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Author(s): Toby Svoboda, Klaus Keller, Marlos Goes and Nancy Tuana

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SULFATE AEROSOL GEOENGINEERING: THE QUESTION OF JUSTICE

Toby Svoboda, Klaus Keller,
Marlos Goes, and Nancy Tuana

INTRODUCTION

Although proposals for geoengineering, or the intentional, large-scale modification of the environment (Keith 2000, p. 245), have been made for decades (Fleming 2007; Keith 2000; Matthews and Turner 2009; Orville 1957; Wexler 1958), there is now renewed interest in this issue (Barrett 2008; Crutzen 2006; Wigley 2006). This is due to the potential of geoengineering to counter some of the most harmful effects of climate change, leading some climate scientists to call for serious research on the subject (Crutzen 2006; Keith et al. 2010). One of the most discussed varieties of geoengineering is deploying sulfate precursor (such as SO_2) aerosols into the stratosphere to mimic the global cooling effects of a volcanic eruption. Sulfate Aerosol Geoengineering (SAG) is expected to counteract global warming by increasing the Earth's albedo and thus reflecting a fraction of solar radiation into space, thereby reducing average global temperature and avoiding some of the expected harmful effects of climate change, such as sea level rise from melting polar ice sheets (MacCracken 2009).

However, implementing SAG could be ethically problematic (Gardiner 2010; Goes et al. 2011) because SAG faces difficult challenges in meeting the requirements of distributive, intergenerational, and procedural justice. We identify three cases in which SAG could be problematic from a justice perspective. First, SAG is expected to alter regional precipitation patterns and thereby threaten some persons' access to adequate food and drinking water resources (Matthews and Caldeira 2007; Robock et al. 2008; Trenberth and Dai 2007), thus posing a challenge for SAG to meet the requirements of distributive justice. Second, implementing SAG puts future generations at risk of SAG being discontinued abruptly, which can result in rapid and dramatic climate change that leads to severe economic damages for those future generations (Goes et al. 2011), thus posing a challenge for SAG to meet the requirements of intergenerational justice. Third, since SAG is inexpensive and does not require multilateral agreement, a single state can

implement it without the consent of other states or even its own citizens, thus posing a challenge for SAG to meet the requirements of procedural justice. We argue that although there might be a version of SAG that avoids these problems and satisfies all the requirements of justice, it is the responsibility of proponents of SAG to address these issues.

We highlight ethical problems with SAG and argue that these problems must be considered carefully before deciding to implement SAG. We do not make a specific policy recommendation for how best to respond to global climate change. It might be the case that all realistic responses to climate change (e.g., greenhouse gas abatement, adaptation to climate change, geoengineering, or some combination of these) have ethical problems, such that none of them is ethically perfect. In that case, one might advocate employing one of these ethically imperfect responses as the least of several evils. Whereas others (Gardiner 2010) have critiqued the argument that SAG is the least of several evils when it comes to responding to climate change, this paper leaves it open whether or not SAG ought to be implemented. We argue only that SAG has serious ethical problems that ought to be recognized and considered carefully before advocating its implementation.

Despite the fact that there are competing accounts of distributive, procedural, and intergenerational justice that disagree on important theoretical points, there is a substantial degree of convergence between these theories when it comes to evaluating SAG as a concrete strategy. In this paper, we characterize each of these kinds of justice, briefly discussing many (but not all) of the central theories for each and showing that they all raise serious ethical problems for SAG. Space limitations prevent us from considering the justice of non-geoengineering climate strategies, such as mitigation of greenhouse gases or adaptation to climate change. Whether or not a SAG strategy ought to be implemented will depend in part on whether such non-geoengineering strategies are more or less just than SAG. Before making such a comparison, however, one must be aware of the ethical problems associated with SAG, which we highlight in this paper. Although we do not offer a definitive verdict regarding whether SAG ought to be implemented, we do argue that SAG faces serious ethical challenges to being a just response to climate change.

In the first section of this paper, we review briefly the science of both anthropogenic climate change and SAG, as well as the current knowledge about the impacts of both of these on natural and human systems. In the second section, we discuss theories of distributive justice and the potential for SAG to cause changes in regional precipitation that might violate requirements of distributive justice. In the third section, we discuss theories of intergenerational justice and the potential for SAG to be discontinued abruptly, leading to rapid climate change that might violate requirements of intergenerational justice. In the fourth section, we discuss theories of procedural justice and the potential for SAG to be implemented unilaterally, which would violate requirements of procedural

justice. We conclude that SAG faces difficult challenges in being a just response to global climate change.

I. THE SCIENCE AND POTENTIAL IMPACTS OF ANTHROPOGENIC CLIMATE CHANGE AND SAG

An appropriate assessment of SAG strategies requires a robust understanding of both the science of anthropogenic climate change and SAG, as well as the potential impacts of both. In this section, we review the current scientific knowledge about (1) the greenhouse effect and anthropogenic climate change, (2) the concept of radiative forcing, (3) the climate effects of radiative forcings, and (4) a subset of potential impacts of SAG. This review is intended to provide a short and accessible summary of an extensive and rapidly growing body of literature (see Barrett 2008; Hegerl and Solomon 2009; Rasch et al. 2008b; Robock 2008a; Royal Society 2009).

The greenhouse effect is driven by greenhouse gases such as carbon dioxide (CO_2) and water vapor. Greenhouse gases are transparent to visible electromagnetic radiation but are opaque to infrared radiation (see Arrhenius 1896; Fourier 1824). The Earth receives most of the energy from the sun in the form of electromagnetic radiation in the visible range. Because the Earth's surface temperature is much lower than the sun's surface temperature, the outgoing electromagnetic radiation from the Earth is mostly in the form of infrared radiation. As a result, some of the energy in the outgoing infrared radiation is absorbed by the greenhouse gases in the atmosphere. A fraction of this absorbed energy is re-radiated back to Earth, thus warming the Earth's surface.

Most of the currently observed greenhouse effect is due to non-anthropogenic processes. Without greenhouse gases, the average surface temperature of the Earth would be below the freezing temperature of water (Bolin et al. 1986). However, anthropogenic greenhouse gas emissions have increased greenhouse gas concentrations, have caused an anthropogenic (or enhanced) greenhouse effect, and have resulted in measurable climate change. For example, the global mean surface air temperature has increased by 0.7 degree Celsius from 1906–2005, most of which is due to anthropogenic climate forcings (Alley et al. 2007). It is important to note that humans have changed the climate not just via the emissions of greenhouse gases but also via the emissions of aerosols into the atmosphere, which have changed the reflective properties of the atmosphere (Morgan et al. 2006; Murphy et al. 2009). These climate forcings are often quantified using the concept of "radiative forcing." Radiative forcing refers to the energy flux (the flow of energy per unit of area and time) due to a specific forcing agent such as carbon dioxide (Baede 2007). Radiative forcings drive changes in the Earth's energy balance and temperature. Simply put, greenhouse gases such as CO_2 act to warm the Earth's surface, while aerosols are estimated to have a net cooling

effect. For example, the radiative forcings due to the anthropogenic increases in atmospheric carbon dioxide and aerosols are +1.7 and -1.2 watts per square meter, respectively (Alley et al. 2007).

The climate response to emissions of greenhouse gases or aerosols occurs on a wide range of time-scales. The overall response is determined by the interactions between two key processes: (1) the atmospheric residence time of the radiative forcing agents and (2) the response time of the climate system to radiative forcing. Characterizing the complex dynamics of the coupled biogeochemical and climate systems by just a few characteristic time-scales is, of course, a gross simplification (Archer and Brovkin 2008; Kasting and Schultz 1996; Stocker 1996). However, this simplified exposition allows for a few general insights.

Sulfate aerosol geoengineering may be able to compensate for some of the effects of increased greenhouse gas emissions, but this compensation would be imperfect. One key reason for this partial and imperfect compensation is that CO₂ emissions affect atmospheric CO₂ concentrations (and hence radiative forcing) over thousands of years (Archer and Brovkin 2008; Eby et al. 2009). In contrast, the atmospheric life-time of aerosols in the stratosphere is on the order of years (Robock 2000). The climate system, in turn, responds to radiative forcing perturbations on two main time-scales: a short-term response over years-to-decades and a long-term response over centuries-to-millennia (Dickinson and Schaudt 1998; Wetherald et al. 2001). The global mean surface temperature can react on short (order annual) time-scales as shown, for example, by the observed short-term cooling in response to the Mount Pinatubo eruption (Soden et al. 2002). However, the atmospheric temperature response is buffered on century to millennia time-scales by the thermal inertia of the oceans (Hoffert et al. 1980). The mismatch between the atmospheric residence times of CO₂ and aerosols has important implications for the risk analysis of SAG strategies (Goes et al. 2011; Matthews and Caldeira 2007). Because aerosols have a much shorter atmospheric residence time than CO₂, SAG strategies have to be maintained over the atmospheric lifetime of CO₂ (centuries to millennia) in order to compensate for a given quantity of CO₂ emissions. Failure to maintain the aerosol counterforcing could result in abrupt and potentially very damaging warming (Goes et al. 2011; Matthews and Caldeira 2007). Whether future societies could reliably maintain this aerosol counterforcing is at this time an open question (see Goes et al. 2011; Victor 2008).

A second key reason for the imperfect and partial compensation of SAG is that emissions of radiative forcing agents (e.g., greenhouse gases or aerosols) into the atmosphere can result in complex spatiotemporal patterns of changes in temperature, precipitation, and climate patterns such as El Niño and monsoons (Adams et al. 2003; Robock et al. 2008; Trenberth and Dai 2007). Radiative forcing agents with different spatial patterns are expected to result in different spatial patterns of the climate response. For example, balancing the global mean radiative forcings from greenhouse gases with aerosols results in substantial

changes in local climate patterns (Lunt et al. 2008). In addition, model simulations suggest that restoring the global mean surface air temperature does not restore the global mean precipitation (Bala et al. 2008). A third key reason for the only partial compensation via SAG is that CO₂ emissions cause considerable changes in the global biogeochemical cycles, such as ocean acidification (Doney et al. 2009), which can result in considerable impacts on marine ecosystems and human livelihoods (Doney et al. 2009; Hoegh-Guldberg et al. 2007; Orr et al. 2005).

Sulfate aerosol geoengineering strategies carry potentially large risks that are deeply uncertain (Bala et al. 2008; Brovkin et al. 2009; Crutzen 2006; Heckendorn et al. 2009; Hegerl and Solomon 2009; Robock et al. 2008; Tilmes et al. 2008; Victor et al. 2009). Deep uncertainty (also referred to as ambiguity or Knightian uncertainty) occurs, for example, when predictions hinge critically on divergent expert assessments and the decision maker is faced with several possible probability density functions (Ellsberg 1961; Keller et al. 2008; Knight 1921; cf. Lempert 2002). The distinction between uncertainty (with a known probability density function) and deep uncertainty (with uncertainty about the probability density functions) is important because the standard economic model of expected utility maximization is of limited descriptive power for situations under deep uncertainty (Ellsberg 1961). Examples of deeply uncertain parameters relevant to SAG proposals include (1) the climate sensitivity (how much the global mean surface air temperature would change in equilibrium to a doubling of atmospheric CO₂ concentrations) (Frame et al. 2005; Hegerl and Solomon 2009; Knutti and Hegerl 2008), (2) the sensitivity of ecological and economic systems to climatic changes (Ackerman et al. 2009; Mendelsohn and Olmstead 2009; Nordhaus 1994), and (3) the probability that future generations would maintain the required aerosol forcing over centuries to millennia (Goes et al. 2011; Matthews and Caldeira 2007). In this paper, we focus on a partial list of these risks. Specifically, we discuss below risks due to changes in spatial climate patterns, changes in climate variability, discontinuous SAG, and unilateral SAG. We argue that these risks pose difficult challenges for SAG to satisfy the requirements of justice.

2. DISTRIBUTIVE JUSTICE

2.1. Theories of Distributive Justice

Distributive justice concerns how harms and benefits ought to be shared among persons. A state of affairs is distributively just if and only if harms and benefits are shared as they ought to be among persons. However, theorists differ as to how harms and benefits ought to be shared. According to egalitarian theorists, harms and benefits ought to be shared equally, but these theorists themselves disagree on what exactly counts as equality of harms and benefits. Among egalitarian theorists, we briefly characterize the positions of John Rawls, Ronald Dworkin, Amartya Sen, and Richard Arneson. As an alternative to egalitarianism, we also

characterize a desert-based approach of distributive justice, which holds that harms and benefits ought to be shared among persons according to the degree persons deserve those harms and benefits.

According to Rawls, the principles of justice (which include but are not limited to the principles of distributive justice) are those that would be chosen by rational persons in an “original position” behind a “veil of ignorance,” where rational persons are self-interested individuals who “try to acknowledge principles which advance their system of ends as far as possible” (Rawls 1999, p. 125). This original position is a hypothetical state in which “no one knows his place in society, his class position or social status, nor does anyone know his fortune in the distribution of natural assets and abilities, his intelligence, strength, and the like” (Rawls 1999, p. 11). Rawls thinks such an original position provides an appropriate situation in which to choose the governing principles of society, because despite the fact that those who choose them are self-interested, they are unable to adopt principles that unfairly benefit their own groups. Thus one can determine the principles of justice by determining what principles would be chosen by rational persons ignorant of their particular status as individuals.

Rawls believes that persons in the original position would agree on two main principles of justice:

First: each person is to have an equal right to the most extensive scheme of equal basic liberties compatible with a similar scheme of liberties for others.

Second: social and economic inequalities are to be arranged so that they are both (a) reasonably expected to be to everyone’s advantage, and (b) attached to positions and offices open to all (Rawls 1999, p. 53).

The first principle has priority over the second (Rawls 1999, pp. 53–54). It holds that each person should have as great a share of basic liberties as is compatible with every other person having the same share of basic liberties. In other words, one is not permitted to have a liberty that comes at the expense of someone else’s liberties. Part (a) of the second principle is known as the “difference principle” (Rawls 1999, pp. 65–73). It allows that socioeconomic inequality might be just in certain circumstances, provided that the first principle and part (b) of the second principle are satisfied first. For example, Rawls’s theory permits an unequal distribution of income as long as this inequality (1) benefits everyone (including poorer persons) *and* (2) does not compromise poorer persons’ basic liberties and opportunities. Such a situation might occur if unequal incomes would result in greater wealth for everyone in a society, including the poorest. According to Rawls’s principles, a state of affairs is distributively just if and only if basic liberties are maximized and shared equally among persons, public office is open to all persons, and any socioeconomic inequality among persons benefits those who are worst off.

As an alternative to Rawls’s theory of justice, Ronald Dworkin (Dworkin 1981a, 1981b) suggests that distributive justice is determined by whether persons

begin with an equal share of resources, not whether harms and benefits are shared equally at a later time. Dworkin argues that persons should be free to utilize their equal share of resources as they wish, which can lead to unequal outcomes and thus an unequal distribution of harms and benefits. Since, for example, some investments are better than others, one person justly can earn a greater return than another on her fair share of resources. This theory of distributive justice permits inequality of harms and benefits, provided that this inequality results from the free choices of persons who begin with equal resources. For Dworkin then, a state of affairs is distributively just if and only if the share of harms and benefits among persons is the result of their free choices, *provided* that all start with an equal share of resources.

According to Amartya Sen's capability approach, the most important benefits for persons are the basic capabilities that allow one to pursue the functionings one values, whereas the most significant harms for persons are the absence of such capabilities (Sen 1982).¹ These basic capabilities include "the ability to meet one's nutritional requirements, the wherewithal to be clothed and sheltered, [and] the power to participate in the social life of the community" (Sen 1982, p. 367). These capabilities are necessary for one to lead a valuable life. Sen critiques both Rawls and welfarism (see below) for failing to recognize the importance of basic capabilities. For example, Rawls's theory is concerned with "rights, liberties, opportunities, income, wealth, and the social basis of self-respect . . . rather than with what these good things *do* to human beings" (Sen 1982, p. 368). However, Sen claims not that the insights of these theories are irrelevant for distributive justice, but rather such theories are incomplete (Sen 1982, p. 369). He argues for equality of basic capabilities as necessary but not sufficient for distributive justice: if a state of affairs is distributively just, then basic capabilities are shared equally among persons.²

Both Dworkin and Sen critique a welfarist conception of distributive justice, or the position that a state of affairs is distributively just if and only if welfare is shared equally among persons. Partly in response to such critiques, Richard Arneson (1989) defends a conception of distributive justice based on equal *opportunity* for welfare, where welfare is the satisfaction of persons' preferences. Arneson writes, "For equal opportunity for welfare to obtain among a number of persons, each must face an array of options that is equivalent to every other person's in terms of the prospects for preference satisfaction it offers" (Arneson 1989, p. 85). However, Arneson allows for inequalities of opportunity for welfare that are the result of persons' "voluntary choice or differentially negligent behavior for which they are rightly deemed personally responsible" (Arneson 1989, p. 86). According to Arneson then, a state of affairs is distributively just if and only if the share of harms and benefits among persons is the result of a state of affairs in which any inequality in a person's opportunity for welfare owes to voluntary choices for which that same person is responsible.

Finally, desert-based theories of distributive justice (Lamont 1994; Miller 1989;

Olsaretti 2007; Sadurski 1985; Sher 1987) claim that harms and benefits should be allocated according to how deserving persons are of those harms and benefits. On such views, some (e.g., those who work the hardest) deserve a greater share of benefits than others, and justice requires that benefits be distributed accordingly. Theories differ as to what determines desert, but all agree that harms and benefits should not be distributed by means of purely egalitarian principles. According to desert-based theories of justice, a state of affairs is distributively just if and only if the harms and benefits shared among persons are correlated with persons' desert, where more deserving persons enjoy a greater share of benefits than less deserving persons.³

There are important differences between these various theories of distributive justice, and sometimes they produce divergent evaluations of a single state of affairs. However, they also sometimes converge in evaluating a certain state of affairs as distributively just or unjust. To take a fairly clear example, refusing an innocent child access to clean water when doing so benefits no one else violates (1) Rawlsian justice since it denies the child a basic liberty that is compatible with others' liberties, (2) Dworkin's theory of justice since it compromises equality of initial resources among persons, (3) Sen's capability approach since it refuses the child a basic capability that is necessary for her to engage in valued functionings, (4) Arneson's equal opportunity for welfare since it reduces the child's equal chance of satisfying her preferences, and (5) desert-based justice since the child is no less deserving than others of access to clean water. Although for different reasons, all five theories agree that denying an innocent child access to clean water violates the requirements of distributive justice. We argue below that certain states of affairs that could result from implementing SAG likewise fail to satisfy the requirements of distributive justice on all five of these theories.

2.2. Precipitation Change, Drought, and Distributive Justice

The potential for SAG to alter regional precipitation levels poses a serious obstacle to SAG satisfying the requirements of distributive justice. While the exact effects SAG would have for the planet are uncertain, various studies suggest that there could be harmful consequences caused by changes in regional precipitation levels. A climate simulation by Matthews and Caldeira (2007) finds that a SAG strategy that reduces temperatures to pre-industrial levels would cause considerable precipitation reduction over land across the globe, most severely in Africa, South America, and southeastern Asia. Specifically, this model suggests that SAG initiated in 2000 would cause average global precipitation to decrease by approximately 0.2 millimeters per day at 2100 relative to 1900, assuming atmospheric CO₂ levels of 880 parts per million (three times higher than the present concentration). However, the decrease is as high as approximately 1.0 millimeters per day in some tropical regions. Alternatively, the same model found that a scenario with identical CO₂ levels but without SAG exhibits an average

global precipitation decrease of only approximately 0.02 millimeters per day at 2100 relative to 1900.

Similarly, a climate simulation by Robock et al. (2008) finds that injecting five megatons of SO_2 per year into the tropical stratosphere would likewise cause considerable precipitation reduction in comparison to a scenario without geoengineering, with up to 3.0 millimeters per day reduction in annual average precipitation in southeastern Asia. Finally, an empirical study by Trenberth and Dai (2007) correlates both a decrease in global precipitation and an increase in global drought with the effects of the Mount Pinatubo volcanic eruption in 1991, which injected 20 megatons of SO_2 aerosols into the stratosphere (Robock 2008a, p. 15). Although the Pinatubo eruption caused global cooling by increasing the Earth's albedo, it also was associated with considerable precipitation decrease and drought in southern Africa, South America, and southeastern Asia (Trenberth and Dai 2007).

It is deeply uncertain to what degree (if at all) a substantial decrease in precipitation would decrease food production and fresh water supplies in these regions, and more research is needed to determine this. However, Robock et al. (2008) notes that SAG could disturb the African and Asian summer monsoons, thus threatening the food and water supplies of millions of persons. Brewer (2007, p. 9915) contends that the release of SO_2 into the atmosphere due to the eruption of Mount Tambora in 1815 caused global cooling that decreased agricultural productivity and led to famine, food riots, and perhaps "hundreds of thousands of untimely deaths." However, unlike the case of the Tambora eruption, which affected only one year of agricultural production, SAG has the potential to lead to precipitation decrease lasting as long as SAG itself is maintained. Finally, Trenberth and Dai (2007) warn that SAG has the potential to cause substantial precipitation decrease and drought comparable to that caused by the Pinatubo eruption. Accordingly, SAG has the potential to increase benefits for some by increasing harms for others. For this reason, as we explain below, SAG faces an obstacle to meeting the requirements of all five theories of distributive justice considered above.

Rawlsian distributive justice requires that each person have an equal share of basic liberties, and it permits socioeconomic inequality only if such inequality is "reasonably expected to be to everyone's advantage" (Rawls 1999, p. 53). While the exact effect SAG would have on regional food and water availability is deeply uncertain, thus making it difficult to predict which particular individuals and groups would be harmed by SAG, it is reasonable to expect that such a policy would produce both winners and losers. Although SAG might benefit some (e.g., those living in coastal cities threatened by sea level rise), it might also harm others (e.g., those living in regions experiencing famines and droughts due to precipitation decrease). This outcome would violate the basic rights of those in the latter group for food and water. Moreover, SAG is not "reasonably expected to be to

everyone's [socioeconomic] advantage" (Rawls 1999, p. 53)—on the contrary, it has the potential to worsen the socioeconomic condition of those (e.g., farmers) whose livelihoods are harmed by shifting precipitation patterns. Accordingly, SAG faces major challenges in meeting the requirements of Rawlsian distributive justice, because it could violate some persons' basic liberties and make some persons economically worse off.

Dworkin's theory of distributive justice requires that each person initially have an equal share of resources that the person is permitted to utilize as she or he wishes. It is distributively just for a person to possess fewer benefits and more harms than others *only if* this is the result of that person's free choices. However, SAG could decrease the benefits enjoyed and increase the harms suffered by some persons living in regions vulnerable to SAG-caused precipitation decrease. This decrease in benefits and increase in harms would not be the result of those persons' free choices. On such an outcome, SAG would fail to satisfy the requirements of Dworkin's theory of distributive justice.

According to Sen, a necessary condition for a state of affairs to be distributively just is that all persons have an equal share of basic capabilities. Although there is not currently an equal share of capabilities among persons globally, SAG might increase this current inequality. This is due to the potential of SAG to impair the basic capabilities of some persons through drought and famine. Lacking access to sufficient food and water, a person is unable to pursue the functionings he or she values.

The matter is likewise with Arneson's requirement that all persons have an equal opportunity for welfare. Although this condition is not met in the current world, SAG might exacerbate this inequality of opportunity for welfare even further. Due to SAG-caused shortages in food and water availability, persons might not have an equal opportunity for welfare, because those who lack access to food and water could have a far lower probability of achieving their own welfare. Sulfate aerosol geoengineering could put many persons at a serious disadvantage in this regard.

Finally, a desert-based theory of distributive justice requires that inequality of harms and benefits among persons be correlated with whether and how much persons deserve to have those harms and benefits. On this view, it is just for persons to enjoy fewer benefits than others only if those persons are less deserving than others of those benefits. However, persons who could suffer from SAG-caused food and water shortages are no less deserving than others of access to food and water. In fact, persons living in regions projected to experience considerable precipitation reduction (South America, Africa, and southeast Asia) (Matthews and Caldeira 2007) are among those least responsible for the greenhouse gas emissions that are causing climate change (see United Nations 2009). Accordingly, such persons do not deserve to suffer disproportionately the harms caused by a climate change policy, but SAG has the potential to cause such undeserved suffering.

Despite substantial theoretical differences, SAG is ethically problematic on all five of the major theories of distributive justice considered above. While more research is needed in order to predict the exact effect SAG would have on food and water availability, current research makes it reasonable to expect that some persons would suffer harms that are incompatible with the principles of distributive justice.

But what about a policy that couples SAG with compensation for those who are harmed by precipitation change? For example, such a policy might offer economic remuneration for farmers whose crops are unable to grow under the new precipitation conditions, food and water supplies for those living in regions stricken by drought and famine, or financial assistance for countries struggling with other problems caused by SAG. It might be the case that SAG coupled with compensation can meet the requirements of distributive justice, but it is incumbent upon proponents of such a policy to demonstrate that this would be so. We note, however, that such compensation could increase the costs of SAG substantially, which is often alleged to be inexpensive (Barrett 2008; Teller et al. 2003). If the inequities of SAG were addressed through compensation for harms, difficult though these might be to calculate, this would make SAG more expensive, perhaps undermining the appeal it has for policy-makers.

Our ethical analysis of whether SAG meets the requirements of distributive justice relies on climate models that are deeply uncertain. SAG's effect on regional precipitation and drought might be greater or less than current models predict, as might the effects of such precipitation change and drought for food production and fresh water availability. As called for by Schneider (1996) and Cicerone (2006), more research is needed to determine the probability of various consequences of SAG. Once again, we do not contend that SAG ought not to be implemented, and we grant that there might be a version of SAG that meets the requirements of distributive justice. However, SAG faces obstacles to meeting these requirements, so it is incumbent upon proponents of SAG either to present a version of SAG that is distributively just or to argue why SAG ought to be implemented despite its ethical shortcomings.

3. INTERGENERATIONAL JUSTICE

3.1. Theories of Intergenerational Justice

Intergenerational justice is focused on relations between persons who are not contemporaries, especially those between present and future generations. In particular, intergenerational justice concerns how harms and benefits ought to be shared across generations. Accordingly, intergenerational justice is a kind of distributive justice, but one that involves temporal issues not considered in our discussion of distributive justice above. A policy is intergenerationally just if and only if its harms and benefits are shared as they ought to be among present and

non-present persons. Theories differ as to how these harms and benefits ought to be shared. Since SAG concerns relations between present and future persons, we limit our consideration of intergenerational justice to the harms and benefits shared among present and future persons, leaving aside consideration of harms and benefits shared among present and past persons.⁴

Since intergenerational justice is a kind of distributive justice, theories of the former can be divided according to the five theories of distributive justice considered above, with the additional proviso that such theories include future as well as present persons. Rawls maintains that persons in the original position are ignorant of the generation to which they belong (Rawls 1999, p. 254), which means that the same principles of justice would be chosen to govern society for all generations. Accordingly, a necessary condition of Rawlsian intergenerational justice is that both present and future persons have a maximum share of basic liberties that are also equal with each other. It follows from this that it is intergenerationally unjust to compromise the basic liberties of future persons, because this would violate the rights of future persons.

More generally, it is arguably intergenerationally unjust for present generations to bring about states of affairs that are distributively unjust for future generations. In other words, one requirement of intergenerational justice is that present persons not compromise the distributive justice of future generations. On this approach, whether a policy satisfies the requirements of intergenerational justice depends on which theory of distributive justice one adopts. On Dworkin's theory, it is intergenerationally unjust to exacerbate the inequality of resources between future persons. On Sen's capability approach, it is intergenerationally unjust to increase the inequality of future persons' capabilities to pursue valued functionings. On Arneson's theory, it is intergenerationally unjust to increase the inequality of future persons' opportunity for welfare. Finally, on a desert-based theory, it is intergenerationally unjust to cause undeserved harms and benefits for future persons. As with distributive justice, there are important theoretical differences between these five theories of intergenerational justice, but they can also converge in raising problems for a potential policy or action.

3.2. Discontinuous SAG and Intergenerational Justice

Future generations are subject to the potential harms of SAG, perhaps most notably because SAG might be implemented and then discontinued abruptly at some point in the future (see Brovkin et al. 2009; Ross and Matthews 2009; Victor 2008). In order to be effective, SAG must be maintained by regular injections of aerosols into the stratosphere. If these injections should cease suddenly, the sulfates already in the stratosphere, which have a residency time of only a few years (Rasch et al. 2008a), would dissipate at a fast rate and thus cease to compensate for the warming caused by atmospheric CO₂, thus leading to rapid climate change. Sulfate aerosol geoengineering could be discontinued for numer-

ous reasons, such as war or socioeconomic breakdown. The analysis of Ross and Matthews (2009), for example, projects a temperature increase of approximately 0.1–0.8 degrees Celsius for the year immediately following the discontinuation of geoengineering, as opposed to an increase of only 0.0 to 0.1 degrees Celsius per year in a business-as-usual scenario. Moreover, their model also predicts with 15 percent probability a temperature increase in excess of 0.5 degrees Celsius per decade for the two decades immediately following the discontinuation of geoengineering. The potential for such an abrupt warming has been characterized as an “increased risk of dangerous anthropogenic interference in the climate system under the criteria laid out in the United Nations Framework Convention on Climate Change” (Ross and Matthews 2009). One key reason for this increased risk is that the difficulty of adaptation to (as well as the expected damages of) climate change increases with the rate of climate change (see Alley 2002; Lempert et al. 1994; Nordhaus 1994).

This challenges Barrett’s estimate that SAG is safe and inexpensive (Barrett 2008), because it does not account for the harms and economic damages of SAG’s potential discontinuation. Barrett holds that such discontinuation is unlikely, because countries that commit to SAG have strong incentives to continue it, given the dangerous consequences of stopping (Barrett 2008, p. 50). Conversely, MacCracken argues that SAG discontinuation is a greater risk, given that its benefits would not be obvious “to the typical citizen” (MacCracken 2006, p. 238). It is deeply uncertain what the probability is that SAG would be discontinued. However, even on Barrett’s more optimistic expectation, SAG discontinuation poses a serious threat to future generations, even if this threat has a low probability of being realized. Accordingly, implementation of SAG raises questions of intergenerational justice. Following de-Shalit (1995), Pogge (2002), and Rawls (2001), we contend that intergenerational justice requires the present generation to ensure that future generations have access to food, water, shelter, and education. If SAG is implemented and then discontinued, future generations’ access to these benefits could be compromised. Thus, any generation that implements SAG accepts the risk that it might later be discontinued, but the subjects of this risk are the future generations who would suffer the harmful effects if SAG should be discontinued abruptly.

Can implementing SAG satisfy the requirements of the theories of intergenerational justice considered above? It is deeply uncertain both whether SAG would be discontinued and what exact effect this would have on future persons. However, given current research (Goes et al. 2011; Ross and Matthews 2009), it is reasonable to expect that abrupt discontinuation of SAG in the future would increase the harms suffered and decrease the benefits enjoyed by some future persons. This outcome has the potential to violate Rawlsian intergenerational justice, which holds that all future persons have rights to basic liberties. For example, discontinuous SAG could compromise some future persons’ access to food and

water due to rapid global warming. Further, Rawlsian intergenerational justice also requires that any socioeconomic inequality among future persons benefit all future persons (including the worst off), but discontinuous SAG could cause economic damages for future persons that increase socioeconomic inequality without benefiting all. This could happen, for example, if the economic damages caused by discontinuous SAG are suffered disproportionately by poor persons. Even if future generations living after discontinuous SAG are richer *on the whole* than they would have been had SAG not been implemented, abrupt discontinuation of SAG could create unjust socioeconomic inequality between *particular* future persons. Accordingly, although it is deeply uncertain how the economic damages of discontinuous SAG would be proportioned, they pose a potential problem from the perspective of Rawlsian intergenerational justice.

Discontinuous SAG could also lead to future states of affairs that, according to the other four theories considered above, are distributively unjust. For example, discontinuous SAG could cause unequal economic damages for different future persons, thus harming some more than others. This outcome would reduce the resources of some future persons in a manner that does not depend on their free choices, thus violating Dworkin's requirement that persons have an initially equal share of resources. This outcome could also increase the inequality of capabilities among future persons by impoverishing some, which would violate Sen's requirement that persons have equal capabilities to pursue valued functionings. Further, unequal economic damages caused by discontinuous SAG could violate the equal opportunity of future persons to achieve their own welfare, thus violating Arneson's requirement that all persons have an equal chance for welfare. Finally, economic damages caused by SAG could harm future persons who, since they would not be responsible for having implemented SAG, do not deserve to be harmed, thus violating the requirements of a desert-based theory of intergenerational justice.

The probability that SAG would be discontinuous is deeply uncertain and requires further research. Nonetheless, there are reasons to believe that SAG could be prone to discontinuation. Long-term SAG would require constant upkeep, which might falter in the future due to war, socioeconomic breakdown, political inertia, technological failure, or other causes. Since such discontinuation could lead to unjust outcomes for future persons, SAG faces an obstacle to satisfying the requirements of intergenerational justice. We do not claim that SAG in fact would be intergenerationally unjust nor that it ought not to be implemented. We contend rather that it is the responsibility of proponents of SAG to recognize and address these ethical problems SAG might pose for future generations.

Finally, what about a policy that combines CO₂ abatement with SAG, as suggested by Wigley (2006)? Such a policy would deploy relatively short-term SAG to buy time for substantial CO₂ abatement, after which SAG would be phased out. One might assume that the probability of SAG being discontinuous

is directly proportional to the duration of SAG. Given this assumption (and all else being equal), a shorter-term SAG strategy would have a lower probability of being interrupted. In this case, a combined policy of short-term SAG and CO₂ abatement might violate intergenerational justice to a lesser extent than a pure SAG strategy, but it still faces the challenge of meeting the requirements of distributive justice. This is because short-term SAG is still expected to alter regional precipitation levels, potentially leading to droughts and famines and thus harming present persons.

4. PROCEDURAL JUSTICE

4.1. Theories of Procedural Justice

Procedural justice concerns how decisions ought to be made from an ethical perspective. A decision is procedurally just if and only if it is reached in the manner it ought to be reached. Rawls assumes that decisions ought to be made fairly. According to his notion of “pure procedural justice,” a decision is procedurally just “when there is no independent criterion of the right result: instead there is a correct or fair procedure such that the outcome is likewise correct or fair, whatever it is, provided that the procedure has been properly followed” (Rawls 1999, p. 75).⁵ Recall that Rawls understands fairness in terms of “the original position,” which includes all persons as decision makers, each of whom is ignorant of his or her particular class, social status, talents, etc. (Rawls 1999, p. 11). A decision in the original position is fair partly because it is made by *all* persons to be affected by that decision. Thus, following Rawls, a decision is procedurally just only if all persons affected by that decision have the opportunity to contribute to that decision process. It is a widespread assumption that procedural justice requires that all those to be affected by a decision have the opportunity to guide that decision in some way (Grasso 2007, p. 228; Müller 1999, 2001).

Norman Daniels and James Sabin propose four conditions of procedural justice: (1) that the rationales behind policy decisions be public, (2) that the rationales behind policy decisions be relevant to those decisions, (3) that policy decisions be subject to appeal, and (4) that there be mechanisms in place to enforce the other three conditions (Daniels and Sabin 1998, p. 57). Although Daniels and Sabin focus specifically on procedural justice for decisions regarding the allocation of limited health care resources, the four conditions they propose can be treated plausibly as general conditions of procedural justice for any public policy. First, the publicity condition requires that public policy decisions be accessible to the public at large, which means that the rationales behind those decisions are to be made available for scrutiny by those who are to be affected by such decisions. Hence, this first condition mandates that the rationales behind public policy decisions be transparent to the public, for example, through full disclosure by governing bodies responsible for such decisions. Second, the relevance condition

requires that the rationales for any public policy decision be such that “fair-minded parties” can agree that those rationales are relevant for how the decision ought to be made (Daniels and Sabin 1998, p. 57). Hence, this second condition mandates that the rationale for any public policy decision be one that can be consented to as pertinent by those who are affected by the decision. Third, the appeals condition requires that there be a means whereby public policy decisions can be challenged and disputes regarding such policies resolved. Hence, this third condition mandates that those affected by a public policy decision be able to dispute that decision, for example, through a judicial process. Fourth, the enforcement condition requires that there be a mechanism that ensures the first three conditions are satisfied. Thus, extrapolating from Daniels’s and Sabin’s approach to procedural justice in health care decisions, a public policy decision is procedurally just if and only if (1) it is accessible to the public, (2) the rationale for the decision is one to which fair-minded persons can agree, (3) there is a mechanism for the public to appeal the decision, and (4) there is a way to enforce the other three conditions.

Both these theories of procedural justice place a premium on fairness, so it is plausible to expect that they will often agree in evaluating a given decision as procedurally just or unjust. We argue below that unilateral SAG fails to satisfy the requirements of either theory and that both theories thus converge on the verdict that unilateral SAG is procedurally unjust.

4.2. Unilateral SAG and Procedural Justice

Interest in SAG is growing in part because it is expected to be less expensive than CO₂ abatement (Barrett 2008; Robock 2008b; Robock et al. 2009). Barrett (2008, p. 49) cites Teller et al. (2003), who estimate the cost of SAG at \$1 billion per year, far lower than the cost of CO₂ abatement. Given the difficulty of securing the international agreement necessary for an effective abatement policy, and given that SAG might seem attractive as a short-term solution to some of the harmful effects of climate change, a single state government might implement SAG without the consent of other countries (Polborn and Tintelnot 2009). As Barrett (2008, pp. 50–51) notes, many countries will have an incentive to implement SAG in order to avoid the harmful impacts of climate change, and one of them could do so unilaterally.

Unilateral SAG violates Rawls’s theory of procedural justice, which holds that a policy is procedurally just only if all persons affected by that decision have the opportunity to contribute to that decision process. This condition is not met in the case of unilateral SAG, because many persons who are affected by SAG have no opportunity to contribute to the decision process whereby SAG is enacted. If a single state decides unilaterally to implement SAG, then those who are not citizens of that state are excluded from the decision process whereby SAG is enacted. However, since SAG will affect virtually everyone on the planet, the decision procedure whereby SAG is enacted excludes many persons who are to be affected by that

policy. If a decision by a single state to implement SAG is truly unilateral, then non-citizens of that state have no means to contribute to the process whereby it is decided that SAG is to be implemented. Accordingly, unilateral SAG fails to meet a necessary requirement of Rawlsian procedural justice.

Unilateral SAG also violates the account of procedural justice based on Daniels's and Sabin's four conditions, because by definition it fails to meet condition (3), since there is no clear way for those who are not citizens of the state implementing SAG to appeal that state's unilateral decision. The effects of SAG are global, so the public that is affected by the decision to implement SAG is the global public. If one state decides to implement SAG unilaterally, then non-citizens of that state have no clear means to appeal that decision. Accordingly, the decision to implement SAG unilaterally is procedurally unjust. Further, as a consequence of unilateral SAG failing to satisfy condition (3), it also fails to satisfy condition (4). If it is impossible for a policy to satisfy a given requirement, then it is also impossible to enforce that policy to satisfy that requirement. Hence, since it is impossible for a state implementing SAG unilaterally to recognize appeals from non-citizens (since the decision would then cease to be unilateral), it is likewise impossible to compel a state implementing SAG unilaterally to recognize appeals from non-citizens. Accordingly, unilateral SAG fails to satisfy conditions (3) and (4).

We recognize that SAG need not be implemented unilaterally. The mere fact that unilateral SAG is procedurally unjust is not sufficient to establish that SAG as such is procedurally unjust. However, given that SAG is inexpensive and can be implemented without multilateral agreement, the prospect of unilateralism poses a challenge for SAG to meet the requirements of procedural justice. Advocates of a just form of SAG, assuming there is one, might urge the international community to develop safeguards against unilateralism. Some climate scientists (Cicerone 2006; Lawrence 2006) propose a moratorium on geoengineering research (including but not limited to SAG) until ethically acceptable research norms are established.⁶ Morrow et al. (2009) suggest that one such norm is the "Principle of Respect," which "requires that the scientific community secure the global public's consent, voiced through their governmental representatives, before beginning any empirical research [on geoengineering]." Meeting this norm might satisfy the requirements of procedural justice, because it precludes the public being affected by a policy to which they do not consent. Such research norms might help alleviate the threat of unilateral SAG. At any rate, it is the responsibility of proponents of SAG to recognize and address this potential problem.

5. CONCLUSION

We have argued that SAG has the potential to violate the requirements of justice. This does not necessarily imply that some other climate change policy (e.g., adaptation) ought to be adopted in favor of SAG. It might be the case that all climate

change policies currently up for debate are ethically problematic in various ways. Further, it might be the case that we ought to implement one of these ethically unacceptable policies as the least of several evils, and this least evil policy might turn out to be SAG (for a critique of this approach, see Gardiner 2010). Due to lack of space in this paper, we consider neither the ethical merits and deficiencies of competing climate change strategies nor the question of which strategy ought to be implemented. Accordingly, instead of claiming that SAG ought to be rejected as a concrete strategy, we have highlighted ethical problems with SAG. First, SAG could cause drought and famine, so SAG has the potential to violate the requirements of distributive justice. Second, SAG could be abruptly discontinued in a way that could put future persons at risk of suffering the harms of rapid climate change, so SAG has the potential to violate the requirements of intergenerational justice. Third, SAG could be unilateral, which would violate the requirements of procedural justice. We grant that there might be a version of SAG that avoids these potential ethical problems and manages to satisfy the requirements of justice. More research is needed to determine whether this is the case. In particular, more scientific research is needed to determine the probable effects of SAG for both present and future generations, while more ethical research is needed to determine whether and how some version of SAG could satisfy the requirements of justice. However, the potential ethical problems with SAG pose serious obstacles to it being a just response to climate change. It is incumbent upon advocates of SAG to recognize and address these obstacles before proceeding with its implementation.

*Pennsylvania State University
Pennsylvania State University
University of Miami and Atlantic Oceanographic
and Meteorological Laboratory NOAA
Pennsylvania State University*

NOTES

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1. See also Nussbaum (2000).
2. For a critique of Sen's capability approach, see Cohen (1989).
3. Space prevents us from considering other theories of justice, such as libertarian ones. We note, however, that libertarians are unlikely to support SAG, because such a policy

is likely to involve significant government intervention in the lives and property rights of persons around the world. Since libertarians usually hold that the role of government should be limited to protecting property rights (Nozick 1974), and since any government that implements SAG probably oversteps this limit, libertarian theories of justice would arguably preclude the implementation of SAG.

4. An example of intergenerational justice between past and present persons might involve keeping promises to the dead.

5. Rawls distinguishes “pure” procedural justice from “perfect” and “imperfect” procedural justice, each of which assumes a “criterion of the right result” (Rawls 1999, pp. 74–75).

6. Victor argues that these norms should be generated by scientists alone, but it is unclear why others should be excluded from this process. Indeed, procedural justice might require broader participation (Victor 2008).

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