Experiment Earth

Responsible innovation in geoengineering

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1 Balloon debate

'When we all stand in that field in Norfolk, all of the engineers will be jumping up and down because they've succeeded in doing something amazing, building the tallest structure anywhere on Earth, and all of the natural scientists will be saying "Oh shit, we're a step closer to doing something bonkers".'

(A scientist working on the SPICE project)

A helium-filled polythene balloon floats three metres off the ground, tethered to a steel platform. The idea is to use this balloon to lift a kilometre-long hose into the sky. Once the balloon is up, some water – no more than it would take to fill a child's paddling pool – will be pumped up the hose and squirted out through a nozzle to form a fine mist. After a few test launches, the balloon will stay in the air for about five days, enough time for the engineers to observe how the apparatus withstands the wind: to see if the balloon dips, kites or spins and to see if the pipe twists, bends or wobbles.

There are two ways of looking at this experiment. From one perspective, it is a straightforward test of a combination of old, mundane technologies. The balloon is an 18-metre-long blimp, normally used at sporting events to hold TV cameras or advertising. It is not aiming that high. In the world of tethered balloons, the current altitude record is around five kilometres. The pump is from the sort of pressure washer that can be bought from a garden centre. The hose will be a longer version of the hydraulic hoses that carry fluids around a car. The small quantity of water means that it will probably evaporate before it hits the ground. The experiment will have no discernible effect on the environment.

The experiment has passed through two university ethics committees. The first responded that as the project did not involve animals or human subjects, it complied with ethical research standards. The second agreed, adding that the team's plans to engage members of the local community around the test site were welcome.

Such experiments are never risk-free. The engineers' own risk assessment points to a number of possible incidents. The balloon could deflate, perhaps because of a bird strike. High winds could drag the balloon back down to Earth. The winch could jam, leaving the balloon stuck in the sky. The tether could break free. (One of the engineers told me a story of a woman in California who had recently been pulled from her bicycle by a rogue rope from a hot-air balloon.)

It is important to bear these risks in mind, but such things are relatively well understood. Engineers have centuries of accumulated knowledge assessing and controlling risk. From a purely technical perspective, it is possible to conclude that nothing new is happening with this experiment. Few people outside the project are worried by the immediate risks. The non-governmental organisations (NGOs) and journalists who have taken an interest in this experiment are less concerned about the experiment going wrong than about it going right.

The second way of looking at this experiment is as '*the first field test of a geoengineering technology in the UK*', to use the researchers' own words. The experiment is part of a larger scientific project, known as SPICE. The playful acronym hides a serious motive – Stratospheric Particle Injection for Climate Engineering. One of the aims of this research is to work out whether it is possible to put particles into the stratosphere to reduce the amount of sunlight that reaches the Earth's surface. On the SPICE project's website, there is a schematic of a much larger balloon attached to a hose more than 20 kilometres long, spraying out a reflective aerosol that has yet to be determined but is likely to be less benign than water. Such a contraption is unachievable using present materials, but the design could be seen as a statement of intent.

The accepted definition of 'geoengineering' (or 'climate engineering') is the 'deliberate and large-scale intervention in the Earth's climatic system with the aim of reducing global warming' (Royal Society 2009, p. ix), through either sucking carbon dioxide from the air or reflecting sunlight back into space. Less than a decade ago, this big idea was given short shrift by both policymakers and scientists. The last five years have seen a dramatic increase in scientific interest. In September 2013, geoengineering was pushed closer to the mainstream of climate policy with a mention in the 'Summary for Policymakers' (SPM) of the fifth report of the Intergovernmental Panel on Climate Change (IPCC 2013).

The SPICE team are among a small but growing number of scientists taking the idea of geoengineering seriously. This is not to say that the SPICE scientists are trying to hasten a geoengineered future. They have, in the main, entered this new field with ambivalence and trepidation. The idea of geoengineering seems to cross Rubicons and break taboos. Some of the scientists are concerned that manipulating a system as chaotic and poorly understood as the global climate is likely to be disastrous. They point to early results from computer models that suggest dramatic effects on local weather patterns if global sunlight is reduced. Others point to the political risks of taking seriously a technological fix that destabilises the fragile political consensus on tackling climate change by cutting greenhouse gas emissions. Alan Robock, a climatologist, has produced an influential summary of 'reasons why geoengineering may be a bad idea' (Robock 2008). These concerns do not apply just to the use of any eventual technology. Given the potential downsides of this imagined technology, most scientists are at pains to emphasise that they would have no wish to deploy such a thing if it were developed. It is hard to find a geoengineering researcher who is in favour of doing geoengineering. But Robock and other scientists recognise that research on geoengineering may be a step onto a 'slippery slope', making technological development and deployment more likely (see also Jamieson 1996).

There are other reasons to be concerned about geoengineering that cannot be assessed by science but are no less important. If geoengineering of the type imagined by SPICE were to happen, it would represent a project of extraordinary hubris. It would concentrate power in the hands of very few people and claim mastery over a part of everyday life that we have until now been happy to admit is in some way out of our control. Even in our secular age, courts and insurance companies refer to extreme weather as an 'act of God'. An engineered climate would mean someone taking responsibility for such things. It is therefore reasonable to ask if this is the sort of world in which we would want to live. Many would legitimately respond that regardless of what the science tells us about risks and benefits, they would rather not head in that direction. It is in this sense that high-profile commentators express repugnance at geoengineering. The broadcaster David Attenborough has called the idea 'fascist',[1] an accessible if overstated recognition of what I and others have described as the anti-democratic political constitution of geoengineering proposals (Szerszynski *et al.* 2013).

Geoengineering is an emerging technology. We do not know precisely what a successful geoengineering device or technique will look like or how it will work. For now, geoengineering brings together a set of diverse proposals and suggestions. These range from the fantastic (sunshades in space between the sun and the Earth) to the well established (growing more trees or burying carbon dioxide underground). A couple of proposed geoengineering techniques have become the subjects of serious research. In addition to considering stratospheric particles, scientists have begun to experiment with ocean iron fertilisation. This involves the seeding of oceans with iron particles to encourage the growth of algae that would absorb carbon dioxide from the atmosphere and take it to the sea floor.

The experiment with the balloon is not attempting to do stratospheric particle injection, nor is it attempting to do climate engineering. But it is in some respects a 'climate experiment', as one journalist dubbed it.[2] A small group of campaigning NGOs issued a press release with the headline 'Say No to the Trojan Hose!' (ETC Group 2011). They wrote to the heads of the research councils and to government ministers, calling for the cancellation of an experiment that they saw as part of a rush to develop geoengineering.[3] Other geoengineering researchers around the world also criticised the haste with which the experiment seemed to be proceeding.

Both views of this open-air experiment are, in a strict sense, correct. But they reflect very different ways of understanding science in society. The first sees science in splendid isolation. The second sees scientific research entangled in the multiple lines of debate that characterise the geoengineering issue. The experiment was consciously public. It was announced at a national science festival with press releases and PR support from the universities involved. It revealed some of the assumptions and interests of geoengineering research to a wider audience for the first time. It therefore allowed for public scrutiny. The experiment, and the controversy it generated, provided a valuable opportunity for sociological research but also for what Arie Rip calls 'informal technology assessment' by those outside the scientific community (Rip 1986).

Our interest in scientific experiments need not be limited to those that take place outside or involve outsiders. Geoengineering of the sort under investigation by SPICE began as a set of thought experiments exploring the possibility of replicating the 'natural experiment' of a volcanic eruption. These ideas are now being tested using experiments run on computer models of the climate. We should take an interest in scientific research whatever its form, particularly when it is tied to such a problematic technological vision. The SPICE project is about much more than a balloon. The questions raised by *in vivo* or *in situ* experimentation can be reflected back on experiments taking place *in vitro* or *in silico*.

Conventionally, we regard thought experiments as constrained only by the scientific imagination. But, as I describe in later chapters, there are limits, norms and taboos that govern what scientists consider important, desirable or even thinkable. The future of the planet may be written in the experiments that take place inside laboratories, as much as outside. The direction of geoengineering research is a function of conversations that happen in public as well as those that involve just scientists. As geoengineering researchers start to take seriously the possibility of engineering the climate, which may profoundly recast humanity's relationship with the planet, we should look closely at dynamics of research, responsibility and governance.

This book is a sociology of geoengineering research. It draws on more than three years of interviews and interactions with the SPICE project and the wider geoengineering research community. It is about the tangle of issues in which geoengineering researchers find themselves. The book considers the various issues raised by geoengineering, focussing in particular on stratospheric particle injection, one of the subset of geoengineering proposals known as solar radiation management (SRM). It looks at how institutions and individuals have begun to make sense of solar geoengineering as it moves from the arena of science fiction into the arena of scientific research.

The book fits into the tradition of science and technology studies (STS), which is concerned with the social and political dimensions of science and engineering with a view to revealing the possibility of alternative directions. I am interested in the public nature of contentious science, its connections with emerging technologies and the negotiation of scientific responsibility. The publicness of geoengineering should make us pay attention not just to what is being done in the name of science, but also to how ideas of politics, ethics and 'the public' are being imagined. We should question the way that geoengineering is being framed as its complexities are made tractable through research and experimentation (cf. Bonneuil *et al.* 2008).

Governance beyond risk and ethics

The conclusions of recent STS studies of emerging technologies suggest the need for a rethink of the governance of science and innovation. We conventionally talk about the downsides of technology in terms of the risks or ethical dilemmas they create. The SPICE balloon debate was not really about either risk or ethics. STS research has revealed how this focus on the downstream impacts of technology can hide more fundamental upstream questions about the direction of innovation (Rayner and Cantor 1987; Wynne 2002).

With geoengineering, there is already plenty being said about risks. Scientists argue that observations of massive volcanic eruptions such as Mount Pinatubo in 1991 reveal both the cooling effect of particles in the stratosphere and the risks, particularly in the form of disruption to weather systems, when such an event happens.

Some see these risks as mountainous, even insurmountable. Others are more confident. For David Keith, currently the world's most prominent geoengineering researcher, volcanic eruptions 'give confidence that there is a strong empirical basis on which to assess these risks, and it is a reason to expect that the risks will be comparatively small' (Keith 2013, p. 12).

My aim in this book is to draw attention away from risk assessment towards uncertainties: the things we don't know, that we can't calculate and that may remain incalculable. Keith states that when it comes to the risks of climate change, 'we can't estimate the uncertainty very well: we don't know what we don't know' (Keith 2013, p. 31). The same applies to geoengineering. Keith admits that 'the largest concern is not the risks we know but rather a sensible fear of the unknown-unknowns that may surprise us' (Keith 2013, p. 70). For all this uncertainty, however, he is confident that science and engineering can find their way to a technology with 'negligible direct side effects' (Keith 2013, p. 110). Geoengineering researchers have begun taming some of these uncertainties and turning them into a research agenda. The assumption is that, as one paper claims, 'many uncertainties could be reduced through a systematic program of theory and modeling' (MacMynowski *et al.* 2011, pp. 5044–5045). STS research has demonstrated that in many areas, research creates more questions than answers, expanding our uncertainty (Nelkin 1979; Ravetz 1986). Uncertainty is just as important a part of science as knowledge is (Stocking 1998), and yet it is often hidden from public view. We can imagine that given the social and political complexities of geoengineering, the range of uncertainties is likely to be ever-expanding. Scientists should not pretend to completely know the risks and ethical challenges we face.

Science in society; science and society

This book is about the place of science, technology and innovation in the world. It is about 'science in society', but the conventional separation between 'science' and 'society' is one of many dichotomies challenged by my approach. Books like this are often categorised as 'science and society', as though these are worlds apart, or as 'science in society', as though science is a separate enclave. Despite the efforts of social scientists, the debate about science and innovation in society has struggled to avoid the implication that the science is somehow immutable, detached and exogenous. The logic follows that it is incumbent upon society and politics to understand, catch up and, if necessary, regulate.

The idea of geoengineering cannot be straightforwardly separated into scientific and social parts. The nascent debate about geoengineering shares some features with previous emerging technologies, including biotechnology and nanotechnology, which are driven by 'sociotechnical imaginaries' (Jasanoff and Kim 2009) – visions of desirable futures that blend social and scientific ambitions and carry narratives of both promise and threat. Their imagined potential demands government investment but also governance. It has become a commonplace of emerging technology discussions to identify a 'governance gap'.

David Keith prefaces his recent book, *A Case for Climate Engineering*, by stating, as if it were incontrovertible, the following:

> It is possible to cool the planet by injecting reflective particles of sulfuric acid into the upper atmosphere where they would scatter a tiny fraction of incoming sunlight back to space, creating a thin sunshade for the ground beneath. To say that it's 'possible' understates the case: it is cheap and technically easy.
>
> (Keith 2013, p. ix)

This argument, reminiscent of claims made at the dawn of nuclear power that people would be able to 'enjoy in their homes electrical energy too cheap to meter',[4] has been allowed to underpin assessments of the promises and perils of geoengineering. Keith goes on to evaluate the risks and benefits of the technology as though it were ready to be pulled off a shelf, with risk assessments all in order. He calls solar geoengineering a 'cheap tool that could green the world' (p. x) but argues for awareness of 'benefits and risks that are distributed at regional to global scales' (p. xx).

Claims about the potency of geoengineering have led to concerns about a gap between science and regulation:

- 'I think the science is certainly far out ahead of the politics' (Jason Blackstock, quoted in O'Neill 2012).
- 'Right now, the politics of geoengineering are far ahead of the science' (Victor *et al.* 2013).

These two quotes from geoengineering commentators, while apparently in disagreement, are actually pointing to the same thing – a technology that is neutral and inevitable, if not already present. The first is a call to govern the technology; the second is a call to better understand the technology. Both are deterministic. Neither admits that the technology remains the figment of a particular technoscientific imagination. This book hopes to contribute to the discussion of the governance of geoengineering by questioning the presence of this imagined governance gap. The STS critique of technological determinism first demands scepticism about the nature of the technology that is under investigation (Wyatt 2008).

The SPICE project does not come with easy distinctions between facts and values. Such distinctions are often made in the geoengineering debate, but that does not mean we should take them for granted. Part of my argument in this book is that a constructive debate about geoengineering requires recognition that its science and its politics have emerged hand-in-hand and will continue to do so. If we are to make sense of, learn from and deal with imaginaries of geoengineering, we should question the lines that are drawn between science and society, between nature and humanity and between research and innovation.

From noun to verb

Despite its non-existence as a viable sociotechnical system, geoengineering is already discussed as if it were a noun, an artefact. There is, oddly, rather little engineering in the world of geoengineering. The technology is simply imagined. Geoengineering, even in the absence of any concerted technology development, is talked about as if it is geotechnology, assessable using conventional geoscience. Geoengineering, as a noun, is becoming important in the climate change debate.

The SPMs provided by the IPCC are the frontline of negotiations between climate science and climate policy. In 2007, when the IPCC produced its fourth assessment report, geoengineering appeared only in the SPM for Working Group III, whose job is to assess options for mitigating climate change.

> Geo-engineering options, such as ocean fertilization to remove CO_2 directly from the atmosphere, or blocking sunlight by bringing material into the upper atmosphere, remain largely speculative and unproven, and with the risk of unknown side-effects. Reliable cost estimates for these options have not been published.
>
> (IPCC 2007, p. 15)

By 2013, geoengineering merited a longer mention:

> Methods that aim to deliberately alter the climate system to counter climate change, termed geoengineering, have been proposed. Limited evidence precludes a comprehensive quantitative assessment of both Solar Radiation Management (SRM) and Carbon Dioxide Removal (CDR) and their impact on the climate system. CDR methods have biogeochemical and technological limitations to their potential on a global scale. There is insufficient knowledge to quantify how much CO_2 emissions could be partially offset by CDR on a century timescale. Modelling indicates that SRM methods, if realizable, have the potential to substantially offset a global temperature rise, but they would also modify the global water cycle, and would not reduce ocean acidification. If SRM were terminated for any reason, there is high

> confidence that global surface temperatures would rise very rapidly to values consistent with the greenhouse gas forcing. CDR and SRM methods carry side effects and long-term consequences on a global scale.
>
> (IPCC 2013, p. 29)

This paragraph is the final one of the summary, giving the unfortunate impression of a twist in the climate change tale. A lazy policymaker might see it as an invitation to explore easy technological fixes rather than hard international negotiations. It is clear, however, that the IPCC sees little to like about geoengineering. The language has become more certain than in the previous report. Technologies that were 'speculative and unproven' in 2007 are now discussed, with relatively little additional evidence, in terms of their potential and their side effects. Tellingly, however, this paragraph is in the SPM from Working Group I, which assesses the 'physical science basis' for climate change. Solar geoengineering is not mentioned in the Working Group III SPM. It seems to have been naturalised as part of the physics of climate change, rather than explored as an engineering or policy option.

Engaging with geoengineering research in action forces us to think about geoengineering not as a noun but as a verb. Viewed as a set of technologies, geoengineering resembles no more than a mixed bag of half-baked schemes. If we take literally the meaning of 'geoengineering' as a present participle, it becomes a project, a work-in-progress. This idea, the idea of exerting control over the atmosphere, demands different sorts of analysis and governance. We can see geoengineering as a new trajectory, reconfiguring social relationships and, ultimately, reorienting people's relationship to the weather. My argument is that rather than talking about the governance of geoengineering, we should bring these things together. In its ambitions for climatic control, geoengineering is itself a form of governance.

This view – of geoengineering as a work-in-progress – changes our view of responsibility. As Oliver Morton (2012) has argued, researchers looking at geoengineering 'tend to naturalise it: to treat it as a thing in the world to be examined'. This leads towards arguments for technological and scientific autonomy. As I will describe, the naturalising of geoengineering has contributed to the framing of expert assessments of the issue and research agendas that have followed, in which scientists have been able to avoid many of the most profound questions of responsibility that geoengineering would seem to present.

If geoengineering is framed alternatively as a technoscientific project, the responsibilities of scientists are mixed: in 'researching' something, they are also implicated in its development, even if their research points to more risks than benefits. (This point applies equally to social scientists and others, me included, attracted to the purported novelties of geoengineering.)

Science is not one thing, nor does it have just one place in society. It is conflicted and its roles are multiple. It deals in truth, but also in innovation, expertise, evidence and critique.[5] Different disciplines, particularly if we include engineering, have different dispositions and come up with very different accounts of the world. It is increasingly hard to justify the activities of contemporary technoscience with reference to an old-fashioned model of scientific purity. I hope to challenge the dominant framing of geoengineering – as a thing to be governed – by instead developing a narrative of the 'co-produced' (Jasanoff 2004) science and politics of geoengineering.

Understanding emerging technologies requires the dismantling of assumed boundaries between science and society. Typically with emerging technologies a division is quickly established between those who want to innovate and those who want to regulate, with the reach of the former always exceeding the grasp of the latter.[6] With geoengineering, such cracks are only just starting to show. Few people are actively promoting the technology. Most geoengineering researchers are openly ambivalent about the technology and appreciate that the relevant questions reach far beyond science. As I will describe in subsequent chapters, however, this does not mean that the technology is stillborn. Some of the more thoughtful geoengineering researchers recognise that by researching something they see as highly undesirable, they may be unwittingly nurturing its development.

From speculation to anticipation

This is a book about geoengineering, but it is unlike other books about geoengineering. It does not share either the excitement or the terror evident in some of the books that have followed in the wake of scientific attention (Goodell 2010; Kintisch 2010; Hamilton 2013). These have all drawn attention to an important set of issues, but they have adopted the dominant scientific narrative of power and novelty that accompanies geoengineering debates.

We do not have to accept the *faits accomplis* suggested by the subtitles of those books. I do not see an 'audacious quest' (Goodell 2010) to engineer the Earth's climate, nor do I believe that we are witnessing 'the dawn of the age of climate engineering' (Hamilton 2013). The response to Kintisch's (2010) question of whether geoengineering is science's 'best hope' or 'worst nightmare' is almost certainly 'neither'. The choice of 'environmental necessity or Pandora's box' (Launder and Thompson 2010) is a false one.

James Fleming has taken a different approach in his history of geoengineering. His narrative of continuity from earlier, mainly spurious attempts at weather modification gives cause for scepticism about the novelty of geoengineering. For Fleming, most geoengineering science is 'geo-scientific speculation' (Fleming 2010, p. 228), based on 'back-of-the-envelope calculations' (p. 233). But the speculation is not just the preserve of scientists. We have seen an array of philosophers, legal scholars, social scientists and others gather to discuss the various non-technical issues that might arise. I confess that I share some of the fascination, which accounts for my writing this book. But the book is in part a criticism of what Alfred Nordmann (2007) has called 'speculative ethics'. As I describe in Chapter 3, there has been a minor explosion of science, social science and humanities research wargaming scenarios of a geoengineered future. There are discussions of who would be most likely to unilaterally use the technology, who would win and who would lose, how agreement might be reached on an ideal planetary temperature, and how planetary temperatures would rebound in the event of a technological shutdown. Ethicists have rushed to describe the questions of justice and rights that would arise from such scenarios.

The critique of speculative ethics is that such thinking cements the speculation, bringing it closer to inevitability. In discussing 'what will happen if . . . ' the 'if' is more likely to become a 'when'. Nordmann describes how, as 'the hypothetical gets displaced by a supposed actual, an imagined future overwhelms the present' (Nordmann 2007, p. 32). With geoengineering, technologies are often discussed as though they are real. Researchers are already talking about whether the technology will be 'applied' (Barrett 2008) or 'deployed' (Victor 2008), rather than whether it can or should be developed.

Anticipating problems with the 'termination effect', the threat of 'unilateral deployment' and the control of the 'thermostat' has sparked important early discussions about the non-scientific aspects of geoengineering and its research, but such discussions risk exacerbating a narrow view of governance. With geoengineering, as with other emerging technologies, we should be concerned with its uses, as well as its abuses. Technological catastrophes may have rapid, visible and wide-ranging effects, but in the long run these are less important than the slow reconfigurations brought about by emerging technologies.

My straightforward response to the books which ask whether geoengineering will be the planet's saviour or a new disaster is 'we have no idea'. Mike Hulme takes a more critical approach to geoengineering science. He makes a strong argument that stratospheric aerosol injection is ungovernable, 'an illusory solution to the wrong problem' (Hulme 2014, p. 130) and therefore deserving of prohibition. He argues that 'the socio-technical imaginary of the thermostat should be dispensed with' (p. 82). I share many of his concerns, but we should not presume that the technologies currently imagined, with all of their hastily constructed 'implications', will come to be realised.

The danger is that, in speculating, we leapfrog the discussions in the present about how geoengineering research should proceed. Geoengineering is what Joel Mokyr (1990, p. 291) would call a 'hopeful monstrosity'. There are no technologies to see or touch, and the vast majority of scientific research has taken place inside computer models. The sociology of geoengineering is necessarily a sociology of ideas, promises, imagined futures and research trajectories. Geoengineering therefore provides a case study in what has been called the 'sociology of expectations' (Borup *et al.* 2006; Selin 2008).

Geoengineering futures

With an emerging technology, we typically see that the claims are grandest when the technology is least developed (Borup *et al.* 2006). In science, it might be reasonable to expect expectations to be at least partly backed up by evidence. But instead we typically see that the more immature the technology, the fewer constraints there are on hype. Futures are framed and constructed with stories, metaphors and clichés. Brigitte Nerlich and Rusi Jaspal point to the various linguistic devices with which actors have begun to make sense of this imaginary technology. The metaphors have joined the litany of narratives that already exist around climate change. Geoengineering is variously a 'dimmer switch', a 'thermostat', 'a sunshade', a 'plan B', a 'tool in scientists' toolbox', a 'parachute' in case of a planetary 'emergency'. Recognising the likelihood of side effects, geoengineering researchers have described it as a 'the lesser of two evils', 'chemotherapy' or 'methadone' for an addicted planet, with planet being a metaphorical body, machine or patient, according to the particular cliché. For critics, geoengineering represents a 'short term fix', a 'runaway technology', a 'moral hazard', 'playing God' or 'playing with fire' (Nerlich and Jaspal 2012). Clive Hamilton (2013) describes it as an archetypical 'Promethean' technology. In most cases, whether from the more techno-optimistic or critical ends of the spectrum, hope is accompanied by warning; hype sits alongside doom.[7] The clear message is that the technology is uniquely and unprecedentedly potent.

As with any new technology, there are definitional wrangles and frequent arguments for name changes and division of research areas. Some, such as adoption of the term 'climate remediation', suggest new ideas about what is desirable or technically plausible. These frames and futures are not just public relations. As one of my interviewees told me, '*framing is everything*'. It determines what seems acceptable or possible, who has a right to speak and the distribution of power (Schon and Rein 1994). My research is inspired by the sociology of expectations, but I do not presume that the futures imagined for geoengineering are either fixed or coherent. As with other areas of science that are accompanied by grand promises, from genomics to nanotechnology (Hedgecoe and Martin 2003; Nordmann and Rip 2009), trajectories of innovation can be modulated by new research, new controversies or new political arrangements.

If geoengineering is indeed 'a bad idea whose time has come' (Kintisch 2010, p. 13), we should ask why and how the promise of this idea has stabilised when a host of other grand technological schemes have been ridiculed, become relics of the Cold War or remained in the realm of science fiction. In the few years since geoengineering was rehabilitated as a credible topic of scientific research (see Chapter 3), geoengineering researchers have become increasingly self-confident. Doubts, uncertainties and ambivalences are being tamed. Ethical and political quandaries are being turned into empirical questions. Extraordinary proposals are being domesticated with ordinary science. The ease and cheapness of geoengineering is often taken for granted in geoengineering research. Geoengineering is often talked about as though it is an inevitable part of humanity's future relationship with the planet, and sometimes talked about as though it is already possible.

There are reasons why scientists such as David Keith pull a geoengineered future so close. Geoengineering is their object of study. Thankfully, it is neither as near nor as inevitable as Keith would have us believe. The sociotechnical system being imagined is highly uncertain, but we can expect the 'socio' part of it to be pretty important as it has proven to be with nuclear power, further compounding our uncertainties.

Geoengineering futures rest on assumptions about what is easy and what is hard, what is intractable and what is mobile. An important paper by Paul Crutzen (2006), discussed in Chapter 3, cemented the idea that the technology to cool the planet could be an easy solution to what has proven to be the hard if not impossible task of cutting greenhouse gas emissions. As I discuss in Chapter 2, geoengineering follows in a tradition of technological fixes that offer seductive alternatives to the difficult and messy business of policy, or what ardent technological fixer Alvin Weinberg (1966) called 'social engineering'.

The scale of ambition means that conversations about geoengineering can rapidly expand to encompass the future of the planet, the future of our species and humanity's relationship with Nature. The SPICE project brings such discussions back down to Earth. It prompts discussions of imagined, speculative and distant futures, but it demands attention to the immediate future too. The SPICE testbed experiment would have been one of the first experiments to test a geoengineering hypothesis outside a laboratory. The project attracted controversy for this reason, but it also created the possibility of unsettling assumptions that had come to dominate geoengineering futures. What if stratospheric geoengineering were more complicated, more expensive and more problematic than assumed?

The SPICE project has lessons for debates about geoengineering and debates about the governance of emerging technologies. But it is not just an interesting case study of scientific research. The SPICE balloon is also a symbol of the ambitions and flaws of contemporary science policy. As rich countries seek to secure their future as 'knowledge economies', science and scientists are under increasing pressure to contribute to economic growth. There is, as yet, no obvious capitalist aspect to solar geoengineering that is equivalent to the 'biocapital' (Sunder Rajan 2006) that now infuses the life sciences. Nevertheless, scientists still find themselves working under a regime of 'technoscientific promises' (Felt and Wynne 2007, p. 24) where, as Arie Rip puts it, 'being first is more important than going in the right direction' (Rip 2009). As I will describe in Chapter 5, the manner in which SPICE was funded displays some of this carelessness. But geoengineering offers an opportunity for an alternative view of the governance of innovation as 'collective experimentation' (Felt and Wynne 2007).

Collective experiments

This book turns on the idea of experimentation. Experiments are conventionally understood to be a scientific activity. But we have seen the term 'experiment' seep through the boundaries of science. It has become common to talk about the experimental nature of technologies that were once thought to be predictable and controllable (Krohn and Weyer 1994). And it is increasingly common to hear policy innovations described as 'experiments in governance' or 'experimental government'.

Experiments are normally part of the private life of science. The public image of science is about evidence, authority and expertise, not uncertainty and surprise, and when 'experiments' take place in public, they are typically displays of certainty (Shapin and Schaffer 1985; Collins 1988). If technologies are imagined as just things, society's questions are pushed downstream. With geoengineering, we see a clear need for democratic discussions to take place upstream (Wynne 2002; Wilsdon and Willis 2004), before we know what technologies will look like, what they will do and what they will mean for humanity. In this sense, geoengineering makes clear a need and an opportunity to democratise experimentation. SPICE provides an example of this happening in a semi-controlled fashion, with the gradual realisation that the outdoor experiment was about more than science.

The SPICE experiment was an early attempt to take geoengineering research out of the laboratory and into the field, from the domain of science to that of technology. The reaction to it took the scientists involved by surprise. Though originally intended as a technical test, it became a social experiment. Geoengineering is experimental in other ways, too. The planetary scale of ambition means that, as with nuclear power and other technologies, if a solar geoengineering technology is used, it will initiate a perpetual experiment with the planet. The technology can't be adequately tested until it is used – at scale and for a long time. The history of technology suggests that claims to be able to predict and control its effects are often overblown. But once society is locked into such experiments it becomes hard to withdraw from them. What begins as an experiment quickly becomes the everyday.

If we buy some of the arguments being put forward for the power of, for example, a future stratospheric aerosol technology, its potential for disruption puts it alongside nuclear weapons. But unlike the bomb, it won't just be created in secret and unleashed onto the world (unless we also buy the more far-fetched scenarios involving eco-terrorists or rogue states operating unilaterally). A geoengineered world, if we can imagine such a thing, would require a vast sociotechnical system of machinery, manpower, infrastructure, rules, laws and institutions. Innovation and experimentation will need to happen in public, with the public.

If geoengineering is to do what is expected of it, it will need to be tried, tested and scaled up. It will need to be experimented upon in the environment, *with* the environment, and the signal of its impact will need to be painstakingly extracted from the noise of a chaotic global climate. These tasks will be technically and politically difficult, and each will be fiercely contested. People will disagree about the shape, size and desirability of the experiments. And when they disagree, there will be further disagreements about who has given their consent to such experimentation. They will disagree about how to interpret the results. And once the technology is deemed – by whom, who knows? – worthy of deployment, the experiment will continue. The technology can only be tested through use, and the test will never provide uncontested certainty (MacKenzie 1990). A central insight from STS is that technologies and knowledge are never complete. Discussions about science and innovation can be closed, but their closure is done socially rather than technically. Such insights, and their occasional overuse, have attracted the accusation that STS is merely interested in deconstructing everything that we think might be solid. With geoengineering research, one does not have to look hard to see the bare bones of science. It is quickly apparent that there is a large range of views that are all in some way 'scientific', and there are plenty of scientists who admit the limits of science in understanding and charting a way forward. If we accept that innovation is somehow 'society in the making' (Callon 1987) and if we take research as an important part of 'innovation in the making', we should surely pay attention to the practice of scientific research.

Arguments about geoengineering are inextricably bound up with those about climate change, which has its own heavy political baggage. As I describe in Chapter 3, part of the commonplace rhetoric of anthropogenic climate change is that it represents an unprecedented 'experiment' with the Earth's climate. The implication is that this experiment has been an unethical one, but talk of this unplanned and uncontrolled experiment has made it easy for some technological optimists to suggest that what is needed is a controlled geoengineering experiment.

This is a book about what good experimentation might look like. If we consider the experimental system of geoengineering to include more than just scientists, their laboratories and their apparatus, how might we democratise experimentation? If we regard experimentation as a collective enterprise, something that is done *with* society rather than just *for* society or even *to* society, what are the responsibilities of scientists and the institutions that govern them?

About this book

This book is not an outsider's view of geoengineering. I do not pretend towards a scholarly detachment. I made the point above that all researchers interested in geoengineering may be in some way implicated in its future trajectory. I have sought to study geoengineering while being in some way part of it. The interactions that constitute the research behind this book are therefore themselves experimental, in the sense developed by Rabinow and Bennett (2012). The effect is that some of the reported conversations in this book are not the product of neutral observation but are snapshots of views at different points in a process of ongoing engagement, research and reflection.

The next chapter takes a step back from geoengineering to present a framework for considering whether and how science and innovation can take better care of the futures that they help bring about. I discuss the politics of technologies and technological fixes and advance notions of responsible innovation and collective experimentation.

Chapter 3 looks at the recent rise of geoengineering research, asking how a previously unthinkable area of science became 'thinkable'. I challenge the dominant history of geoengineering that has been adopted by geoengineering researchers, a story of disconnect from coventional climate science. The chapter draws threads together from the history of environmental science, the entangling of science and politics within the debate about climate change, and the mixed motivations for understanding, prediction and control within climate science.

Chapter 4 takes the Royal Society (2009) report on geoengineering as a case study in expert advice and technology assessment. I describe what was happening backstage as the Society wrestled with an issue that took the institution out of its scientific comfort zone. The Society's assessment was instrumental in the further construction of geoengineering. While the report, the Society staff and the working group were admirably open-minded in their approach, the issue became scientised in some important ways through their endorsement.

Chapter 5 looks in detail at the SPICE project, starting with the proposed outdoor experiment that initially attracted scrutiny. Asking what lessons about governance can be learnt from such experiences, I conclude that regulation of experimentation with clear lines around risk and ethical concern is unlikely to attract public credibility. We should instead seek to engage with the purposes of experimentation as part of a collective exploration of responsibility.

Chapter 6 looks at models in climate science and geoengineering research. I discuss the use of computer 'experiments' in climate science and ask what happens when the motivations for these experiments start to twist towards geoengineering. I look at the practice of climate science and the foibles of models that become visible up close.

Chapter 7 looks at dynamics of interdisciplinarity within and around the SPICE project. I ask how science fares when unfamiliar research cultures clash in new and contested areas. I consider the 'engineeringness' of geoengineering and argue that the disruption that comes from these forms of collaboration can be healthy as a precursor for taking greater responsibility.

In the book's concluding chapter, I consider the potential for democratising the collective experiment of geoengineering and offer suggestions for improved governance and careful research.

Taking responsibility

The story about the balloon experiment needs an ending. After lengthy discussions within the team and with the funders and others, the SPICE team decided not to launch the balloon. A patent application that included two of the SPICE researchers was unearthed, fuelling disagreements within the team about the merits of the experiment. Following an earlier postponement, and in recognition of the complexity of issues that had been surfaced by the proposal, the researchers called off the test.

The experimental gallimaufry was left unbuilt. The balloon that would have carried the hose was redeployed to some other task. The order for the hose was cancelled. The engineers on the SPICE project turned their attention to other ways of investigating the potential for giant stratospheric balloons, and the rest of the SPICE team continued with their research, albeit slowed by the administrative burdens of dealing with the fallout from the proposed experiment. The experiment had become a topic of conversation at all levels of British science policy, from the government chief scientific adviser downwards. The decision to cancel the testbed attracted wide news coverage, particularly in scientific publications such as *Nature*,[8] and initiated a period of soul-searching among scientists regarding what was at stake in geoengineering research.

The proposed SPICE experiment, the controversy it generated and the scientists' decision not to carry it through, all of which the SPICE scientists subsequently labelled 'the SPICE experience', prompt questions about responsibility that have become a central theme of this book. At the most abstract level, geoengineering raises the question of whether we are ready to take responsibility for the climate and therefore for the weather. But there are more immediate questions of responsible research and innovation that have been ignored for too long in cultures and institutions of science. At the time of writing, some solar geoengineering researchers are concocting and starting to propose a new set of outdoor geoengineering experiments. These researchers claim to have understood the lessons from SPICE, but it is clear that some lessons have been easier to hear than others. The lessons for responsible experimentation from this case are more profound than is immediately apparent.

As part of an extension of the typical risk-and-ethics model of governance described above, responsibility is often understood in the legalistic, retrospective sense of blame. As I explain in the next chapter, such a view reflects an impoverished view of governance in science. Science is, especially at its frontiers, largely self-governing. With emerging technologies, scientists are setting rules and norms as much as following them. We should pay attention to vested interests and any conflicts that may arise, but explaining the politics of geoengineering research does not require the construction of a conspiracy. Jane Long and Dane Scott have identified four vested interests that might contribute to shaping the future of geoengineering – fortune, fear, fame and fanaticism (Long and Scott 2013). To these we might add 'fascination', the everyday curiosity that drives scientists and other researchers to explore and in doing so construct the technoscience of geoengineering.[9] Many geoengineering researchers ventured into the area precisely because of a concern that others were seeking to geoengineer the planet. They now worry that their research may in some way be hastening a future they don't want to see. Some have forced themselves to keep an open mind about the desirability of doing geoengineering. Others display a more shameless enthusiasm. David Keith admits that in the geoengineering community,

> we're hiding a genuine and I think not-wrong joy in the fact that we understand something about the world that potentially gives us the ability to do these things. That understanding that nature gives us power to do great harm as well as, potentially, power to do good. But the understanding is a triumph of human ingenuity and I think it deserves some celebration although people are afraid to do that.
>
> (David Keith, quoted in NPR/TED Staff 2013)

Most geoengineering researchers make more pragmatic arguments for research. The basis for many of these arguments is inevitability: either the planet will need geoengineering, or the technology will be used unilaterally. In either case, as Granger Morgan puts it, 'If we haven't done the research . . . the international community has to fall back on a moral argument, as opposed to a science-based argument' (quoted in Inman 2010). The binary choice placed before society is between knowledge and ignorance, between an accelerator and a brake. My argument challenges such a simplification and asks instead what sorts of directions and qualities we might look for in responsible research.

Notes

1 Sir David Attenborough, speaking on the BBC's *The Andrew Marr Show*, 11 December 2011.
2 A story by John Vidal, 'Giant pipe and balloon to pump water into the sky in climate experiment', on the *Guardian* website, 31 August 2011, 16:00 BST, although the print edition had a different headline ('Want to mimic a volcano to combat global warming? Launch a Wembley-size balloon').
3 SPICE opposition letter, 26 September 2011. Available online at http://www.handsoff-motherearth.org/hose-experiment/spice-opposition-letter/ (accessed 29 July 2014).
4 Lewis Strauss, chairman of the United States Atomic Energy Commission, in a 1954 speech to the National Association of Science Writers.
5 Sheila Jasanoff (2014) refers to the tension between truth and 'gain' in science.
6 Approaches such as Constructive Technology Assessment try to bring promoters and controllers together into a common project (Schot and Rip 1997).
7 This dynamic has also been observed with nanotechnology and synthetic biology. See, for example, Ginsberg *et al.* (2014).
8 An incomplete list includes the following: Daniel Cressey (2012), 'Cancelled project spurs debate over geoengineering patents'; Geoff Brumfiel (2012), 'Good science, bad science'; *The Economist* (2012), 'Implicit promises: a geoengineering experiment has come unstuck. But there will be more'; Clive Cookson (2012), 'Scientists call off geoengineering trial'; and Mark Brown (2012), 'First test of floating volcano geoengineering project cancelled'.
9 David Santillo from Greenpeace is to be credited with this fifth 'F'.

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