Discussion paper: Will Solar Radiation Management enhance global security in a changing climate?

Rose Cairns

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1. Introduction

Over the past decade, climate change (and particularly the risk of abrupt, catastrophic changes), has been increasingly framed not simply as an environmental or social problem, but as a security threat (UN 2007; UN 2011; German Advisory Council on Global Change 2007; Steinbruner et al. 2013; United States Department of Defense 2014), in an on-going process that has been referred to as the 'securitization of climate change' (Brauch & Scheffran 2012, p.7). Amelioration of this threat has been cited as an important rationale for research into climate geoengineering (Schwartz & Randall 2003), in particular forms of solar radiation management (SRM) such as stratospheric aerosol injection, which have in recent years received increasing attention as potential policy options alongside climate mitigation and adaptation (IPCC 2013). In one (albeit atypically unrestrained) case, deterministic claims about the link between climate change and security have been used to call for immediate deployment of forms of solar geoengineering:

> '[T]here now exists an extremely high international security risk of acute climate disruption followed potentially by runaway global warming … Rapid warming of the Arctic has already led to a disruption in the normal weather of the Northern Hemisphere, leading to widespread crop failures and societal disruptions which now threaten the existence of our civilization… There is now only one course of action that will begin to have a sufficient impact in the available time … we must intervene rapidly. We must geoengineer with great urgency' (AMEG 2013).

Others have framed geoengineering in terms of humanitarian intervention, suggesting that the normative framework of 'Responsibility to Protect' (that emerged in the context of UN Security deliberations around international responses to genocide) might be interpreted as providing a normative basis for geoengineering:

> 'if geoengineering techniques might provide a means for avoiding some of the worst climate induced suffering of these populations — which would otherwise have no protection — does the international community have a 'responsibility' to explore and develop them?' (Suarez et al. 2010)

However, framing SRM as a response to the purported security threats – or humanitarian disasters - posed by climate change, downplays the complexities of the relationships between environmental change such as climate change, and forms of insecurity and violence, as well as overlooking the massive physical and social uncertainties surrounding the impacts of SRM at regional and local scales, and the multiple ways in which these forms of geoengineering might themselves constitute novel threats to human security. This discussion paper will examine the inter-linkages between climate change, solar radiation management and notions of security, proceeding in three stages. Firstly the contested relationship between climate change and (in)security will be explored, and situated in the context of longstanding debates around environmental scarcity and conflict. Secondly the emergence of ideas around climate engineering in general, and SRM in particular, will examined, and the historical and contemporary relationship of these ideas to military interest in environmental manipulation and weather warfare will be explored. Thirdly the potential security implications of SRM will be examined. Claims that that these technologies might themselves constitute security threats (for example through potential for weaponisation/dual-use or through having regionally destabilising consequences) will be examined, and a number of scenarios featuring SRM will be reviewed. Finally the content of a contemporary belief that SRM is being carried out in secret (the belief in so-called 'chemtrails') will be examined in order to explore the social dynamics – in particular issues of power and trust – that are already apparent in certain discourses around geoengineering. The paper concludes that solar geoengineering as a security motivated response to climate change is seriously flawed, and argues that rather than improving human security, the development and deployment of certain forms of solar geoengineering may have the opposite effect.

2. Climate change and (in)security

In order to assess claims that solar radiation management might be able to alleviate the purported security threats posed by climate change, it is necessary to ask what claims about climate change and security are being made, what the evidence for these claims is, and to understand how and why this framing of climate change has emerged. Although consideration of the potential security implications of climate change stems back to at least the late 1980's[1], over the past decade there has been an increasing uptake of the idea of climate change as a security threat (Campbell et al. 2007) by influential military think tanks (e.g. RUSI), national governments (German Advisory Council on Global Change 2007; Schwartz & Randall 2003; CNA 2007) and international institutions such as the UN (UN 2007; UN 2011), and even suggestions that wartime mobilisation might now be an appropriate model for rapid climate change mitigation (Delina & Diesendorf 2013).

Clearly in some instances – such as the case of some Pacific Island States - the potential national security implications of climate change are very clear, with sea level rise threatening the very habitability of these places. As the President of the Federated States of Micronesia stated in 2001:

[1] See for example the World Conference on the Changing Atmosphere – Implications for Global Security, held in Toronto in 1988.

> ‘Sea level rise, and other related consequences of climate change, are grave security threats to our very existence as homelands and nation states’ (Falcam 2001).

Similarly, various authors have highlighted the national security implications and potential for ‘conflict over natural resources and sea lanes in Arctic regions that may become newly accessible as a result of the melting of sea ice’ (Steinbruner et al. 2013, p.31). In other cases the purported security threats associated with climate change are less direct, and include claims that climate change will lead to increased disruption and violent conflict globally as a result of struggles for increasingly scarce natural resources; state failure; increased proliferation of diseases; and tensions related to large scale migrations. For example, the U.S. Centre for Naval Analyses produced a report in 2007 suggesting that ‘Climate change can act as a threat multiplier for instability in some of the most volatile regions of the world’ and argued that this ‘presents significant national security challenges for the United States’ (CNA, 2007: 1)

Tensions associated with large scale migrations were raised as a particular concern in a report prepared for the U.S. Pentagon in 2003, which warned that:

> ‘climate change could become such a challenge that mass emigration results as the desperate peoples seek better lives in regions such as the United States’ (Schwartz & Randall 2003, p.5)

Another report highlights the potential for climate change to destabilise ‘weakened and failing governments’ fostering internal conflicts, extremism and ‘movement toward increased authoritarianism and radical ideologies’ (CNA 2007, p.6), and suggest that the U.S. ‘may be drawn more frequently into these situations’ (*ibid* p.6)(See also Ministry of Defence 2010).

Within current debates on climate change and security, the referent object – what exactly is to be secured, for whom, and how – varies. Although the nation state still dominates security discourse and policy (Barnett 2001, p.4), many observers have highlighted the inability of traditional national and international security approaches to deal with the threats posed by climate change. As the report from the German Advisory Council on Global Change (WBGU) put it, climate change:

> 'poses a challenge to international security, but classic, military-based security policy will be unable to make any major contributions to resolving the impending climate crises' (WBGU, 2007, p.6).

Similarly a CSIS report argues that:

> 'At a definitional level, a narrow interpretation of the term "national security" may be woefully inadequate to convey the ways in which state authorities might break down in a worst case climate change scenario' (Campbell et al. 2007, p.9)

The limitations of the national security framework for encompassing the range and nature of the threats posed by climate change has prompted some observers to argue that '[c]limate change is transforming the way we think about security' (Parry 2007), and more expansive conceptualisations of climate change as a threat to *human* security (WBGU 2007) have thus come to the fore. The term 'human security'[2] shifts the referent object from the state world to 'human beings, families and communities' (Brauch & Scheffran 2012, p.3). Although sometimes critiqued for being overly vague and all-encompassing[3], and suggestions that the concept itself has become a 'new orthodoxy'(Christie 2010, p.170), the concept of human security has proven useful for thinking about the more complex destabilisation processes that may accompany climate change, and has been (according to proponents of the term) a necessary shift in terminology in response to the changing context of contemporary conflict and forms of insecurity. As Renner explains:

> 'Traditionally [security] is seen as closely related to the threat or use of violence, and military means are regarded as central to the provision of security. This may once have made sense, when conflicts took place predominantly between different countries, when territorial control was a key objective, and when uniformed

[2] First outlined in detail in the UN Human Development Report (1994), human security is comprised of seven constituent parts: 1) economic security (income) 2) food security (physical and affordable access to food); 3) health security; 4) environmental security (access to safe water, clean air and non-degraded land); 5) personal security (freedom from physical violence); 6) community security (freedom from ethnic violence); and 7) political security (basic human rights and freedoms).

[3] E.g. Paris compares the term to 'sustainable development', arguing that 'everyone is for it, but few people have a clear idea of what it means' (Paris 2001, p.88).

> soldiers were the combatants. But over the last several decades, this type of conflict has become more the exception than the norm' (Renner 2006).

The lens of human security has proven to be a useful framework for academic and policy analysis of the emerging threats posed by climate change (E.g. Brauch & Scheffran 2012), and the subject is currently being considered as part of the fifth assessment report of Working Group (WG) II of the IPCC, due for release in 2014. It has also been taken up by a range of other actors concerned about climate change (including NGOs such as Greenpeace and Friends of the Earth). One explanation for the ready uptake by a diverse range of actors of this framing of the problem, is that the concept of security conveys a particular urgency, capturing 'some of the more substantial political interest and superior financial resources associated with more traditional, military conceptions of security' (Paris 2001, p.95). This shift can also be understood as part of a broader trend since the end of the Cold War toward the consideration of environmental change in terms of security, which is, according to Barnett, 'as much a product of national security institutions seeking new raison d'etres as it is the dangers of environmental change' (Barnett 2001, p.2). Although framing climate change in terms of security has been argued to be an effective way of bringing climate change into the realm of 'high politics' (Karafoulidis 2012, p.260), there are long-recognized risks to this process of 'securitization' including increasing the risk that this framing will be used to justify the implementation by states of exceptional measures, and the suspension of 'normal' political procedures and the rule of law (Waever 1989). It has also been argued for instance that the framing of climate change as a security issue,

> 'risks making it a military rather than a foreign policy problem, and a sovereignty rather than a global commons problem. This may help justify further securing of the unsustainable livelihoods of the North …It may also lead to increased attention on securing territory against undesirable knock-on effects of climate impacts such as environmental refugees' (Barnett 2001, p.11)

Debates around the appropriateness or otherwise of framing climate change as a security issue can be traced back to earlier debates about the concept of 'environmental security' that emerged in the post-Cold War period. Deudney famously argued for the need to challenge what he referred to as the 'chronic militarisation of public discourse' (p. 214), and made the case that:

> 'Environmental degradation is not a threat to national security. Rather environmentalism is a threat to the conceptual hegemony of state centred national security discourses and institutions. For environmentalists to dress their programs in the blood-soaked garments of the war system betrays their core values and create confusion about the real tasks at hand.' (Deudney 1999, p.214)

Similar critiques have been elaborated in the Copenhagen School's theory of 'securitization', which has drawn attention to powerful consequences of the speech act of denoting an issue as a security threat, and the tendency for this to bringing about a set of problematic practices including the expansion of state capabilities, the use of exceptional, illiberal and emergency measures and the suspension of normal rules of law and democracy. The theory of 'securitization' describes this process as fundamentally negative in that it represents 'a failure to deal with issues as normal politics […which should ideally] be able to unfold according to routine procedures without extraordinary elevation of specific threats to a pre-political immediacy' (Buzan et al. 1998, p.29)

Others have countered however, that climate change has the potential to transform the meanings of security (Parry 2007; Angela Oels 2012), and argued that there is little empirical evidence to suggest that 'securitization' necessarily results in exceptional measures (Trombetta 2012). For example, Trombetta argues that in fact there is

> 'little evidence that appeals to security, even those related to violent conflicts and the representation of climate change as a threat to global order, have brought about exceptional measures and 'actions outside the normal bounds of political procedure' (Trombetta 2012, p.159).

Rather according to Trombetta, debates around environmental security has had a transformative effect on security practices. She argues that the 'logic of security and the practices associated with it are not fixed…but open to a process of transformation' (p.161). A similar point is made by Dalby who argues that:

> 'Neither security nor environment can be taken for granted; one of the advantages of juxtaposing them is precisely that we are then forced to read each against the other and in the process challenge what is conventionally read into both of them' (Dalby 2009, p.55).

Climate change and human security

Although the academic and policy debates on climate change and human security are relatively recent (Brauch & Scheffran 2012), debates around the purported linkages between environmental change, scarcity and forms of violence and insecurity stretch back at least as far as the 18th century ideas of Malthus (Malthus 1798). Neo-Malthusian ideas suggesting a causal link between scarcity induced by environmental degradation and violent conflict/social breakdown re-emerged in the 1970's debate around Limits to Growth, and were further elaborated in the much-cited work of Homer-Dixon on 'Environmental Changes as Causes of Acute Conflict' (Homer-Dixon 1991), and apocalyptic articles such as Kaplan's 'The Coming Anarchy' (Kaplan 1994), who argued that the environment needed to be understood as 'the national-security issue of the early twenty-first century'.

However, more than 20 years of empirical research now exists critiquing simple linear linkages between scarcity and violence/insecurity (Cole et al. 1973; Eastin et al. 2011), and empirical evidence paints a much more complex picture. For example, Barnett argues that while there may be some links between environment change and conflict, there is little evidence to suggest that environmental factors are the only (or even important) factors, and that:

> 'Other factors such as poverty and inequities between groups, the availability of weapons, ethnic tension, external indebtedness, institutional resilience, state legitimacy and its capacity and willingness to intervene, seem to matter as much if not more than environmental change *per se*' (Barnett 2001, p.6)

Dalby highlights that processes of globalization and the commodity chains that span the globe also problematize assumptions about local food shortages and abundance, which are ' increasingly a matter of trade as much as they are one of proximate ecologies' (Dalby 2009, p.77). There is also evidence that rather than resulting from scarcity, it is often the case that violent conflict results more in situations in which there are abundant natural resources coupled with high levels of inequality (particularly the case for example, in oil rich countries).

With regard to climate change, echoes of earlier debates between more neo-Malthusian ideas and their critics, are apparent in current debates. Thus a number of deterministic arguments about the links between climate change and violent conflict and insecurity have been made by think-tanks, NGO's (e.g. AMEG), popular science literature (Dyer 2010; Welzer 2012) and the global intelligence community. For example the 2014 Worldwide Threat Assessment of the US Intelligence Community lists 'extreme weather' as one of the global threats, and argues that

> 'Extreme weather will increasingly disrupt food and energy markets, exacerbating state weakness, forcing human migrations, and triggering riots, civil disobedience, and vandalism. Criminal or terrorist elements can exploit these weaknesses to conduct illicit activity, recruit, and train' (Clapper 2014, p.9).

Despite this, there is also a growing body of research in this area (Jurgen Scheffran et al. 2012; Barnett & Adger 2007; Werrell & Femia 2013) that provides evidence that the purported linkages between climate change and (in)security and violent conflict are complex and convoluted, and that highlights the 'difficulty of drawing precise causal arrows' between climate change and particular instances of violence or insecurity (Werrell & Femia 2013, p.2).

Some work highlights the interplay between climatic factors and social, political and economic context. For example a recent project on water conflict and climate change highlights the importance of context, pointing toward stronger links between political, economic and social factors and water-related conflict than between climate-related variables and water conflict. Researchers observed that:

> 'climate and hydrological factors, socio-economic, institutional and political conditions are all important drivers of human (in)security, but their relative importance depends on the specific context in which they interact. Adaptation plays a key role in determining whether climate change is likely to undermine human security' (Kloos et al. 2013, p.7)

In some cases it has been argued that climate change is best understood as a 'stressor' that can ignite a volatile mix of underlying causes that erupt into revolution' (Werrell & Femia 2013). For example Sternberg draws out the linkages between climatic events in one region (China) and their global effects. He examines the way in which a once-in-a-century winter drought in China reduced global wheat supply and contributed to global wheat shortages and skyrocketing bread prices in Egypt, the world's largest wheat importer. These '[hi]gher wheat prices affected the cost and availability of bread in Egypt, influenced citizen protests, and indirectly led to regime change in Egypt' (Sternberg in (Werrell & Femia 2013).

Part of the difficulty of understanding the linkages between climate change and insecurity is a lack of empirical evidence. For example Nordas and Gleditsch argue that 'while the hard science in the climate change debate is backed up by peer reviewed studies, this is not the case for the literature relating climate change to conflict' (Nordas & Gleditsch 2007). Others have suggested that the difficulty with attributing particular instances of violence, or particular security threats to climate change, is simply a reflection of the broader 'longstanding difficulties in finding meaningful evidence of the determinants of violent conflict and war' (Barnett 2001, p.5).

Significantly for discussions around geoengineering, there is also a strand of work which highlights the way in which, rather than coming about as a direct result of scarcity due to environmental degradation, conflict may emerge due to changes in the political economy of energy resources as a result of efforts to *mitigate* climate change. For example Dalby highlights the ways in which mitigation practices associated with Carbon Markets, such as the purchasing by Northern Countries of large tracts of land in Southern countries in order to act as carbon sinks (e.g. REDD+ mechanisms), may disrupt local land uses, have an inflationary impact on land prices and availability, thereby contributing to rural instability and insecurity (Dalby 2013). Similarly a recent NAS publication also touches upon the potential security risks associated with a range of policy responses to climate change, including geoengineering:

> [s]everal plausible security risk scenarios begin with policies to limit climate change. For example, the expanded use of nuclear power in some countries to replace fossil fuels could increase risks of nuclear proliferation. Some policies to increase biofuel production could

> contribute to food price spikes and thus reduce effective food availability to low-income populations around the world. A single country's decision to counter global warming by geoengineering, perhaps by fertilizing the ocean to grow photosynthetic organisms or by injecting sulfate particles into the stratosphere, could create conflict with other countries (Steinbruner et al. 2013, p.31).

Scheffran et al. have pointed out that the addition of geoengineering measures for deliberate climate intervention would add 'a new dimension of complexity' into this already highly complex and uncertain picture (Jürgen Scheffran, Brzoska, Brauch, et al. 2012, p.810), and argue that this kind of extraordinary measure would be likely have negative outcomes:

> "If the debate on the securitization of climate change provokes military responses and other extraordinary measures, this could reinforce the likelihood of violent conflict."(Jürgen Scheffran, Brzoska, Kominek, et al. 2012, p.870)

The following section will trace the emergence of the idea of climate geoengineering within historical attempts at weather modification and environmental warfare before considering in more detail some of the possible security implications of future deployment of solar radiation management (SRM) as a response to climate change.

3. Climate geoengineering, weather modification and 'weaponising nature'

Climate geoengineering[4] has received an increasing amount of academic and policy interest in recent years (Belter & Seidel 2013), as a possible response to climate change. Although the definition of geoengineering often includes reference to ameliorating the impacts of climate change (E.g. Shepherd et al. 2009), research into climate and weather modification has a long history, pre-dating concerns about climate

[4] The term geoengineering is used to describe large scale technological attempts to manipulate the climate and climatic processes. Interventions that fall under the label of geoengineering are highly diverse (to the extent that the utility of the umbrella term has been questioned (E.g. Buck 2014), and some authors have called for its disaggregation (E.g. Heyward 2013), but all share certain characteristics, namely: vast scales and massive infrastructure requirements, and significant but as yet poorly understood local and global impacts.

change, reflecting a variety of other interests, aims and concerns, from drought alleviation to hail and fog suppression, aircraft de-icing, to hurricane modification. Historically, much of the research in this area was carried out by governments, conscious of the potential military relevance of such research. As a 1996 report argues:

> 'the tremendous military capabilities that could result from this field are ignored at our own peril. From enhancing friendly operations or disrupting those of the enemy via small-scale tailoring of natural weather patterns to complete dominance of global communications and counter-space control, weather-modification offers the war fighter a wide-range of possible options to defeat or coerce an adversary' (House et al. 1996, p.vi).

The sometimes murky historical roots of contemporary ideas about climate geoengineering in historical efforts at weather modification for a variety of peaceful and offensive military purposes have been explored by a number of authors (Fleming 2006; Fleming 2010; Keith 2000; Hamblin 2013; Harper 2008; Fleming 2013). For example, Fleming (2010) situates the current interest in geoengineering in the context of a long history of efforts to control weather and climate: from the pseudo-scientific practices of the 'rain-makers' of the 19th century, to the discovery of cloud seeding with silver iodide by Irving Langmuir in the 1940s, which spawned a number of military weather modification research projects as well as the beginnings of a commercial cloud seeding sector, and led eventually to the deployment of cloud seeding during the Vietnam War. Hamblin (2013) situates the military interest in and eventual offensive use of weather modification within the context of military planning for World War III during the Cold War, which saw massive efforts towards the 'weaponisation' of nature more broadly, including research into: the development of biological and chemical weapons; the usage of nuclear weapons to create tsunamis or rising sea levels; the usage of pest species and ecological invasions as 'crop warfare'; and weather modification.

During the 1940s various attempts at local weather modification and larger scale modification of the climate were taking place on both sides of the Atlantic. In the Soviet Union, Stalin announced his 'Great Plan for the Transformation of Nature' in 1948, which aimed (although ultimately failed) to create nearly six million hectares of new forest in the form of windbreaks along the rivers of the Russian south and the perimeters of the collective farms. The plan was founded upon the premise that new forests would 'halt desiccating Central Asian winds, cool and dampen the climate of southern Russia, and eliminate the periodic droughts that had afflicted the steppe for decades' (Brain 2010, p.671).

Meanwhile in the United States, one of the first weather modification research projects, known as Project Cirrus, was underway from 1947 – 1952 (Havens 1952). The project was carried out by a team from General Electric under government contract with the U.S. Army Signal Corps and the Office of Naval Research, and with the close cooperation of the U.S. Air Force, who provided airplanes and the associated personnel. Government involvement was felt to be necessary given potential national interest implications of weather modification, as well as the possibility of liability for damage from cloud- seeding experiments, or unanticipated side effects which was at the time felt to be a 'very worrisome hazard in this new form of cloud experimentation' (Havens 1952, p.13). Project Cirrus involved numerous experimental cloud seeding flights, and the first (unsuccessful) attempt, in 1947 to modify a hurricane. A quote by Langmuir in 1947 opining that the chances were 'excellent that, with increased knowledge … we should be able to abolish the evil effects of these hurricanes' (Langmuir cited by Havens 1952 p. 64) was characteristic of the techno-optimism of the time. However the project was largely unable to live up to the high expectations that accompanied it, and issues of definitive attribution plagued weather modification projects from the earliest days. While the production of ice crystals and precipitation in the laboratory and under certain field conditions was/is relatively uncontested, the precise nature of the impacts of any given seeding mission were harder to establish. The write-up of Project Cirrus lists a number of 'apparent limitations' to the advancement of weather modification, largely 'imposed by known physical laws' (p. 76). The most significant limiting factor was the presence of clouds of the requisite type and size:

> 'Certain clouds such as the fair-weather cumulus, have such a small volume and restricted area that, even though they are easily modified when super-cooled, their total liquid water content is inconsequential' (p.77).

Despite these ‘apparent limitations’, military interest in weather modification continued. According to Harper, military planners could not let go of ‘the tantalizing possibility of a non-polluting, untraceable, offensive and defense weapon’ (Harper 2008, p.20). From 1962 to 1983 the U.S. Navy and the U.S. department of Commerce ran a collaborative project called Project Stormfury, during which various attempts to modify hurricanes using cloud seeding techniques were carried out. However, as with Project Cirrus, the results remained inconclusive.[5]

During the Vietnam War the U.S. Military operated a secret program of cloud seeding over North and South Vietnam, Laos, and Cambodia from 1967 to 1972. Codenamed Operation Popeye, the aim was to extend the Monsoon season and thus ‘muddy up’ the Ho Chi Minh trail that served as a conduit for Viet Cong supplies and personnel (Certini et al. 2013). The operation involved ‘over 2,600 cloud seeding sorties and expended 47,000 silver iodide flares over a period of five years at an annual cost of approximately $3.6 million’ (Fleming 2006, p.13). While some suggest that the project was a success in terms of extending the Monsoon season from 30 to 45 days (Certini et al. 2013, p.4) and making more difficult enemy movements, Fleming points out that no scientific data were collected to verify these claims, and cites sources involved at the time who claim that the cloud seeding produced ‘no appreciable increase’ in rain (Fleming 2010, p.181). Despite the inconclusive nature of the project, the revelation in an article in the New York Times (Hersh 1972) that the U.S. had been cloud seeding as part of its operations in Vietnam was a catalyst for the eventual passing of the ENMOD treaty which came into force in 1978. ENMOD prohibits state signatories from engaging in:

> ‘military or any other hostile use of environmental modification techniques having widespread, long lasting or severe effects as the means of destruction, damage or injury’ (Art I).

The treaty has never been tested, partly because it seems that weather modification strategies never worked particularly well (Fleming 2013) and hence according to some, militaries lost interest (Ricke et al. 2008, p.12). Spending on weather modification research in the U.S. (which had

[5] For example Willoughby et al. showed that ‘something very like the hypothesized Stormfury chain of events happens in unmodified hurricanes’ (Willoughby et al. 1982, p.411).

reached a high of $20 million in the late 1970's) had dropped to just $500,000 by the early 2000's (NRC 2003). Then, in 2003 the U.S. National Research Council called for a coordinated program of research to reduce key uncertainties around weather modification (NRC 2003). Interest in hurricane modification which appeared to have waned, re-emerged in 2008 when the U.S. Department of Homeland Security convened a workshop on hurricane modification. The security-relevance of which was presented in the following terms:

> 'The potential loss of life, physical devastation, economic impact and loss of public confidence posed by a major hurricane could be as detrimental to the United States as any terrorist attack… [Sponsoring the workshop on Hurricane modification] is consistent with the Homeland Security Act of 2002 [and] the Department of Homeland Security (DHS) mission to respond to threats and hazards to the nation…'(US Department of Homeland Security 2008, p.3)

Meanwhile the term 'geoengineering' had re-emerged onto the global research agenda following publication of the Nobel prize laureate Paul Crutzen's 2006 article on Stratospheric Aerosol Injection (Crutzen 2006) which had appeared to break an unspoken 'taboo' among climate scientists on climate modification research. There followed a flood of articles and an increase in funding for this work (Belter & Seidel 2013).

Discussions of geoengineering are largely framed as a response to the failures of climate change mitigation efforts, and thus as being distinctive in aims and scale from earlier efforts at weather modification. However, despite efforts to draw a clear distinction between weather modification research and geoengineering research as operating a different temporal and spatial scales and thus being incomparable [6], it has been argued that the manipulation of weather and climate phenomena are in fact inextricably connected. Indeed a number of prominent 'geoengineering' researchers[7] were involved in the aforementioned DHS hurricane modification workshop indicating the cross-over of research interests and expertise. Fleming makes the point that:

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[6] E.g. Bodansky refers to geoengineering as 'Large scale, capable of affecting the global temperature, as compared to more limited local weather modification techniques such as cloud seeding'

[7] Including prominent proponents of marine cloud brightening, John Latham and Stephen Salter.

> 'Any intervention in Earth's radiation or heat budget (such as managing solar radiation) would affect the hydrological cycle and the general circulation… [T]he weather itself would be changed by such manipulation. Conversely, intervening in severe storms by changing their intensity or their tracks or modifying weather on a scale as large as a region, a continent, or an ocean basin would obviously affect cloudiness, temperature, and precipitation patterns, with major consequences for monsoonal flows and ultimately the general circulation. If repeated systematically, such interventions would influence the overall heat budget and the climate' (Fleming 2013, p.2).

Solar radiation management

Solar radiation management (SRM) is term that describes a sub-set of geoengineering proposals that attempt to offset the effects of increasing greenhouse gas emissions by reducing the amount of solar radiation reaching the earth's surface, and thus cool the planet[8]. These techniques have sometimes been described (somewhat euphemistically) as 'global sun block' (Keith et al. 2010) or 'sunshade' technologies (Kosugi 2010). Due to its potential to reduce global temperatures rapidly, SRM has often been framed as a possible response to a current or future 'climate emergency.' Within this framing of geoengineering, the security risks posed by sudden catastrophic climate change are felt to justify either increasing research into (e.g. Schwartz and Randall 2003) or even immediate deployment of, solar geoengineering (AMEG 2013). The so-called 'emergency framing' has received widespread critique (Markusson et al. 2013; Sikka 2012; Nerlich & Jaspal 2012). In common with critics of securitization more broadly, critics of the emergency justification for climate engineering argue that the invocation of an emergency is dangerous in that it can be used to justify exceptional measures and the suspension of normal democratic procedures.

Proposed SRM techniques include *inter alia* Marine Cloud Brightening (Latham et al. 2012), the placing of mirrors or other reflective bodies in space (Angel 2006), and Stratospheric Aerosol Injection (SAI) (Rasch et al. 2008; Crutzen 2006). The latter (SAI) is the technique frequently

[8] Although the term is still widely used in the literature on geoengineering, some have argued that it is in the 'process of being abandoned' because there are 'too many unknowns to really consider it a form of management' (Fleming 2013, p.4).

referred to as the 'most promising' of the solar radiation management geoengineering techniques (Volodin et al. 2011; Baum et al. 2013; Millard-ball 2012). SAI has been referred to as a 'high leverage' technique (Bodansky 2011, p.12), with the potential to reduce global mean temperature by a matter of degrees within months (Keith et al. 2010; Crutzen 2006). It has also been suggested to be relatively cheap (Boyd 2008; Lane & Bickel 2013; Scott Barrett 2008), and hence within the reach of most countries – or even very wealthy individuals - to carry out. However Pielke has pointed out that the uncertainties and 'fundamental ignorance' surrounding both the costs and benefits of SAI tend to make cost-benefit analyses of SAI less than meaningful (Pielke 2010, p.126). Others have pointed out that the phenomenon of 'appraisal optimism'(cf. Flyvberg et al. 2003) is likely to be a factor in these estimates, and have highlighted the fact that the costs of a new technology frequently exceed estimates and expectations. As MacKerron puts it, '[t]hese escalations have been frequent – virtually pervasive – where technologies are novel and/or the scale of activity has been large ('megaprojects') (MacKerron 2014). Furthermore, MacKerron argues that economic analyses need to go beyond the simple calculation of costs, and to consider the *economics* of geoengineering, including a consideration of wider social costs and resource allocation issues.

SAI is associated with a number of well-recognized, extremely serious problems. One of the most serious of these is that although observations from analogous emissions of sulphate aerosols from large volcanic eruptions suggest that an SAI intervention would indeed act to reduce global mean temperature (Volodin et al. 2011), it would not perfectly offset global warming but would have a range of as yet poorly understood effects on regional climate and weather patterns (Angus J Ferraro et al. 2014; Rasch et al. 2008; Trenberth & Dai 2007), including an impact on regional precipitation patterns (Hegerl & Solomon 2009; Angus J. Ferraro et al. 2014) and ozone depletion (Tilmes et al. 2008). Furthermore, it has been argued that the exact nature of these regional impacts could not be determined with any degree of accuracy before full scale implementation (Robock et al. 2010).

SAI would not ameliorate ocean acidification associated with increasing carbon dioxide in the atmosphere (Robock 2008), indeed, by providing what appears to be a quick fix to the climate change problem, it may in fact weaken commitments to carbon emissions reductions and hence act to worsen these impacts (this is the basis of the so-called 'moral hazard argument' (Gardiner 2011)). SAI is also associated with the need for forms of social and political commitment (forms of socio-technical 'lock-in' (Rayner et al. 2013; Cairns 2014) of a scope that are arguably unprecedented in human history: once embarked upon, a programme of SAI would need to be continuously carried out for hundreds of years in order to avoid the so-called 'termination effect' of rapid and dangerous heating of the planet (Jones et al. 2013). It is this combination of traits that point to SAI having some of the most pressing security implications of the range of proposed geoengineering techniques. Some are novel (e.g. the implications of the 'termination effect' for which there is no comparable analogy) while others are what Dalby refers to as 'very old security concerns related to the potentially dangerous decision by one power to act unilaterally in a way that other leaders may feel is a challenge either to their power in general or to their national interests directly' (Dalby 2013, p.39).

SRM: security dimensions

There are a number of overlapping concerns around SRM, both from the point of view of human security and more traditional notions of national security: these include the possibility that some SRM technologies might have 'dual-use' (i.e. military as well as civilian uses); the possibility that SRM might be regionally destabilising; the vulnerability (of natural and social systems) associated with the so-called 'termination effect'; and the security implications related to the exacerbation of (or the *perception* of exacerbation of) regional climate and weather damages (e.g. shifting monsoon patterns, drought in Africa Etc.) as a result of SRM deployment.

Dual-use or weaponisation of SRM technologies

Given the history of military interest in weather and climate modification, one concern about the development of various geoengineering approaches (and SRM technologies in particular), is the so-called 'dual-use' potential that these technologies might have (i.e. their potential for military as well as non-military applications) (House of Commons 2010). Hale makes the case that unlike other technologies that are understood to have ‘dual uses’ such as nuclear power or genetic modification, ‘the traditional distinction between innocuous versus pernicious applications is considerably hazier for geoengineering technologies’ (Hale 2013, p.199). Others have gone further, highlighting the inherently ‘dual use’ nature of technologies or engineering practices more broadly, and critiquing the inclusion of climate change amelioration within the definition of geoengineering. For example, Fleming argues that to ‘constrain the essence of something that does not exist by its stated purpose, techniques or goals is misleading at best’ (Fleming 2010).

With regard to the potential for SRM to be ‘weaponised’, some observers have claimed that the ‘uncontrolled’ nature of SRM techniques makes them unattractive to military planners (Briggs 2013), and have suggested that this, coupled with their highly controversial and politically and legally sensitive nature, has meant that in the U.S. at least, ‘the U.S. Department of Defense has no interest in pursuing concrete actions in this field’ (Briggs 2013, p.1). However, Schellnhuber has referred to SRM as exhibiting ‘MAD traits’ (Schellnhuber 2011), that is, traits for ‘mutual assured destruction’ similar to the characteristic of the nuclear arms race. Despite the lack of (available) evidence that the military is currently interested in the potential of SRM as a weapon, Olson points out that:

> ‘if geoengineering research should lead to major advances in knowledge and techniques relevant for weather control, it is hard to imagine that knowledge not being put to use. In this respect, geoengineering is no different from other powerful technologies, from rocketry and atomic energy to computers and genetic engineering that have been put to military as well as peaceful uses’ (Olson 2011, p.16)

It is also the case that, despite fears of a ‘rogue geoengineer’ or a ‘greenfinger’ character (Bodansky 2013) acting unilaterally, it is more likely that any deployment of SRM (particular SAI or space mirrors) would likely be carried out one (or more likely a coalition of) military bodies. Indeed it is highly implausible, given the global security interest in ‘space superiority’ (Lord 2005) and the so-called ‘counterspace threat’ (Clapper 2014) amongst intelligence communities, that these technologies (in particular for example, space mirrors) would been seen as ‘neutral’ objects. But rather would be incorporated into existing patterns of interests and military strategies. As expanded in more detail elsewhere (Nightingale & Cairns 2014), it is more likely that the military, rather than scientists, would undertake geoengineering, and that (SRM activity in particular) would be covered by Critical National Infrastructure policies, and as such would require a significant level of secondary security infrastructure.

SRM and regional instability

While the potential for 'weaponisation' of SRM technologies may be small, the destabilising potential of SRM techniques has been long recognised, as Schelling wrote in 1983:

> 'if the capacity to affect the radiative balance at non-prohibitive cost were acquired by several nations that disagreed about the optimum balance, that technology could be a source of conflict… The possibility of unilateral action, especially if it could be surreptitious and unverifiable, could cause trouble' … 'Weather and climate modification may be more a source of international tension than a relief' (Schelling 1983, p.470).

Although some observers have downplayed the risks of unilateralism as 'myths' (Horton 2011), even David Keith – a leading proponent of research and possible eventual deployment of SRM - has recognised the potential for SRM to have massively destabilising consequences (Keith 2013). Ricke et al. (2013) argue that while it is unlikely that a single small actor could implement and sustain global-scale geoengineering without intervention from other world powers, a sufficiently powerful international coalition might be able to do so. Indeed they illustrate that the regional differences in climate outcomes likely under different geoengineering scenarios would create incentives for any such coalition to be as small as possible, as it would be in coalition members' interests to exclude non-members prefer levels of SRM other than those deemed to be optimal for the existing coalition'.

One of the countries about which concerns over possible unilateral deployment of SRM have been raised is China (Victor 2011; Hamilton 2013). This is partly due to the country's vulnerability to climate changes, the pressure facing the government to cut emission whilst maintaining economic growth, and in particular, its extensive existing programme of weather modification activities (Xueliang 2009). However, various commentators have suggested that speculations about possible

Chinese rationales for geoengineering are not supported by solid evidence (Weili & Ying 2014) and highlighted that here are very few research articles on geoengineering-related topics in Chinese academia. Similarly Edney and Symons (2013) surveyed Chinese public discourse, and examine the policy factors that will influence China's position. They argue that while Chinese climate scientists are 'keenly aware of the potential benefits of geo-engineering as well as its risks' there is no significant constituency promoting unilateral deployment of SRM. Thus, they conclude that

> 'China will probably play a broadly cooperative role in negotiations toward a multilaterally governed geo-engineering programme but will seek to promote a distinctive developing world perspective that reflects concerns over sovereignty, Western imperialism and maintenance of a strict interpretation of the norm of common but differentiated responsibility' (p. 1)

Given the limitations to modelling and prediction of the future, one methodological approach to assessment of potential instability around SRM is scenario planning. Scenario planning emerged as a formal tool in military circles during the Cold War, and has become a widely used strategic tool in business, as well as becoming increasingly prevalent as a tool of environmental governance, particularly in the arena of climate change (Hulme & Dessai 2008). Scenarios are commonly understood as 'plausible, challenging and relevant stories about how the future might unfold' (Raskin et al. 1995, p.36)[9]. The exploration of future scenarios featuring solar radiation management range from simple thought experiments described by individuals (Schellnhuber 2011; Bodansky 2011) or multiple authors (Baum et al. 2013; Sweeney 2014), to structured exercises involving groups of 'experts' with multiple iterations and formal facilitation (Banerjee et al. 2013), or deliberative focus group discussions with 'mini-publics' (Macnaghten & Szerszynski 2013).

Within the current range of scenarios featuring SRM one theme that emerges a number of times is that of conflict. Schellnhuber for example,

[9] While some scenarios – such as those produced by the IPCC - may have a significant quantitative dimension, applying particular consistent logics and assumptions to explore the outcome of a given set of starting conditions and trends, others may be more qualitative, imaginative explorations of possible futures. Either way, scenarios are not meant to be predictive, but rather provide imaginative resources, possibly helpful in steering present-day decision making.

imagines a future pattern of SRM-related conflict and escalation of counter-warming strategies:

> 'Certain countries like Russia might actually welcome some warming of their territories. So would they shoot down, say, Indian or Chinese geoengineering missiles launched for stabilizing the Asian monsoon pattern or other tipping elements in the Earth system? One step further up the escalation ladder, the supposed beneficiaries of climate change might deliberately increase their greenhouse gas emissions for overcompensating SRM, and so on' (Schellnhuber 2011, p.20278).

Another scenario has explored the potential for SRM technologies to herald a future in which 'countries, all following their own interests, [abandon] any pretence of returning the climate to how it was, and [start] to think about what kind of climate they would like to have..' (Banerjee et al. 2013, p.13) In this future, increasing greenhouse gas levels combined with SRM have had a range of complex climate effects, requiring:

> 'a deeper and deeper commitment to more and more sophisticated global SRM technologies, along with a parallel array of regional to local weather modifications technologies to achieve 'finer tuning' of desired outcomes' (Banerjee et al. 2013, p.13)

In this imagined future, countries struggle repeatedly to find common purposes, but—much like the carbon mitigation negotiations of recent years —they eventually pull apart at the last minute.

The 'termination effect' is the term used to describe the rapid warming that would accompany the cessation of a programme of SAI[10], the potential implications of which have been explored in a scenario examined by Baum et al. The scenario (in this case a genuine 'worst-case scenario') examines the possibility of total societal collapse and potential human extinction resulting from a 'double catastrophe' involving the termination of a programme of SAI. In this scenario, SAI is started, but halted due to a global catastrophe (e.g. nuclear war) resulting in global societal collapse

[10] There is agreement among climate models that 'significant climate change would ensue rapidly upon the termination of geoengineering, with temperature, precipitation and sea-ice cover very likely changing considerably faster than would be experienced under the influence of rising greenhouse gas concentrations in the absence of geoengineering' (Jones et al. 2013). The rate of warming would depend on the length of time that SAI had been carried out, the rate of greenhouse gas emissions during that period, and whether the programme of SAI was ceased immediately or phased out gradually.

and the inability of the survivors to maintain the SAI. The resulting rapid temperature increases puts additional stresses on the remaining population, potentially threatening their survival. While the causes of the initial catastrophic collapse could be unrelated, Baum et al., (like Schellnhuber), do touch upon the possibility of the implementation of SAI itself being the cause of the initial conflict:

> 'Other states might object to SAI implementation—perhaps Russia would view warmer temperatures as beneficial for its agriculture, its Arctic shipping and oil drilling, and its overall quality of life. This dispute could increase geopolitical tensions and contribute to a major international conflict. A sufficiently severe conflict could induce a societal collapse and in turn an SAI double catastrophe' (Baum et al. 2013, p.9).

While some scenario planning exercises have as an explicit aim to better predict possible issues that might arise, and thus test 'whether emerging governance proposals are able to effectively grapple with the array of issues manifest therein' (Banerjee et al. 2013, p.6), in many cases (such as the 'double catastrophe' scenario), it is hard to imagine what kinds of governance structures would be able to deal with the kinds of vulnerabilities flagged up. Indeed, the issue of 'audience' has been raised as a general problem with scenarios such as those of the IPCC which appear to have little impact in terms of policy, but are widely used in a range of different contexts, understandable as 'boundary objects' (Pulver & Vandeveer 2009).) The imaginative process of exploring possible futures has led some to claim for example that this technology is at odds with any kind of democratic governance (Macnaghten & Szerszynski 2013) or 'simply ungovernable' in any kind of desirable sense (Hulme debate). For example, these authors argue that the 'social constitution' of solar radiation management is inimical to democracy:

> 'While plausibly able to accommodate diverse views into the formulation of its use, once deployed, there remains little opportunity for opt-out or for the accommodation of diverse perspectives. By its social constitution it appears inimical to the accommodation of difference. Following deployment it could only be controlled centrally and on a planetary scale' (Macnaghten & Szerszynski 2013, p.8).

Their analysis of public discourse around SRM lead them to the conclusion that SRM is likely to create:

> 'a particular kind of world, one with an increased probability of geopolitical conflict, a new condition of global experimentality, and major threats to democratic governance'.

Hence the purpose of exploring scenarios in this case is not to plan governance structures, but to argue that humanity should abandon SRM entirely.

Regional and local impacts (real or perceived)

Based on climate models and empirical observations following volcanic eruptions, it is widely acknowledged that the regional impacts of an SAI intervention are potentially severe (e.g. impacting on the Indian and African summer monsoons (Vaughan & Lenton 2011)). However, given the impossibility of determining regional impacts in the absence of full-scale field trials, the impacts of an SRM intervention would remain uncertain until deployment (Robock et al. 2010). As Szerszynski et al put it, '[d]eployment will thus always have the character of research' (Szerszynski et al. 2013, p.2811). Indeed, even in the event of full deployment, (as is the case for attribution of particular events to anthropogenic climate change (c.f. Pielke Jr. 2010, chap.7)), natural climate variability would make any definitive attribution of cause□and□ effect between a given SAI intervention and a particular regional or local impact extremely difficult if not impossible to ascertain.

The impossibility of determining the regional impacts of SAI is for some, sufficient in itself to constitute a case against further research and development of SAI (Bunzl 2010), but others counter that scenarios of possible futures in a warmer world without SRM are equally risky and uncertain, and that therefore SRM might represent the 'least bad' option (Hunt in Specter 2012). However, Hulme (2014) makes the case, that in order to substitute one set of 'global bads' (i.e. the consequences of anthropogenic climate change) for another (i.e. the consequences of SRM) one has to be able to show that there is a net welfare benefit[11]. This is, arguably, impossible to do with SRM. The problem is that while SRM might be effective at reducing global temperatures, these globally

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[11] The reduction of choice to two stark, generally unappealing options, has also been critiqued as a rhetorical tool: Sikka for example, points out that 'setting up of this kind of exceptional scenario buttressed by panic-ridden language makes it difficult to have a reasonable discussion about geoengineering' (Sikka 2012, p.168).

averaged quantities are not what cause climate loss and damage, rather it is the regional and local weather impacts that do this. As examined at the outset, the linkages between climate change, regional and local weather changes and insecurity is a complex picture, with local impacts poorly correlated with increasing global temperatures. Modelling by Ferraro et al. suggests that while SAI might be 'broadly effective at counterbalancing regional changes in annual- mean surface temperature', nearly half of the Earth's surface would experience an increased risk of substantial precipitation change under an SAI geoengineered climate as compared to a climate change scenario of a quadrupling of carbon dioxide (Angus J. Ferraro et al. 2014). Hegerl and Solomon make a similar point that

> '[c]limate change is about much more than temperature change, and using temperature alone as a proxy for its effects represents an inappropriate risk to the health of our society and to the planet' (Hegerl & Solomon 2009, p.956).

The potential for a global SRM programme to exacerbate or cause regional and local climatic disruptions also raises the possibility that there might be an increase in attempts at local weather modification such as cloud seeding in order to attempt to 'balance out' the effects of the SRM. The potential increase in local weather modification efforts as a result of climate change has been touched upon by Harper (Harper 2008, p.26), and emerged as a possibility in scenarios described by Banerjee et al. (2013). The ways in which these weather modification efforts might interact with any global geoengineering programme adds an additional element of uncertainty into the picture.

In the same way that climate change is often referred to as a 'threat multiplier', so an SAI intervention might similarly be conceived. However the crucial difference with SAI is that the problematic nature of attribution means that under an SAI-geoengineered climate, there would be a high potential for any local and regional climate damages to be attributed to the SAI intervention, with the accompanying possibility that these damages are interpreted as being the result of deliberate, aggressive acts. The issues of perception, trust and power are crucial in understanding likely dynamics in this area.

Attribution, perceptions, trust and power: 'chemtrails'

In a survey carried out in 2011, Mercer et al found that 2.6 % of a sample of 2893 people agreed entirely that a secret program of SRM is currently taking place, while 14% of this sample believed this to be partly true (Mercer et al. 2011). A Google search of the term 'geoengineering' reveals a large number of websites and organisations dedicated to exposing what is felt to be a 'crime against nature'[12]. For example, one site asks:

> 'Could there be a connection between the trails [left by aeroplanes] and our severe weather? While there are many agendas associated with these damaging programs, evidence is now abundant which proves that geoengineering can be used to control weather… While geoengineers maintain that their models are only for the mitigation of global warming, it is now clear that they can be used as a way to consolidate an enormous amount of both monetary and political power into the hands of a few by the leverage that weather control gives certain corporations over the Earth's natural systems. This of course, is being done at the expense of every living thing on the planet.'[13]

The passionately held belief that an on-going programme of SAI geoengineering is causing widespread environmental damage and is responsible for millions of deaths has led to the expression of anger and violence towards those felt to be responsible. Thus David Keith, Ken Caldeira and other proponents of research into SRM technologies have been subjected to harassment and even death threats (Keith 2013). Although these views may be scientifically unfounded, dismissing them out of hand is arguably to miss the insight that they reflect not so much a lack of science, but a lack of trust in scientists and a general scepticism towards powerful institutions (Cairns n.d.). From the point of view of debates about climate change, SRM and security, the content of these claims is of interest in so far as it reveals the kinds of social dynamics that are already at play around these issues, and that are likely to become ever more significant in the future if research and activity in this area continues.

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[12] E.g. http://www.geoengineeringwatch.org/ ; http://www.globalskywatch.com/ ; http://www.chemtrailsprojectuk.com/

[13] http://globalskywatch.com/featured/Why-In-The-World-Are-They-Spraying.html

The possibility that SRM might be carried out 'clandestinely' (Banerjee et al. 2013, p.9) or 'surreptitiously' (Schelling 1983, p.470) has long been recognised, and this potential, coupled with the difficulty surrounding attribution of any given weather event to either climate change or SAI, has been highlighted as a potential source of conflict and insecurity. Given the historical association of weather modification and the military (as well as the wider history of the 'weaponisation' of nature (Hamblin)) the idea of an SRM conspiracy is perhaps not as far-fetched as some might imagine. For example, in 1962 at the height of the Cold War, just before the Cuban Missile Crisis, and at a time when Project Stormfury was underway, Hurricane Flora hit Cuba having made a '370 degree turn before lingering over Cuba for 4 days' (Fleming p. 179). The behaviour of the hurricane struck many as suspicious and prompted Fidel Castro to claim that the U.S. was waging strategic weather warfare on Cuba. While no evidence ever emerged that Hurricane Flora had been manipulated in any way, the fact that it later came to light that just four years later in 1966 the U.S. was indeed spending millions of dollars per year on cloud seeding operations over Vietnam as part of Operation Popeye during the Vietnam war, illustrates the difficulty in drawing a 'bright line' between real and imagined conspiracy (Dean 2000).

While the belief in an ongoing 'chemtrail conspiracy' may currently be marginal, the kinds of fears that these beliefs articulate and the ways in which blame is attributed within them, arguably offer a window of insight into the likely sources of conflict and insecurity in an SRM geoengineered world. The recent attacks against polio vaccination workers in Pakistan as a result of a widespread belief that vaccination programmes in the country are part of a conspiracy to make male Muslim children sterile[14], are a powerful illustration of the ways in which an apparently marginal idea can take root in a given context as a result of reflecting widely held worldviews and experiences (in this case anti-American sentiment and distrust of international institutions after years of conflict). The 'chemtrail conspiracy' view arguably provides an indication of the shape of future conflicts and dynamics around SRM.

[14] http://www.aljazeera.com/news/asia/2014/01/bomb-hits-pakistan-police-patrol-201412254410448576.html

Conclusions: will SRM enhance global security?

This discussion paper has explored the calls for more research into, and possible deployment of, solar radiation management as a response to the purported global security threats posed by climate change, situating these calls within longstanding (controversial) debates about the linkages between environmental change and forms of insecurity and violence, and a critique of what has been referred to as the 'securitization of climate change'. The discussion problematized claims of simple causal linkages between climate change and insecurity, highlighting the lack of empirical evidence of these links. Where evidence exists, it suggests that political, economic and social factors are more likely determinants of conflict and insecurity than climate-related variables. Furthermore there is some evidence, relevant to debates around geoengineering, that conflict may emerge as a result of efforts to mitigate climate change (e.g. REDD+). Current ideas about climate engineering were then situated in the historical context of efforts at weather modification for a variety of peaceful and military ends, before the possible security implications of an SRM intervention were examined.

Although increased research into solar radiation management might reduce to some degree some of the uncertainties around physical impacts of an intervention, or the feasibility of possible delivery methods, research cannot predict or reduce uncertainties about possible *social and political impacts* of such an intervention. These would remain unknown – as would the full extent of global physical effects of SRM – until deployment. However, knowledge of contemporary geopolitical realities from a range of social and political sciences or as explored through scenario exercises, suggests that the risks of negative security impacts of an SRM intervention would be high, and that the consequences would be severe. For example: the difficulties associated with attribution of negative regional or local climatic impacts to a given SRM intervention suggest potential for conflict and regional instability as a result of real or perceived negative impacts of SRM. A window into the social dynamics that are likely to accompany further research and development of SRM can be gained by analysis of the contemporary belief in 'chemtrails', which highlights the crucial role that trust and power are likely to play in how these technologies and their (real or attributed) impacts are perceived. Furthermore, the vulnerability of natural and social systems that would accompany an SRM intervention due to the prospect of the so-called termination effect mean that these technologies would likely be accompanied by high levels of military attention and would require high levels of secondary security infrastructure. Taken together, the serious global security implications of SRM arguably constitute a persuasive case against any further development in this area, and neither the enhancement of national security, nor the protection of human security more broadly framed, would appear to provide a sound justification for increased research into, or deployment of a programme of solar radiation management.

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