# Climate Change: Climate Engineering Through Stratospheric Aerosol Injection

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A Progress Report for *Progress in Physical Geography*

4600 words, 30 April 2012

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## Abstract

In this progress report on climate change, I examine the growing literature dealing with the proposal to engineer global climate through the deliberate injection of aerosols into the stratosphere. This is just one of a wide range of technology proposals to geoengineer the climate, but one in particular which has gained the attention of Earth System science researchers and which is attracting wider public debate. I review the current status of this technology by exploring a number of different dimensions of the proposal: its history and philosophical and ethical implications; how it is framed in public discourse and perceived by citizens; its economic, political and governance characteristics; and how the proposed technology is being researched through numerical modelling and field experimentation. Unlike many other geoengineering interventions, stratospheric aerosol injection has no additional societal co-benefits: its sole *raison d'etre* would be to offset planetary heating caused by rising concentrations of greenhouse gases. The deployment of such a technology would have profound implications for the view humans have of themselves in relation to the non-human world.

### Key Words

climate change, geoengineering, Solar Radiation Management, stratospheric aerosol injection, science governance, public engagement

## I Introduction

This is the second of three progress reports I am writing for *Progress in Physical Geography* covering the broad theme of (anthropogenic) climate change. Two years ago I reviewed the growing scholarly literature examining (critically or otherwise) the knowledge-making practices of the IPCC (Hulme & Mahony, 2010). Here, I turn my attention to another feature of climate change discourse which has gained salience in certain scientific, political and social settings in recent years, namely the prospect of controlling the Earth's heat balance through deliberate injection of aerosols into the stratosphere.

This is not a review of the much wider field of deliberate engineering of the Earth's climate (sometimes referred to as 'geoengineering', although this term is rather imprecise). This topic would be too broad for a short progress report and a good introduction exists in the form of the Royal Society's (2009) report on geoengineering (see also popular books such as Goodall, 2010, and Kintisch, 2010a). The technical and environmental aspects of many of these other forms of intervention have been comprehensively reviewed by Vaughan and Lenton (2011). Rather, this review reports on studies which consider the specific technology of stratospheric aerosol injection (SAI), which is itself merely one technology within the geoengineering family of Solar Radiation Management (SRM) interventions. I focus on SAI because of the danger that the policy and public discourse around geoengineering 'closes down' on this particular technology (cf. Stirling, 2008): this technology has been deemed 'affordable' and 'effective' (Royal Society, 2009) and substantial work research into SAI is now being undertaken. It therefore demands close critical scrutiny.

SAI might be thought of as deliberate 'global dimming' (Wild *et al*., 2007) with the intention of offsetting the accumulation of heat in the lower atmosphere and oceans caused by rising concentrations of greenhouse gases. The progress report does not survey other SRM techniques such as cloud-whitening or surface albedo enhancements, nor the other geoengineering family of Carbon Dioxide Removal (CDR) techniques. As Robock (2008, 2011a) points out, the philosophical, ethical and governance aspects of SRM and CDR interventions are radically different; and as I suggest here some of these aspects with regard to SAI are also particularly distinctive.

Nor is this a review of merely the numerical simulation studies of SAI which have been conducted using a variety of Earth System models to explore the atmospheric and biogeochemical response to aerosol injection. My concern is much broader than this. The very idea of deliberately modifying the composition of the stratosphere to effect a global system response – namely some form of temperature regulation or 'global climate control' – evokes a wide range of cultural, social, political and ethical responses. The progress report is therefore divided into five sections dealing with, respectively, context and history; philosophy and ethics; framings, discourse and public perceptions; economics, politics and governance; and numerical modelling and field experimentation.

I survey the literature in this order because at the very heart of SAI technology lies a series of crucial questions about, *inter alia*, the meaning of nature, the human desire for climate control, the ethics of technology and the public governance of science. Earth System scientists, atmospheric engineers and physical geographers who embark on research into the technical feasibility and environmental sensitivities of such interventions, need alerting to these prior questions emerging from human imagination and public concern (cf. Macnaghten & Owen, 2011). The literature reviewed here therefore extends well beyond physical geography and includes publications in science and technology studies, policy studies, political science, environmental sociology, philosophy of science and human geography.

## II Context and History

The growth of scientific, scholarly, political and public attention to the idea of stratospheric aerosol injection is frequently attributed to an article written in 2006 in the journal *Climatic Change* by the Nobel Prize winning atmospheric chemist Paul Crutzen (Crutzen, 2006). Although the idea of SAI was not new at this time (cf. Budkyo, 1977; NAS, 1992), Crutzen argued that "*the usefulness of artificially enhancing Earth's albedo and thereby cooling climate by adding sunlight reflecting aerosol in the stratosphere might again be explored and debated as a way to ... counteract the climate forcing of growing CO2 emissions*" [p.212]. Although recognising the important legal, ethical and societal dimensions of such an undertaking, Cruzten called for "*active scientific research of the kind of geo-engineering discussed in this paper*" [p.216]. Six years later, such active research is now taking place.

With SAI grouped alongside a range of other large-scale climate intervention technologies, rather loosely labelled together as ‘geoengineering’, Crutzen’s 2006 article prompted significant scientific attention being given to the idea of deliberate engineering the Earth’s climate. For example, a simple Scopus search for ‘solar radiation management’ in peer-reviewed journal article titles, keywords and abstracts finds none pre-dating 2007. It has also prompted significant media attention - especially in Anglophone nations (Nerlich & Jaspal, 2012; Buck, 2012a) – and the emergence of a new public discourse about ‘Plan B’ and ‘global climate control’.

Within three years of Crutzen’s paper, the first national academy assessment of ‘geoengineering’ was published (Royal Society, 2009), followed by governmental reports in the USA (USGAO, 2010; 2011) and from a variety of NGOs and think-tanks (e.g. ETC Group, 2010; Olson 2011). In 2010, the Asilomar International Conference on Climate Intervention Technologies was organised by the nonprofit foundation the Climate Response Fund together with the Climate Institute in Washington DC. Mimicking the 1975 Asilomar Conference on recombinant DNA, Asilomar-2 as it became known sought to develop a set of voluntary guidelines for the conduct of research and testing such intervention technologies, SAI included (Kintisch, 2010b). The conference statement from the 175 scientists gathered there included the call “*to initiate further research in all relevant disciplines*.”

Through Crutzen’s intervention, therefore, it can be claimed that SAI is the technology that has catalysed this resurgent interest in planetary climate control. And it remains the emblematic technology to achieve such ends because of the frequently made claim that SAI is relatively cheap, simple and brings about rapid results (Boyd, 2008). The Royal Society report, for example, claimed it to be the most ‘affordable’ and ‘effective’ of all the geoengineering technologies they surveyed (Royal Society, 2009).

The present context in which SAI has gained this emblematic status needs to be understood against a much longer history of human desire for climate control. Fleming’s excellent historical survey of human efforts to ‘control’ climate (Fleming, 2010) is recommended as the place to start such an examination (also Keith, 2000; for a critical assessment of Fleming’s history see Hamblin, 2011). The desire to ‘improve’ climate for human benefit is a long-standing one, whether on regional scales through land modification, locally through cloud-seeding or domestically through indoor and outdoor temperature regulation (e.g. Meyer, 2002a,b; Hitchings, 2011). The distinctiveness of SAI should be understood and analysed in this context. Rather than seeking local or regional climate *improvement*, SAI is about limiting global climate *deterioration* believed to be underway as a result of other large-scale human changes to the environment; what some would term climate remediation (e.g. Long *et al*., 2011). SAI proposals result from a contemporary anxiety about climate and human flourishing which has deep cultural roots (Boia, 2005; Fleming & Jankovic, 2011).

But in contrast to the above historical discourses, it is the distinctively *global*-scale of SAI technologies which provokes some of the most challenging philosophical, ethical, legal and political questions which are surveyed below.

## III Philosophy and Ethics

Jamieson (1996) developed one of the first significant assessments of the ethical dimensions of what he termed 'intentional climate change' (i.e., geoengineering). Many of the concerns now being explored in much greater depth were raised by Jamieson, although he didn't specifically refer to SAI as one of his intentional technologies. What I am interested in highlighting here is recent work which has considered some of the philosophical and ethical considerations that are particularly significant for SAI.

Galarraga and Szerszynski (2012) have developed an interesting argument about solar radiation management and what they call 'the ethics of fabrication'. In particular, in considering what it means to 'make something' – as in to re-make global climate - they draw out distinctions between the ideas of 'production', 'education' and 'creation'. This raises philosophical questions about what it might mean to bring global climate under the orbit of human-made entities. What sort of a god would we become? They introduce the idea of the 'climate artist' as a way of capturing some of the imaginative practices involved in the technology of SAI. Their conclusion is not dissimilar from Buck's call to assess all geoengineering technologies, but especially SRM, within much wider socio-cultural frameworks than merely those of techno-environmental risk assessment (Buck, 2012b,c). This is a proposition that will be familiar to many geographers (e.g. Hulme, 2008; Tadaki *et al*., 2012). It also resonates with the argument against SAI put forward by Clive Hamilton (Hamilton, 2011)

Buck's argument is to widen the setting in which ethical considerations of technologies such as SAI take place. If new cohorts of climate engineers are to re-fashion planetary climates then we all become clients of these engineers. And we need to decide what kind of Earth our engineers are being commissioned to make. Buck (2012c) doesn't explore the problematic 'we' here (see the section on governance below), but she does ask what societal 'goods' other than merely climate benefits might be co-delivered by the various geoengineering technologies. In her judgement SRM fares rather poorly here relative to CDR technologies and even within SRM interventions SAI fares worst of all. Conversely, there are certain aesthetic effects which are unique to SAI and which might be considered as public 'bads', namely whitening of the skies and redder sunsets. This would be a very visible consequence of SAI and would carry considerable psychological significance (Robock, 2008).

Another distinctive feature of the ethics of SAI concerns the 'slippery-slope argument' in relation to research and deployment. This was outlined originally by Jamieson (1996) in a generic sense, the danger being that "*in many cases* [geoengineering] *research leads unreflectively to development*" [p.333] and ultimately deployment. This argument is now much more pertinent, especially in relation to research into SAI. Geoengineering research is increasingly framed in relation to SAI – and conducted too: not just through numerical simulations, but also through field experimentation (e.g. Izrael *et al*., 2009; Macnaghton & Owen, 2011). The consequences of 'just' researching such technologies need to be evaluated up-front. This is an argument made forceably by Bunzl (2009). He suggests that the social history of scientific research shows that new technologies, once embarked upon, are more than likely to be deployed. Betz (2012) also reaches this conclusion in his critique of the 'arm the future' argument for research (cf. Gardiner, 2009). In the case of technologies like SAI, large-scale research and deployment become one and the same thing (although MacMynowski *et al*., 2011, offer a partial rebuttal of this claim).

The conclusion of these and other such studies into the ethics of SAI is the necessity to differentiate *between* different geoengineering and SRM technologies. They do not all carry the same ethical or philosophical concerns and they can be analysed using different ethical frameworks: for example, deontological, consequentialist and virtue-based ethics as suggested by the Royal Society (2009). (SAI perhaps most easily falls into a consequentialist framework; i.e., the end justifies the means). But *some* ethical stance is inevitable when assessing (and indeed researching) geoengineering technologies; the concern is whether this stance is made transparent (Gardiner, 2011). All scientists who intervene publicly and who also undertake research into SAI should make it very clear what their ethical position is[1]. This is especially so given the increasing salience of SAI in the public sphere – to which we now turn.

## IV Framings, Discourse and Public Perceptions

The few longitudinal studies that have been conducted into media representations of geoengineering have not differentiated between different technologies – and nor to my knowledge have they moved outside Anglophone cultures. The post-2006 rise in media coverage is very evident in all such studies (Buck, 2012a; Nerlich & Jaspal, 2012; Porter & Hulme, 2012). What is also clear from such work are the particular framings and the narrow range of authoritative voices which are being offered to citizens. Buck's analysis of the 93 substantive articles dealing with geoengineering she found in the world's major English print newspapers between 2006 and 2010 showed that natural scientists and engineers together contribute 70 per cent of all reported claims about geoengineering. And of these claims, over half are made by the very small 'geoclique' (Kintisch, 2010a) comprising just 10 Earth System scientists. Whether it be SAI or other climate intervention technologies, through such media a very small elite of Caucasian male scientists are shaping the discourse surrounding these putative technologies of climate control.

Sikka (2012) explores this exercise of discursive power in her investigation of the particular ideologies being displayed by these authorial individuals and institutions. "*Language gains power by the use powerful people make of it*" (Sikka, 2012: 173, citing Wodak, 2001) and she suggests that technological determinism, philosophical exceptionalism and a market-driven ideology underpin the discursive strategies of many of these prominent geoengineering advocates. Nerlich and Jaspal (2012) also survey a corpus of English language popular literature about geoengineering between 1988 and 2010, but their interest was in the development and deployment of metaphor, or how geoengineeing

[1] My own normative stance in relation to SRM technologies can be discerned from these two popular articles I have written: e.g. 'The Star Wars solution to climate change that will crash back to earth' *Times Higher Education* June 2008 http://www.timeshighereducation.co.uk/story.asp?sectioncode=26&storycode=402520&c=1; 'Climate intervention schemes could be undone by geopolitics' *YaleEnvironment360*, June 2010 http://e360.yale.edu/content/feature.msp?id=2283;

was 'linguistically engineered'. In this corpus taken from the publication category of 'Industry Trade Press', they found one master argument, that of philosophical exceptionalism (backing up Sikka's assertion above): geoengineering is the only option to avoid a planetary catastrophe. Supporting this master narrative were three dominant metaphors: the planet as a machine, the planet as a body and the planet as a patient. SAI therefore is framed as either fixing the machine, screening the body or healing the patient. Nerlich and Jaspal conclude their study by asserting the power of metaphor to influence political debate and public understanding.

What these studies on representation, discourse and metaphor suggest is that the results of public surveys such as that reported by Mercer *et al*. (2011) need careful and critical scrutiny. In a survey of over 3,000 citizens in the USA, Canada and UK, these authors found that 72 per cent of respondents 'somewhat' or 'strongly' supported scientific research into SRM. Mercer *et al.* (2011:5) conclude that "*The public support for SRM found here provides empirical support for oft expressed fears of a rush toward implementation.*" However, such a conclusion needs cautioning. When asked at the beginning of the survey 'Have you ever heard of geoengineering', only 20 per cent said 'yes'; furthermore, only 8 per cent could offer an adequate definition of 'geoengineering'. How subsequent questions about SRM were therefore framed – in this study they went on to use a 'climate emergency' framing - must have considerable bearing on the answers elicited.

This points to a considerable dilemma in attempts to engage publics with ideas such as SAI. Drawing upon lessons from previous technology controversies, Corner and Pidgeon (2010) argue for widespread public engagement *before* research into SAI and other geoengineering technologies proceeds, what has elsewhere been termed 'upstreaming' (Wilsdon & Willis, 2004; Corner *et al.,* 2012). Yet citizen exposure to these technologies and their implications remains either very weak (as in Mercer *et al*., 2011, and backed up in other survey work; see Corner *et al*., 2012) or else heavily framed through selective discursive strategies (as in Sikka, 2012). These concerns were recognised in the Royal Society's 2009 report and in subsequent work funded in the UK to engage citizens in upstreaming activities around geoengineering (NERC, 2011). In the NERC study, SAI technology was not popular amongst UK citizens and even though perceived as a 'quick fix' to global heating, participants recognised it carried moral hazard and did not deal with the underlying causes of climate change. The fiasco (Macnaghton & Owen, 2011) over one of the first field experiments to test a possible SAI delivery mechanism – spraying water into the atmosphere through a 1 km balloon-tethered hose - shows the difficulty both of how to satisfy citizen concerns deploying the 'slippery-slope argument' (see above) and how to speak intelligibly across different scholarly communities. Further careful work is clearly needed in this area (e.g. Kahan, 2012), not just in Anglophone cultures but, given the global repercussions of technologies such as SAI, across the world (Corner *et al.,* 2012).

## V Economics, Politics and Governance

Given the pre-embryonic state of SAI technology at the present time, there are no reliable costs of deployment for different levels of aerosol loading. The Royal Society (2009) reported relatively modest costs in the order of tens of billions of dollars, while Morgan (2010) suggests that very fine-sized particle injection could be done at relatively low cost. As part of Bjørn Lomborg's Copenhagen Consensus process, Bickel and Lane (2009) were commissioned to estimate the costs of different SRM technologies and for SAI claimed costs of order $230 billion to offset 21$^{st}$ century global warming: a benefit-cost ratio of 25:1. All such estimates must be taken with some incredulity (Goes *et al.,* 2011).

Nevertheless, it is the claimed ease and cheapness of SAI that lends this particular technology as a site of political protest. For example, if the economic attractiveness of the technology is reason to mobilise the global financial system to direct capital into SAI development and deployment, then global capitalism needs to be brought to account (Storm, 2009; Castree, 2009; ETC Group, 2010). Furthermore, scientists such as those gathered by the IPCC for an expert meeting on geoengineering in Peru in June 2011 (IPCC, 2010), are deemed by some to have neither the expertise nor the legitimacy to determine the suitability of geoengineering governance mechanisms. Shortly before this meeting, the campaigning coalition HOME ('Hands Off Mother Earth') organised an open letter from many dozens of civil society organisations around the world to the Chair of the IPCC Rajendra Pachauri claiming that "*The likelihood that geoengineering will provide a safe, lasting, democratic and peaceful solution to the climate crisis is non-existent*" (HOME, 2011). This would be a conclusion seemingly shared by the experienced German climate scientist John Schellnhuber. On close inspection, he argues, SAI exhibits some of the same characteristics as the Mutually Assured Destruction (MAD) of the Cold War, *"... that is, the* *ominous doctrine of the arms race frenzy. If the climate can be influenced rather inexpensively by sending aerosol rockets to the stratosphere, then who decides when and where the buttons are pushed?*" (Schellnhuber, 2011:20277).

Questions of how SAI would be governed therefore become central (Allenby, 2010; Suarez et al., 2010) and are now the subject not just of research, but even of graduate summer schools[2]. Virgoe (2009) offers an early account of generic geoengineering governance concerns, drawing attention to the different roles that could be played in relation to SAI by the United Nations, by single states or by consortia of states such as the OECD. Following the Royal Society's report in 2009, a set of governance principles for geoengineering - known as the Oxford Principles - have been developed by social science scholars such as Steve Rayner, Catherine Ridgewell and Nick Pidgeon. They were adopted at the Asilomar Conference and, with caveats, endorsed by the UK House of Commons Report into the regulation of geoengineering (UK Parliament, 2010).

These principles are being further researched and developed as part of one of the SRM Governance Initiative (SRMGI). Their first report was published in 2011 (SRMGI, 2011) in which they argue for research into the 'governance of risk' (cf. Van Asselt & Renn, 2011) associated with SRM – drawing in more countries and wider perspectives. They do not call for a moratorium on research into technologies such as SAI, although even the SRMGI members were divided on this position. Many commentators have suggested that the complexity of this governance challenge will dwarf the difficulties of finding governance mechanisms for reducing global carbon emissions (e.g. Humphreys, 2011; although see Millard-Ball, 2012, for a different reading of the problem) – a task which itself has proved largely intractable. As Robock summarises: "*The UK SRMGI is just beginning to address these issues, but it is not obvious that they will be successful. In any case, fundamentally new international rules, observing systems, and enforcement will be needed before we start spraying*" (Robock, 2011b:5).

## VI Modelling and Experimentation

One of the arguments I make throughout this progress report is that the technologies of geoengineering cannot be analysed as though they belong to a single genre or family. And

[2] For example: 'Governing climate engineering – a transdisciplinary summer school' July 12-16, 2010, held at the Max Planck Institute for Comparative Public Law, Heidelberg, Germany.

nor can those technologies grouped under SRM. Each proposed climate intervention technology has a unique set of technical characteristics and environmental side-effects, and hence a unique set of ethical, legal and governance concerns (Betz, 2012). Vaughan and Lenton (2011), for example, argue that the simulated uncertainties of SAI are much greater and more meteorologically complicated than those relating to CDR technologies.

There is already considerable environmental and technical research being conducted into SAI (Robock *et al*., 2010) – as called for in the Asilomar-2 Conference Declaration. Most of this research is currently being conducted through numerical model simulation. Rasch *et al*. (2008) provided one of the first syntheses of SAI environmental research, mostly an assessment of climate modelling experiments but also including some speculation about methods - such as guns, balloons and high-level aircraft - for delivering sulphur species into the stratosphere. Since then new modelling work has offered an SAI-optimisation framework using reduced-form models (Moreno-Cruz *et al*., 2012), explored the effectiveness of SAI as a function of climate sensitivity (Ricke *et al*., 2012), simulated the regional climatic effects of SAI (Robock *et al*., 2008; Irvine *et al*., 2010) and shown, using a multi-model ensemble, the impossibility of stabilising *both* regional temperature and precipitation through SAI (Ricke *et al.,* 2010). In relation to precipitation effects of SAI, MacMynowski *et al.* (2011) show that given the very large natural variability of regional precipitation, establishing the effects of SAI experimentation on regional hydrology would require decades of experimental monitoring. This result reinforces the concern expressed in the 'slippery-slope argument': research and deployment become one and the same.

But the environmental consequences of SAI extend well beyond the merely climatic. Additional sulphate aerosols in the stratosphere provide surfaces for enhanced heterogenous chemistry thus resulting in potentially increased ozone depletion (Crutzen, 2006; Rasch *et al*., 2008), although the associated radiation scattering and attenuation effects are complex. The ratio of direct to diffuse radiation, too, would be altered with consequences for photosynthesis, ecosystems (such as coral; Crabbe, 2009) and crop yields (e.g. Pongratz *et al*., 2012). And if SAI were to be used as a technology for limiting the rate of global sea-level rise then significant contradictions arise between achieving this goal at the same time as stabilising global temperature (Irvine *et al*., 2012).

All of these studies are, of course, simulation studies using a variety of Earth System simulation models. Their conclusions remain subject to the well known and enduring limitations of such models. For this and other reasons therefore, Kravitz *et al.* (2011) have called for a Geoengineering Model Intercomparison Project (GeoMIP), along the lines of other climate and biosphere model intercomparison projects. Specifically applied to model investigations into the consequences of SAI, these authors call for standard SAI scenarios to be applied to multiple climate models to compare results and to determine the robustness of model-simulated responses. Jones *et al.* (2010) show the results of one such study in which the effects of SAI, simulated in two leading climate models, were intercompared.

Experimental research into SAI has tended to study natural analogues to gain insight into the effects of deliberate injection. The injection of sulphate aerosols into the lower stratosphere to cool the climate seeks to mimic the effect of large volcanic eruptions such as Mt Pinatubo (Crutzen, 2006). The aggregate large-scale effects of such eruptions are reasonably well known (e.g. Robock *et al*., 2008; Rasch *et al*., 2008; Kralitz *et al*., 2009). Going beyond natural analogues, however, Izrael *et al*. (2009) have conducted limited-area field experiments to study solar radiation passage through aerosol clouds of differing thicknesses and particle sizes. These empirical results were compared against model simulations and found to be in close agreement. And in proposed work in the UK, the SPICE Consortium plan to test at least one possible aerosol delivery device (see above).

## VII Conclusions

Of the various climate engineering technologies that have been proposed – Vaughan and Lenton (2011), for example, reviewed 19 such – SAI is one that has gained particular salience within the climate science and Earth system modelling community. SAI offers a brute force way of re-balancing the Earth's heat budget and offers most obviously perhaps the creation of what some have metaphorically labelled a 'global thermostat'. It scored most highly of all the geoengineering technologies evaluated by the Royal Society (2009) against the criteria of 'effectiveness', 'affordability' and 'timeliness', although it gained only a 'low' score with respect to 'safety'.

In contrast to other SRM technologies however, and certainly in comparison with CDR, there are no societal or ecological co-benefits to offer alongside the primary objective of adjusting the radiative balance of the planet. This is the argument explored by Buck (2012c), where she was unable to offer any social co-benefits of undertaking SAI – as opposed to some that could be imagined for other SRM and CDR technologies (such as, respectively, urban albedo enhancement or biochar).

What therefore is at stake in the emerging research agenda into SAI technologies and with respect to embryonic efforts to stimulate public deliberation about the technology? What should be immediately clear from this brief survey of the literature is that SAI cannot simply be evaluated on the basis of some narrow techno-environmental assessment of risk. Even the very proposition to conduct research into SAI carries with it a set of ethical and political judgements, not to mention the much deeper philosophical presumptions about the nature of nature, the nature of technology and the nature of humanity. As Gardiner (2011) observes in his essay exploring the ethical assumptions buried in the Royal Society's 2009 report into geoengineering the climate, any assessment of technologies such as SAI necessarily involves adopting an ethical stance. What matters is "*whether it is made perspicuous*" (Gardiner, 2011:184). My other claim here is the importance of differentiating between the individual climate engineering technologies being proposed. This is as true for upstream public engagement work as it is for considerations about research, implementation, ethics or governance. SAI is radically different as a form of technology from, say, biochar or roof albedo enhancement. The distinctions must not be blurred by labelling them all together as simply 'geoengineering'.

Geographers have inherited the moniker 'earth-describers' – *geo-graphia*. As a new cohort of human actors and entrepreneurs come in to being – the 'earth-engineers' – it is important that geographers engage in conversation with them and facilitate wider scrutiny of their mission. What is the nature of this 'geo' being engineered? Whose stakes are at risk and whose are being defended? To whom should the engineers be accountable? For geographers to remain useful to society, are not the new worlds that are today being created, mapped and colonised by SAI explorers exactly those worlds we are called upon to describe?

## Acknowledgements

The author wishes to thank Rob Bellamy and Kate Porter in the School of Environmental Sciences at the University of East Anglia for helpful comments on an early draft of this paper.

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