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Should we geoengineer larger ice caps?

Jacob Haqq-Misra

Blue Marble Space Institute of Science, 1200 Westlake Ave N Suite 1006, Seattle, WA 98109, United States

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ABSTRACT

The climate of Earth is susceptible to catastrophes that could threaten the longevity of human civilization. Geoengineering to reduce incoming solar radiation has been suggested as a way to mediate the warming effects of contemporary climate change, but a geoengineering program for thousands of years could also be used to enlarge the size of the polar ice caps and create a permanently cooler climate. Such a large ice cap state would make Earth less susceptible to climate threats and could allow human civilization to survive further into the future than otherwise possible. Intentionally extending Earth's glacial coverage will require uninterrupted commitment to this program for millenia but would ultimately reach a cooler equilibrium state where geoengineering is no longer needed. Whether or not this program is ever attempted, this concept illustrates the need to identify preference among potential climate states to ensure the long-term success of civilization.

1. Introduction

Climate catastrophes are events that could compromise the integrity of the biosphere and render the planet unsuitable for human civilization. Anthropogenic climate change has resulted in an increase in greenhouse warming that threatens several potential climate catastrophes. One possibility is the collapse of large ice sheets, such as the Greenland Ice Sheet or the West Antarctic Ice Sheet, which could increase sea level by ten meters or more and cause a shutdown of the thermohaline circulation in the Atlantic ocean (Overpeck et al., 2006; Lenton et al., 2008). Another risk is that a rise in global average temperature of seven degrees Celsius or more will induce heat stress and cause hyperthermia in humans and other mammals (Sherwood & Huber, 2010). Even more extreme is the possibility that climate change could initiate a runaway greenhouse state that would lead to the loss of all oceans and leave the planet uninhabitable (Goldblatt & Watson, 2012; Ramirez, Kopparapu, Lindner, & Kasting, 2014). Any of these events would pose significant challenges to the longevity of human civilization.

Geoengineering provides a possible remedy to these threats by using technology to modify the global climate (Keith, 2000). The most direct geoengineering strategy is to reduce the amount of incoming sunlight reaching the surface, which is referred to as "solar radiation management" or SRM (Caldeira, Bala, & Cao, 2013).[1] One of the widely discussed methods for SRM is the injection of reflective particles into the stratosphere (Crutzen, 2006; Wigley, 2006; Matthews & Caldeira, 2007; Rasch et al., 2008; Brovkin et al., 2009; Keith, 2010; Goes, Tuana, & Keller, 2011; Pidgeon, Parkhill, Corner, & Vaughan, 2013)

E-mail address: jacob@bmsis.org (J. Haqq-Misra).

[1] Other forms of geoengineering, such as carbon dioxide removal (CDR), can also help to address present-day climate concerns by reducing the abundance of greenhouse gases in the atmosphere. This paper will focus on SRM strategies because they offer the possibility of cooling the climate much more than CDR could accomplish (Shaffer, 2010; Smith & Torn, 2013).

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because it provides a "fast, cheap, and easy" (Caldeira, 2015) way to cool the planet. A similar effect could be achieved by deploying an orbiting solar shield to reflect away a portion of sunlight from space (Early, 1989; Angel, 2006), although this option is orders of magnitude more expensive than aerosol injection. Cloud seeding to enhance the reflectivity of marine stratocumulus clouds is another SRM option that can provide significant cooling to particular regions (Jones, Haywood, & Boucher, 2009; Rasch, Latham, & Chen, 2009; Korhonen, Carslaw, & Romakkaniemi, 2010). Other SRM options such as enhancement of oceanic transport or managed changes in the land carbon cycle operate too slowly to be effective at reducing atmospheric carbon dioxide to pre-industrial levels (Lenton & Vaughan 2009).

For present-day climate change, geoengineering can supplement mitigation and adaptation strategies (Keith, 2000; Wigley, 2006; Caldeira et al., 2013) to avoid crossing dangerous tipping points in the climate that are difficult or impossible to reverse (Lenton, 2011). Geoengineering raises significant ethical and political dilemmas (Lovelock, 2008; Gardiner, 2010; Tuana et al., 2012; Svoboda, Keller, Goes, & Tuana, 2011; Haqq-Misra, 2012; Preston, 2013; Pidgeon et al., 2013; Svoboda & Irvine, 2014) and also makes civilization more vulnerable to other catastrophes (Baum, Maher, & Haqq-Misra, 2013), so geoengineering may serve best as a last resort if all other options fail (Victor, Morgan, Apt, & Steinbruner, 2009; Gardiner, 2013). In the distant future, as the sun undergoes its course of stellar evolution, geoengineering may become necessary to prevent the loss of oceans due to a runaway greenhouse and may be the only way of preserving civilization on Earth (Goldblatt & Watson, 2012). Whether or not civilization decides to use geoengineering today, it remains a technological option that could be used at some point in the future.

While most geoengineering proposals focus on the short-term use of SRM to alleviate climate threats, another option is to employ a long-term geoengineering strategy to increase the overall climate stability of Earth. In particular, the polar ice caps reflect away a portion of sunlight reaching the surface and help to mediate global temperature. Larger ice caps would serve to reflect away more sunlight and thereby cool the climate, so SRM geoengineering could be used over an extended period of time for the purpose of permanently increasing the size of the polar ice caps. Such a strategy would result in a stable climate with more ice coverage, different from Earth today and with a lower global average temperature.

This possibility of geoengineering to increase the size of the polar ice caps raises a broader issue of deciding exactly which climate states are more or less desirable than others. This paper examines a range of possible stable climate states to consider how humanity could reduce the risk of climate catastrophe through intentional manipulation of the climate system.

2. Hysteresis in climate models

The climate of Earth is powered by the sun, and the amount of sunlight absorbed by the surface is proportional to global average temperature. Of the sunlight that reaches the top of the atmosphere, about 70% is absorbed by the surface of Earth today while the remaining 30% is reflected away by features such as clouds, aerosol, deserts, and glaciers. Planetary albedo refers to the fraction of incoming radiation that is not absorbed by a planetary system, so for Earth today the planetary albedo is about 0.3. In the past, however, Earth has experienced a range of cooler and warmer climate states with more or less ice coverage that corresponds to a larger or smaller planetary albedo. These various climate states have been investigated with computational models to interpret geologic evidence and demonstrate the potential for the Earth system to exist in more than one equilibrium state (e.g., North, Cahalan, & Coakley, 1981; Haqq-Misra, 2014).

The climate system appears to exhibit hysteresis, meaning that a given climate state depends not only on the amount of radiative forcing but also upon its initial conditions. This suggests that more than one stable climate state could exist for a particular level of sunlight and also indicates the existence of irreversible transitions in the amount of glacial coverage. A schematic diagram of hysteresis in Earth's climate is shown in Fig. 1, adapted from a one-dimensional climate model (Haqq-Misra, 2014). The horizontal axis corresponds to an increase in radiative forcing toward the right (either from sunlight or greenhouse gases), and the vertical axis indicates the latitudinal extent of glacial ice. Solid lines show stable climate states, while dashed lines show discontinuous transitions between climate states. For many values of radiative forcing there are multiple stable climates, and the availability of a particular climate state depends upon the previous state. In other words, climate evolution is path dependent, so that the future state of global ice coverage is limited by past history.

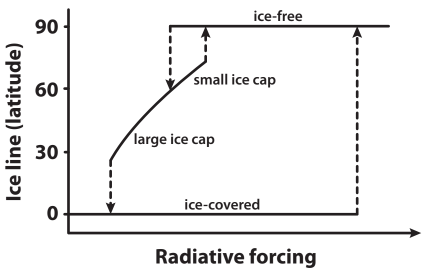

Fig. 1. Schematic diagram of hysteresis in Earth's climate. Solid lines indicate stable equilibrium climate states with ice-free, small ice cap, large ice cap, and ice-covered conditions. Dashed lines show discontinuous transitions between climate states as radiative forcing increases or decreases.