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Glacier Defense: A Material Science Proposal

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Abstract

Global warming is accelerating the disappearance of glaciers, with approximately 200,000 glaciers worldwide being affected. In response to these crises, scientists are actively seeking glacier melt interventions, spawning a new discipline, the so-called glacial geoengineering. This paper proposes a new proposal mainly from a viewpoint that combines engineering thermophysics and material science. The measures proposed comprehensively consider the science, the engineering feasibility, the time cost, the environmental protection, and the economic burden, after a brainstorm and a deepening understanding of glacial geoengineering. If applied to glacier protection projects in the global cryosphere, our solutions delay glacier melting by at least a few decades. Compared with other geoengineering projects, our proposal is competitive in raw materials, low cost, feasible construction and protection efficiency. In the way towards glacier protection, we believe that our proposal provides decision-makers with options to contribute to the development of coastal zones, economic societies, and ecosystems.

Keywords: Glaciers; Glacial geoengineering; Glaciers defence; Engineering thermophysics; Material science.
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1. Introduction

Glaciers are an integral component of the cryosphere, exerting a profound influence on global climate, freshwater resources, and the regulation of hydrological and ecological processes.[1] However, global warming is accelerating the disappearance of glaciers,[2] with approximately 200,000 glaciers worldwide being affected.[3] At the current rate of change, the sea level is predicted to rise by about 1 meter by 2100,[4] directly threatening the survival of about 200 million people living along the coastline.[5] In particular, rising sea levels caused by the continued melting of the ice sheets in Greenland and Antarctica threaten the sustainability of lives in nature, drinking water, and food security of more than 1 billion people over the next 30 years.[2]

In response to these crises, scientists are actively seeking glacier melt interventions, spawning a new discipline, the so-called glacial geoengineering.[6] A typical and impressive example is the construction of flexible barriers around vulnerable ice sheets or deep drilling to slow their slide into oceans.[7] This year, global glaciologists released a visionary whitepaper on glacial climate intervention after a lively debate, calling on scientists from all of the research fields around the world to propose practicable measures accordingly.[8] These measures should comprehensively consider the science, the engineering feasibility, the time cost, the environmental protection, and the economic burden, after a brainstorm and a deepening understanding of glacial geoengineering.

This paper proposes a new proposal mainly from a viewpoint that combines engineering thermophysics and material science. From the perspective of engineering thermophysics, glaciers exchange heat with their surroundings mainly through the upper and lower surface. On the upper surface, ice exchanges heat by solar (0.4-3.0 μm) and infrared (3.0-200 μm) radiation, and convection with the surrounding airflow.[9,10] The melting of ice in seawater is mainly due to heat convection and conduction with seawater. Therefore, the glaciers are divided into two types, 'land glaciers' and 'glaciers in seawater', from the standpoint of heat transport. The ice surface is susceptible to ice-water phase dynamics, and the ice melting is caused by temperature-salt double-diffusive convection.[11] Based on the above analyses, we have simulated 'land glaciers' and 'icebergs' and designed different protection strategies for these two types of glaciers (Fig. 1A). For 'land glaciers', a two-layered particulate film: a highly reflective layer and a low-emission layer, is designed to increase the reflectivity of the ice sheet to solar radiation and to reduce heat loss to 'insulate the glacier' via a low-emission layer 'quilt' (Fig. 1B). For the 'icebergs', an underwater 'barrier' of hydrophobically modified 'thermal curtain' is built to insulate

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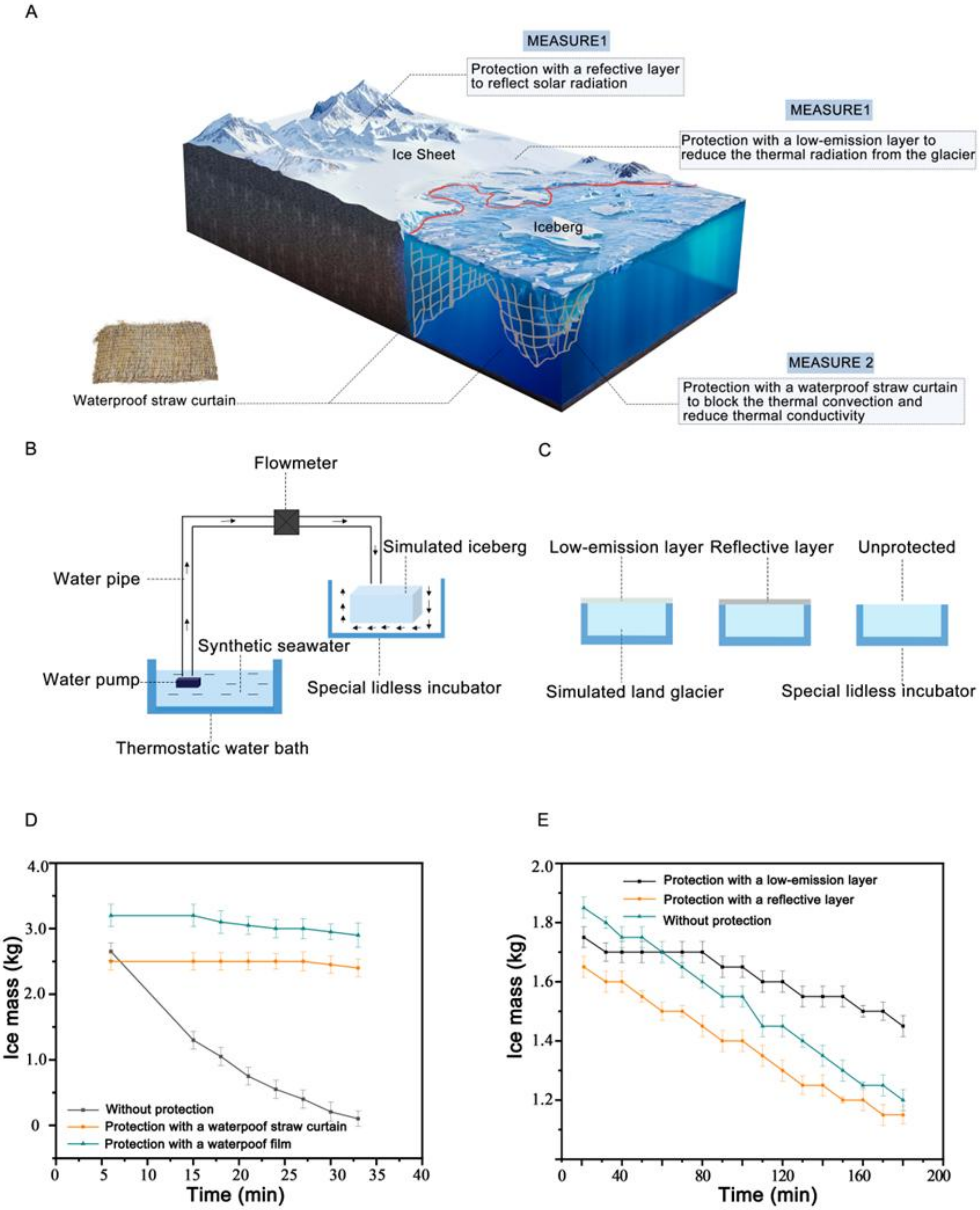

Fig. 1: An illustration of our glacier protection project. A) Schematic of the two measures. Measure 1 protects the land glacier with a reflective layer to reflect solar radiation and a low-emission underneath layer to provide thermal insulation. Measure 2 is a waterproof straw curtain as a barrier around the submerged iceberg to isolate the thermal convection of seawater, and reduce the thermal conductivity. B) Schematic diagram of reflective layer test. Schematic diagram of protective measures for the upper glacier. Comparison of aluminum foil, reflective layer, and unprotected glacier, respectively. C) Scheme of a circulation device to simulate the convection of ocean currents and icebergs. Synthetic seawater is pumped from the thermostatic water bath with a pump, through a flow meter into a container containing a simulated iceberg, and pumped out from the other side of the iceberg into the thermostatic water bath. D) Mass loss of simulated land glaciers protected with a reflective layer, a low-emission layer, and unprotected glaciers. E) Mass loss of simulated iceberg protected with waterproof film, waterproof straw curtain, and unprotected iceberg.

the glacier and prevent the ice from contact with seawater (Fig. 1C), thus reducing heat convection. Through experiments and estimations, the mass loss rate was reduced by more than 20 % and 50 % for simulated 'land glaciers' and 'glaciers in seawater', respectively (Fig. 1D and 1E). If applied to glacier protection projects in the global cryosphere, our solutions delay glacier melting by at least a few decades.

2. Specific measures

2.1 Reflection of solar radiation

Two simulated 'land glaciers' (size: 20*16*12cm) were placed in a special lidless incubator. One 'glacier' was protected by a reflective layer of about 0.5mm thick (titanium dioxide and calcium carbonate, mass ratio of 1:1, with polylactic acid adhesive (15% solids)) on the surface towards sunlight, while the other 'glacier' was left unprotected (Fig. 1B). After the same period of sunlight radiation, the protected 'glacier' mass loss rate was measured to be about 30%. In comparison, the value for unprotected 'glacier' reached 35%. The absorption of solar radiation was measured to be about 5% for the protected 'glacier' and about 19% for the unprotected, means a nearly 4-fold reduction in glacial heat absorption (Fig. 1D).

2.2 Blocking thermal radiation from ice

To understand the role of the low-emission layer, two blocks of ice of the same size are simulated as a 'land glacier' with a surface either protected by aluminum foil (to simulate the low-emission layer) or unprotected (Fig. 1B). The mass loss rate of 'glaciers' was calculated after the same period of exposure to sunlight and was 17% for the protected 'glaciers' and 35% for unprotected 'glaciers' (Fig. 1E). The reason is that the emissivity coefficient of aluminum foil ($\varepsilon = 0.04$) is much lower than that of ice ($\varepsilon = 0.98$),[12] which means that it radiates less energy in the infrared band of the glacier.

2.3 Blocking of seawater heat convection and heat transfer

Two simulated 'icebergs' of the same mass are placed in a circulation device that simulates the convection between ocean current and iceberg. One 'iceberg' is protected by a waterproof 'straw curtain' and the other is not (Fig. 1C). After the same time of convective cycling, the mass loss rate of the protected 'iceberg' is 4%, a significant reduction than that an unprotected (96%) (Fig. 1E). The waterproof 'straw curtain' acts as a barrier to both the thermal convection of seawater and heat transfer.[13]

3. Feasibility and perspectives

Compared with other geoengineering projects,[7,14] our proposal is competitive. The first lies in the raw material advantage. The raw materials include inorganic minerals such as calcium carbonate and titanium dioxide, and biomass material straw, which are widely distributed around the world, abundant in content, low cost, and environmentally friendly. Calcium carbonate and titanium dioxide are adhered by polylactic acid to suppress nanoparticulate dispersion and mitigate the photocatalytic activity of titanium dioxide nanoparticles. And polylactide-straw composites would correlate with inhibited mineralization kinetics in polar subzero regimes, thereby curtailing nutrient leaching pathways and secondary trophic cascades.

The second is cost benefit. They are used by simple mixing, coating, and weaving processes. For the protection of Antarctic glaciers, the material cost of only about \$0.3 billion is estimated for each 500 km^2 of the land glacier or 500 km^2 of the iceberg, incorporating material cost and straw pre-treatment expenses. The capital expenditure demonstrates an order-of-magnitude reduction compared to \$ 88 billion for constructing an 80-kilometer glacial protection embankment, which can decelerate surface ablation over approximately 500 km^2 of iceberg.[7] And, construction is highly feasible. Aircraft spraying techniques can spread powdered materials onto the glacier surface[15] and hydrophobic 'straw curtains' can be dropped upstream from water sources to reach the sea ice in the direction of the ocean currents.

Finally, protection efficiency is expectably high considering the easy accessibility of the raw materials, simple processing along with their environmental friendliness and being free of secondary maintenance.

There is a long way toward glacier protection, and we believe that our proposal provides decision-makers with options to contribute to coastal zones, economic societies, and ecosystems.[8]

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Conflict of Interest

There is no conflict of interest.

Supporting Information

Not applicable.

CRediT Statement

Qingchun Zhang: Writing, Original draft, Visualization, Methodology, Investigation, Formal analysis, Data curation. **Zhang Chen:** Writing, Review & editing, Supervision. **Qian Zhang:** Investigation, Data curation.**Yanfeng Gao:** Writing, Review & editing, Validation, Supervision, Resources, Funding acquisition.

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