as an interconnected whole, was not yet predominant part of the popular (or even the scientific) imagination. Climate and weather control were still predominantly *regional* dreams. Even anthropogenic climate change, which was slowly making its way onto the political and scientific agenda, was still predominantly understood in local and regional effects. But slowly, people inside and outside science started to understand that human influence on natural systems was increasingly problematic.

From deliberate climate invention to unwitting geophysical experiment

Weather and climate modification expectations peaked in the 1960s. Projects like Stormfury, speculation about using climate modification to counteract climate change, and excitement about computer modelling and satellite imagery coalesced in a techno-optimist imaginary of control over nature. At the same time, however, the scientific and cultural imaginations of the climate and nature were already changing. This change eventually made weather and climate modification dreams disappear from view (temporarily). Growing environmental and technological concerns had been foreshadowed by John von Neumann's and Harry Wexler's earlier warnings about the unintended consequences of large-scale interventions. In the 1960s and 1970s, these concerns led to a significant reimagination of weather and climate. During that time, the environmental movement became an increasingly important part of the public sphere. The success of Rachel Carson's *Silent Spring* (1962) woke Western societies up to the dark side of industrial agriculture. 'Pollution' and environmental degradation became widely accepted features of modernity. Simultaneously, anthropogenic climate change slowly started to become a scientific worry (Schneider, 2009). According to Hart and Victor (1993), 'by 1968 the notion that pollution could modify the climate was a commonplace' (Hart and Victor, 1993, p. 662). In 1970, environmentalists even organised the world's first Earth Day. Shortly after, in 1972, the Club of Rome published its *The Limits to Growth* report. The report's neo-Malthusian argument stated that unbridled economic and population growth would lead to disaster because Earth's resources are finite. Immediately, many criticised the report's methods and politics. The 'world models' that the Club of Rome pioneered, which would feed into contemporary integrated assessment models (IAMs), were seen as technocratic, leading to narrow global gaze resulting in a 'technocratic authoritarianism' (Ashley, 1983). The models' design, moreover, seemed biased—only confirming what their creators already thought (Edwards, 1996). Despite these valid concerns, however, the *Limits to Growth* tapped into a changing scientific and public imagination of the environment, *catalysing* pre-existing worries about human influence on the biosphere.

Through Rachel Carson's *Silent Spring* and the Club of Rome's *Limits to Growth*, environmentalism itself also came to be reimagined. Prior to this new wave of environmentalism kickstarted by the pollutants of the 1960s, environmentalism had mostly been a form of 'conservationism' or 'preservationism' (Warde, Robin, & Sörlin, 2018). Inspired by Henry-David Thoreau's *Walden* (1854) and the writings of Ralph Waldo Emerson, early environmentalism aligned with affluent conservatives concerned about the destruction of what they saw as pristine nature.[19] Until the 1960s, environmentalism retained its conservative connotations of affluence. Being an environmentalist was a luxury. With the adoption as the word 'the environment' as its discursive carrier, however, environmentalism became more concerned with detrimental effects of modernity and its distribution of environmental risks. Its focus shifted. The Club of Rome's *Limits to Growth* (Meadows, 1972) and the closely connected book *The Population Bomb* (1971) by biologist Paul Ehrlich voiced concerns about modernity and industrial society itself. At the same time, a growing environmental justice movement put questions of racism, inequality, and equity at the heart of their environmentalism. It asserted that industrial societies distribute environmental risks unfairly. Pollution risks are borne disproportionately by the poor, because richer and more well-educated people have more ways to fight pollution allocation—and to simply move away from pollution. Poorer people and discriminated minorities do not have this option, bearing the costs of industrial societies in their bodies and minds (Bullard, 1983). In the United States, this environmental justice movement grew in the 1970s and 1980s, aided by the work of sociologist Robert Bullard. In Europe, Ulrich Beck's *Risikogesellschaft* (1986) made similar points. Its central thesis that human-made risks were the primary risks experienced in modern society was driven home forcibly by the Chernobyl disaster in the year of its publication. In the USSR, increasing environmental awareness resulted from the failure of the Stalin plan to modify nature at will (Fedorov, 1974; Ivanov, 2002). Increasingly, people in both the United States and the USSR came to see nature as fragile.

This growing and changing environmental awareness tied into a changing conception of the Earth and its biosphere as a *global whole*. Throughout the 1960s, a view of the Earth as a fragile interconnected system had taken shape. As processing power grew, climate and weather computer modelling could cover growing regions in their simulations. Environmentalists stressed the complex relationships between different parts of the biosphere. Imagery of the Earth as a whole became available through the space programs of the United States and the USSR. One photograph in particular was important in solidifying this global view of a fragile Earth: the Earthrise photograph (Figure 2.1). Taken by William Anders on the Apollo 8 space mission, the photograph showed 'a grand oasis in the big vastness of space' (in the words of Apollo 8 command module pilot Jim Lowell) (Chaikin, 2007, p. 54). The photograph, released without copyright, became one of the most iconic images of the 20th century. Finding fertile soil in the already common understanding of the planet as a 'Spaceship Earth' (Jasanoff, 2001), the global view of the Earth inspired contributed to a notion of common fragility of and common responsibility for the well-being of the biosphere (Höhler, 2015).

This changing conception of the Earth paved the way for climate change to become a serious concern and for climate and weather modification to become highly controversial. During the 1960s and early 1970s, climate change for the most part received little attention. Scientists were curious but unsure, politicians uninterested. Part of this disinterestedness had to do with the fact that 'computer modelling, the tool on which warming theories depended

Figure 2.1 NASA photograph AS8-14-2383—the famous Earthrise photograph by William Anders (public domain).

for their credibility, had yet to acquire full scientific legitimacy' (Edwards, 2010, p. 358). 'Most sciences had barely begun to think about simulation modelling, let alone to accept it as a fundamental method of discovery' (ibid.). The first model runs of the global climate, by Syukoro Manabe, in the 1960s put climate models on the political agenda, but they weren't fully accepted as fundamental knowledge about the climate yet. Not until the late 1960s did climate modelling engage with environmental politics in a meaningful way[20] (Howe, 2014). Used as an important tool to determine whether or not supersonic aviation would damage the environment, climate modelling soon became a core feature of environmental politics. According to Paul Edwards, this controversy was followed

> in quick succession, by a series of new global atmospheric issues, including ozone depletion and acid rain (mid 1970s), 'nuclear winter' (early 1980s), and global warming (late 1980s). Together and separately, these concerns manifested the theme that human activity could affect Earth's atmosphere not only locally and regionally—as 'pollution,' the typical frame for environmental issues of the 1960s—but on a planetary scale.
>
> (Edwards, 2010, p. 358)

The *Limits to Growth* report also played a major role in normalising and legitimising environmental modelling politically. Based on early IAMs, the report modelled the *whole* Earth, integrating environmental, economic, and population trends in a dire warning about the future of the Earth. Despite the severe criticism of its models, the report managed to solidify a belief in the use of models for environmental projections. Around these models, a community grew around a new genre of scientific study; Wynne, 1984), called 'world-modelling' (Ashley, 1983). Even today, climate science and the IPCC operate in that same tradition (Edwards, 2010; Hulme and Mahony, 2010).

This interplay between the advance of world modelling, on the one hand, and changing public and political environmental imaginations, on the other, decreased enthusiasm for uncertain weather and climate modification schemes. Paradoxically, the availability of ever-improving models *undermined* confidence in predictive certainty. The prospect of accurate forecasts, so enticing after the Second World War, proved elusive when nonlinearity in mathematical system showed that barring *perfect data at every place and every time* accurate predictions would simply be impossible. In nonlinear systems, often described as chaos theory, the smallest perturbation can lead to exponential differences (Lorenz, 1963). Nonlinearity consistently showed up in complex systems everywhere (Lorenz, 1993). Time and again, different disciplines found the same outcome: some systems are inherently unpredictable. In complex systems, the slightest perturbation (or measurement inaccuracy) would be amplified exponentially. Accurate predictions, for example weather predictions for more than several days, were therefore *axiomatically* impossible (Gleick, 1987).

Another blow to the popularity of weather and climate modification was outrage about clandestine cloud seeding operations by the U.S. military in the Vietnam War, aiming to increase rainfall in an attempt to disrupt Vietcong supply routes. Because the United States also seeded clouds above neighbouring country Cambodia, Project Popeye was a direct violation of the rules of war. It sparked both international and domestic outrage. Capitalising on the global outrage, the Soviet Union proposed an international treaty to ban the military use of weather and climate modification (Fleming, 2010). This treaty, the Convention on the Prohibition of Military or Any Other Hostile Use of Environmental Modification Techniques (ENMOD), was drafted by the Soviet Union in 1974, negotiated in the following years, and opened for signature in 1977 (United Nations, 1976).[21] In 1972, shortly after Project Popeye became public knowledge, a cloud seeding operation in South Dakota indirectly led to a devastating flood killing over 200 people. Popular support for cloud seeding and other types of weather and climate modification reached a post-Second World War low (Kwa, 2001). Citizens protested against weather modification, Project Stormfury, the hurricane seeding research program came under fire, and apprehension *inadvertent* weather and climate modification grew. Until the 1970s, the 'inconclusive but promising' (Kwa, 2001, p. 162) scientific results of cloud seeding and other weather modification schemes had always been promising enough to continue research. In the 1970s, however, both scientists and the public started to weigh the benefits and risks of weather and climate modification differently. Inadvertent detrimental effects of weather modification received more attention, and nature became seen as fragile. Weather modification and climate modification fell victim to the changing times. Increasingly, large-scale modifications came to be seen as dangerous and problematic—in no small part due to some high-profile failures of large-scale experiments. As a result, the militaristic hubris of the weather warriors looked increasingly out of sync with social realities and concerns. Instead, whole Earth imaginations of climate and Earth systems led to a public conception of nature in which nature increasingly had to be protected from human influence. Complexity, and science's inherent reduction of it, seemed difficult to reconcile with the increasing recognition of a complex and unpredictable interplay of the Earth's systems. In the words of Chunglin Kwa,

> in the course of three decades, American attitudes toward technology, nature and society shifted dramatically. From hopes in the 1950s for a technology triumphant that would control the fury of storms to fears in the 1970s for the environment in the face of human society's technological excesses, Americans re-evaluated their relationship to nature and science. This, more than anything else, tipped the scales against weather modification.
>
> (Kwa, 2001, p. 163)

Of course, cloud seeding and weather modification never fully disappeared. Most notoriously, and reprehensibly, cloud seeding was used after the nuclear disaster in Chernobyl to prevent nuclear radiation to rain out of Moscow and St. Petersburg[22] (Fleming, 2010). The Chinese have also used cloud seeding 'to keep the opening ceremony dry' during the 2008 Summer Olympics (Coonan, 2008). The efficacy of these seeding procedures (and the accuracy of the publicity) is hard to estimate. Nonetheless, there seems to be a continued faith, in the efficacy of cloud seeding, and general scientific opinion seems to stay that it is 'inconclusive but promising'.

Conclusion

For Jeremy Baskin (Baskin, 2019), the main driver in the early story of climate and weather control is the sociotechnical imaginary of 'mastery'. Both the Soviets and the Americans had emerged from the war with the idea that any and all issues could be addressed by technoscientific progress. These post-war dreams of weather and climate control only gave way for a more careful mindset when the complexity of the atmosphere and the fragility of nature became part of both the public and the scientific imagination. Looking back, it is clear that Cold War weather warriors were in the dark about many important features of the climate and weather system, most importantly its nonlinear chaotic behaviour. As the triumphant war years got more removed, a new generation of climate scientists, such as Syukuro Manabe, James Hanssen, and Stephen Schneider, came of age who were far more attuned to inherent unpredictability of the climate and the atmospheric systems—and that changing them, wittingly or unwittingly, might be dangerous. It was a changing conception of climate and of science that made climate and weather modification after the Second World War imaginable. After the Second World War, scientists imagined both weather and climate to be controllable, often regional entities that could be subjugated by perfect knowledge and cutting-edge technology. It was another shift in the conception of climate and of science, towards a whole Earth understanding, that subsequently made global warming comprehensible, simultaneously solidifying an image of the Earth as fragile. The summer of 1988 *was* a watershed moment. In Bush's acknowledgement that the Earth spoke back, in Hansen's call to 'stop waffling and acknowledge global warming', and the resonance of these statements, the imagination of a global, fragile Earth finally took clear precedence over the techno-optimism of the post-war era. Climate and weather modification had become controversial and dangerous. Environmental degradation through human action, on the other hand, had become an essential part of the post-modern social imagination. As we will see in Chapter 3, however, this global view of the Earth would eventually play an important role in facilitating new dreams of climate engineering 'to counteract anthropogenic climate change' (Royal Society, 2009).

Notes

1 At the same time, many scientists felt Hansen might have jumped the gun (Schneider, 2009). Not many of them were as certain as Hansen was that 'the greenhouse effect was already there'. They agreed on the likelihood of global warming, but not many would have (yet) staked their career on definitive statements as Hansen had.

2 As the Iron Curtain fell, there was a more general sense of the possibility to find international collaborations and solutions—especially given the signalled willingness of the hegemonic United States to lead.

3 Teller's idea still lives on: in 2019, U.S. President Donald Trump reportedly suggested that a nuclear bomb might work to blow up cyclones.

4 Importantly, it is also a legacy that is carried in the systems of measurement and the technopolitical capacities that might facilitate large-scale interventions in the climate system (Hecht and Edwards, 2010). This means that, even disregarding the militarised history of climate engineering, 'deployment' of climate engineering technologies would always rely on (re-purposed) military systems.

5 Not related to the later U.S. presidents.

6 From the Great Depression, American policymakers had also learned that economic stability was intimately tied to political stability.

7 For GE, liability issues resulting from rainmaking attempts were an important reason to cede their rainmaking interests to the U.S. military. For the military, these attempts were interesting because they might be used in warfare—as, as I address later this chapter, they *were* in the Vietnam War.

8 According to von Neumann, Jules Charney, one of the pioneers in numerical weather prediction, had speculated that changing the Earth's albedo could an effective way of manipulating the climate. It is a clear indication of the formative role of post-climate science that albedo modification is now the starting point for solar radiation management that aims to reduce global warming.

9 My expertise on Soviet history is limited, and much of the climate control research in Soviet Russia may have been classified (as the military applications were in the United States). I, as the author, can make no authoritative claim that this overview of Soviet weather intervention schemes is exhaustive. In fact, it is necessarily brief and spotty. It is likely that I have missed important aspects. A fuller account of Soviet interest in climate intervention would lead to different conclusions. Most of the information on climate and weather modification schemes in Soviet Russia, at least in the Anglophonic sphere, is still drawn from three sources: J.O. Fletcher's *Changing Climate* (1968), an early assessment of whether humans were influencing the climate; Mikhail Budyko's body of work (upon which Fletcher's work also heavily draws); and the overview of two decades of Soviet scientific work on the subject produced by Zikeev and Doumani (1967). My account is no different.

10 In the Soviet Union, such dreams of domination of nature and the use of science and technology as a way of legitimising communist planning also predated the post-war era. Already in 1920, Lenin famously said, 'Communism is Soviet government plus the electrification of the whole country' (Lenin, 1920). The Soviet GOELRO plan, for example, intended to combine technological progress (in the form of the electrification of Russia) with economic recovery after the First World War.

11 Lysenkoism, a pathological belief in dated genetic evolutionary theories on the basis of ideology and politics that led to severe food shortages, is the most infamous result off the Stalinist connection between science and politics.

12 Scientific and intellectual freedom in the United States during the Cold War was, of course, also hemmed in significantly, but not to the same extent.

13 These proposals were not unlike the exchanges between Svante Arrhenius, the first scientist to calculate the heating on CO_2 on the Earth's temperature, and Nils Ekholm. Arrhenius stated that

> By the influence of the increasing percentage of carbonic acid in the atmosphere, we may hope to enjoy ages with more equable and better climates, especially as regards the colder regions of the earth, ages when the earth will bring forth much more abundant crops than at present, for the benefit of rapidly propagating mankind.
>
> (Arrhenius, as quoted in Fleming, 1998, p. 74)

14 Incidentally, Budyko was at the 22nd Congress of the Party in 1961, one of the first to provide dire warnings of anthropogenic global warming.
15 Translated and published in English in 1974, under that title (Budyko, 1974).
16 As we will see in Chapters 4 and 5, treating the environment as a *resource* has particular effects on one's view of environmental interventions.
17 Of course, Arrhenius calculations were not the first attempts to quantify the greenhouse effect, nor were they the first attempt to redefine climate as a meteorological phenomenon. The work of Joseph Fourier and John Tyndall, earlier in the 19th century, for example, was a crucial influence on Arrhenius.
18 This report was, as Warde, Robin & Sörlin (2018) note, one of the first official reports to mobilise the word 'environment' in comprehensive relation to human influence on both planetary and regional processes, signifying the arrival of a new political discourse around the environment, environmental protection, and environmentalism.
19 The Boone and Crockett Club, the first wildlife conservation organisation, was founded by Theodore Roosevelt, for example, and included members of the American wealthy conservative class.
20 Especially through the astounding resonance of the 'world models' of the *Club of Rome*.
21 ENMOD remains one of the few international agreements that directly pertain to climate modification (and only in relationship to military applications).
22 Instead, the radiation rained out over the Baltic states and Belarus. While this choice was defensible—those regions were far less densely populated, limiting the amount of people at risk—the fact that the populations of those regions were never informed was not.

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