Geoengineering and the Distant Future of Earth's Climate

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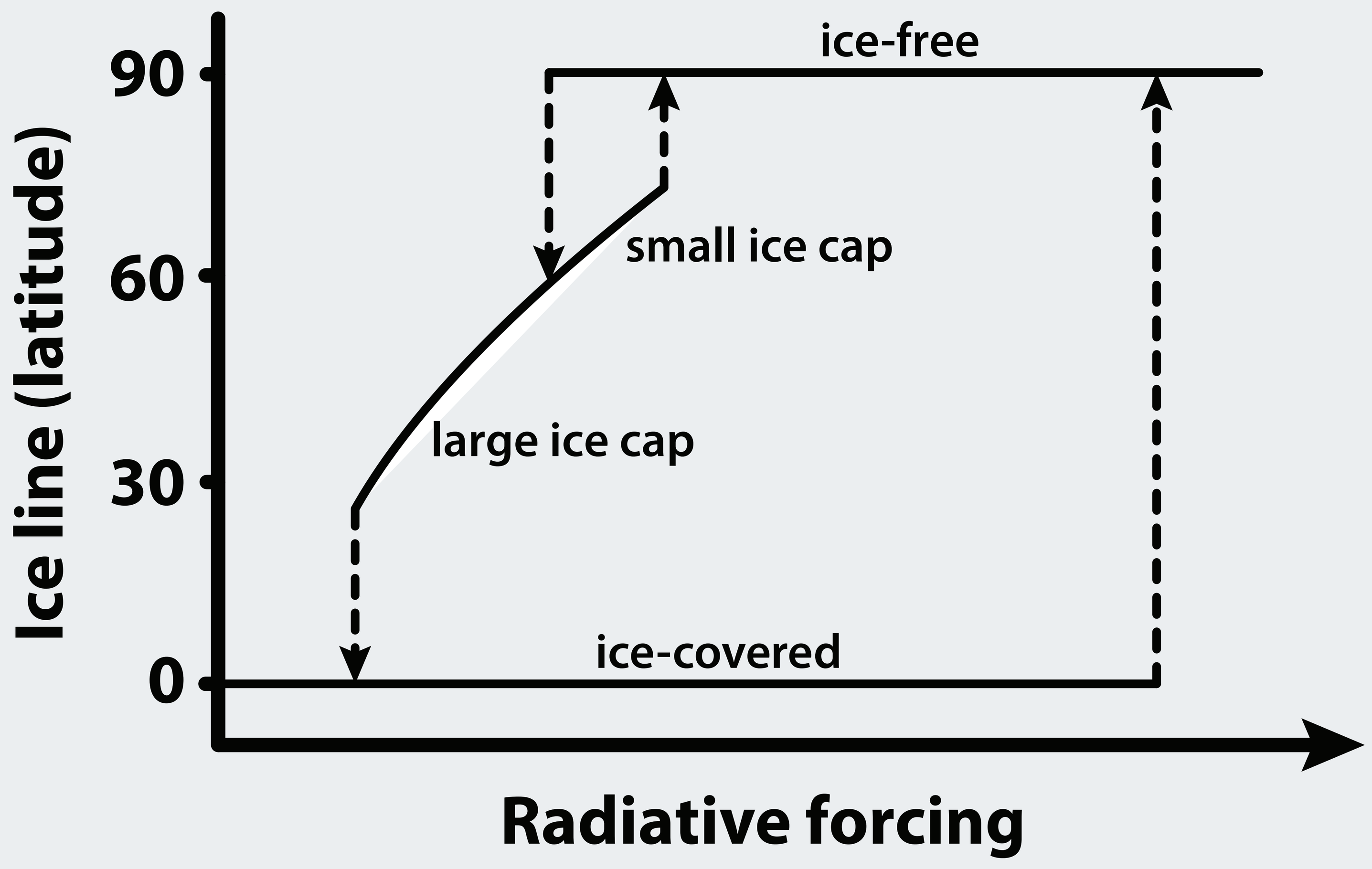
The climate of Earth is susceptible to catastrophes that could compromise the integrity of the biosphere and render the planet unsuitable for human civilization. The collapse of the Greenland Ice Sheet or the West Antarctic Ice Sheet could increase sea level by ten meters or more and cause a shutdown of the thermohaline circulation in the Atlantic ocean[1,2]. A rise in global average temperature of seven degrees Celsius or more could induce heat stress and cause hyperthermia in humans and other mammals[3]. Even more extreme climate change could initiate a runaway greenhouse state and lead to the loss of all oceans[4,5]. Al of these climate catastrophes challenge 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 or to keep on hand in case of a "climate emergency"[6], while geoengineering may also serve as humanity's last hope to withstand the sun's transition into a red giant[7]. But **geoengineering could also be deployed preemptively on a thousand-year timescale to enlarge the size of the polar ice caps and create a permanently cooler global climate**. Such a large ice cap state would be more resilient to climate threats and could allow human civilization to survive further into the future than otherwise possible.

Hysteresis in Climate Models

Earth's 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 also also indicates the existence of irreversible transitions in the amount of glacial coverage. A schematic diagram of hysteresis adapted from a one-dimensional climate model[6] is shown in the figure to the right.

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.



Geoengineering to Increase Glacial Coverage

The growth rate of ice sheets depends on environmental factors that allow a net accumulation of moisture. Geologic evidence suggests that changes in global temperature from Milankovitch orbital forcing take anywhere from about 6,000 to 10,000 years to cause a corresponding growth or retreat in ice sheet size[7]. But intentional solar radiation management (SRM) geoengineering could be used to create strong global cooling that persists stably for thousands of years and damps out any variations from ice-age cycles. This could reduce the amount of time required to grow the size of the polar ice caps so that a commitment of a thousand years or more to strong geoengineering could be sufficient to permanently grow the size of the polar ice caps and leave the planet in a significantly cooler state.

The major problem with this proposal is the long-term commitment required to achieve the desired state. However, this strong geoengineering option to grow the polar ice caps presents a technological solution to increase the long-term climate stability of Earth and guard the future against any potential climate catastrophes. Maintaining a geoengineering program for thousands of years is a challenge that has little precedent in human history, and any failure to keep the program running could set back all process and even initiate a climate catastrophe in the wake of rapid warming. Any long-term geoengineering program to permanently modify the climate will only succeed if structures are in place to ensure the continual pursuit of this goal for an uninterrupted stretch of millenia.

Selecting a Desirable Climate State

Earth's present small ice cap state is vulnerable to an increase in greenhouse gases and shows continued signs of warming. In the distant future, Earth's climate could cross the small ice cap instability and result in an equilibrium climate state many degrees warmer than today and with no reflective glacial coverage. Failure to address these concerns will risk catastrophes that could cripple the foundations of civilization. To this extent, the current small ice cap state may be less than ideal for the long-term future of humanity.

Glacial cycles feature prominently in Earth's geologic record, and the concept outlined here suggests using a long-term geoengineering program to increase the size of the ice caps permanently. The resulting climate state would be several degrees cooler than today, which would provide greater flexibility in the degree to which future civilization can interact with the atmosphere. Even if civilization transitions to efficient and renewable sources of energy, rather than emit more greenhouse gases, a large ice cap state would provide a climate that can better withstand changes in the steady brightening of the evolving sun. Alterations in land use would be required due to the changes in snow and ice cover, which would likely shift agricultural zones, require a massive migration of human populations, and grossly modify regional climate. Yet if the objective is to ensure a resilient climate so that civilization can exist for millions of years into the future, then perhaps such changes may be a small price to pay.

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