'Snowball earth' might be slushy

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Credit: Sylvain Donà from Pexels

Imagine a world without liquid water—just solid ice in all directions. It would certainly not be a place that most life forms would like to live.

And yet our planet has gone through several frozen periods, in which a runaway climate effect led to global, or near global, ice cover. The last of these so-called "Snowball Earth" glaciations ended around 635 million years ago when complex life was just starting to develop. It's still uncertain if ice blanketed the entire planet, or if some mechanism was able to halt the runaway.

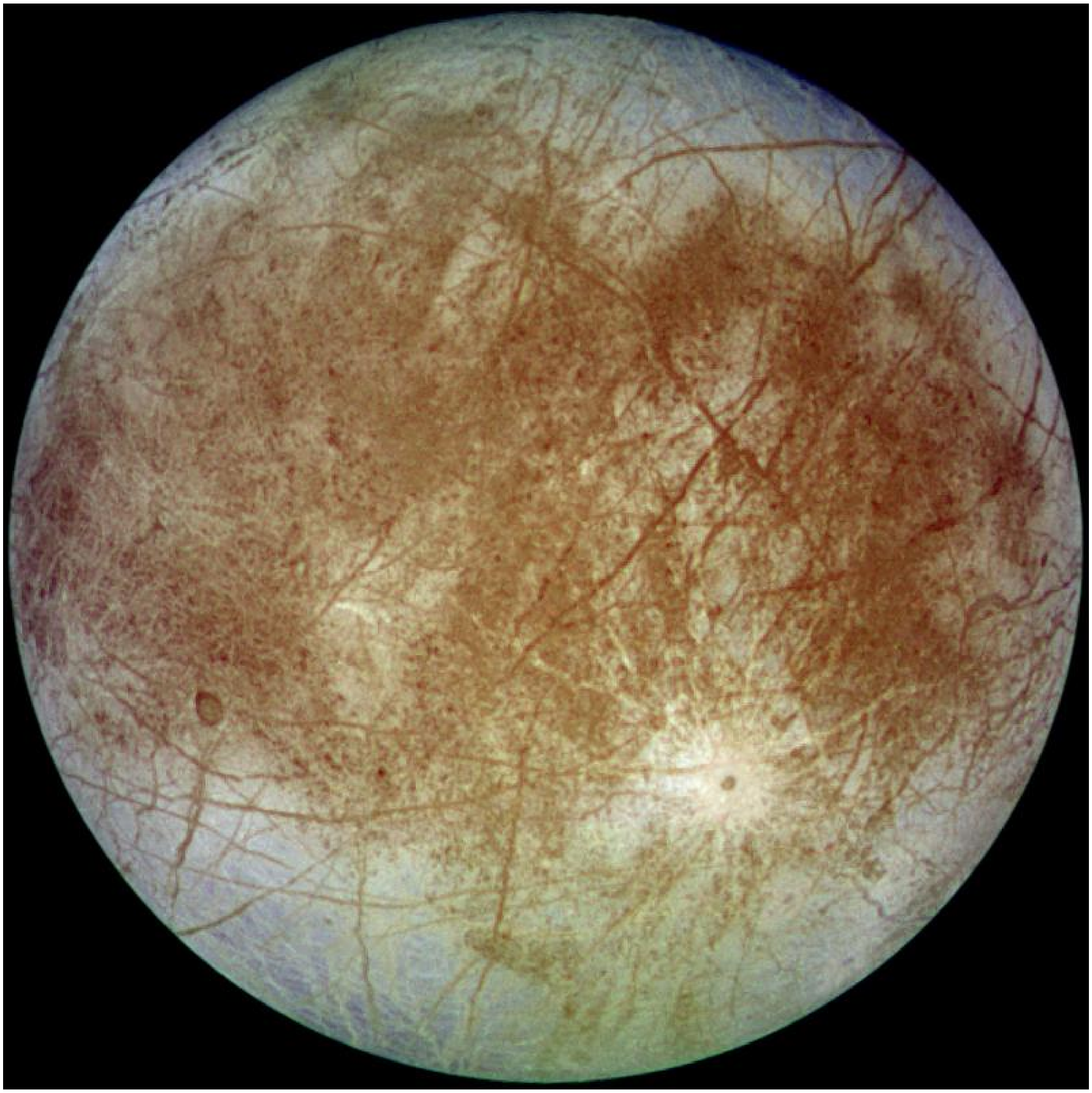
"Studying Snowball Earth glaciations can tell us just how bad it can get, in which case life as we know it would probably not survive," says geologist Linda Sohl of Columbia University.

Sohl and her colleagues are taking global climate models—the ones most people use to predict where our planet is heading in the future—and modifying them to study where our planet has been in the past.

In their simulations of the Cryogenian period (850-635 million years ago), the group has found that the Earth's global mean temperature could have fallen 12 degrees Celsius below freezing, and yet the world would not completely freeze over. The models predict that half of the oceans remain ice-free even under these extreme conditions. The implication is that Earth resisted snowballing into a solid ice ball at this crucial point in Earth's history.

The team has received a grant from the Exobiology & Evolutionary Biology element of the NASA Astrobiology Program to explore other Snowball Earth scenarios. The goal is to identify which factors, such as the arrangement of continents and ocean circulation, play a role in driving glaciation or halting it.

The results could influence discussions on the limits of habitability around other stars. Water-bearing planets like Earth may carry some natural defense mechanism against global freezing, and this might mean liquid water is more common in the Universe than astrobiologists have traditionally assumed.



Jupiter’s icy moon, Europa. Credit: NASA/JPL/DLR

Hard or slushy

Scientists contend that at least two Snowball Earth glaciations occurred during the Cryogenian period, roughly 640 and 710 million years ago. Each lasted about 10 million years or so.

The main evidence of the severity of these events comes from geological evidence of glaciers near the equator. If ice on land made it down to the low latitudes, as the argument goes, then it must have gone everywhere.

This "all in" climate response is due to the high reflectivity, or albedo, of ice. Ice reflects 55 to 80 percent of incoming sunlight, sending that energy back into space before it can warm the planet. By comparison, ocean water reflects just 12 percent, and land areas reflect between 10 and 40 percent, so more of the sun's heat is absorbed by these surface conditions. An additional factor in cooling the planet is that the Sun was 6 percent fainter during the Cryogenian period than it is now.

Early models showed that once ice reached tropical latitudes, a positive feedback loop would take hold, in which ice cover would lead to lower temperatures, which would add more ice cover, which would lower temperatures even more. This runaway effect would presumably continue until the entire planet froze over, with even the oceans covered with as much as a kilometer-thick layer of ice.

This so-called "hard snowball" would lock the planet into an eternal winter, à la the Disney hit, "Frozen." The difference is that no magical spells exist to release a Snowball Earth from such a deep freeze.

Indeed, scientists have had a hard time explaining how a hard snowball could ever thaw. One proposal is that volcanic activity releases greenhouse gases that eventually warm the planet back up. The amount of carbon dioxide (CO2) needed might be several hundred times higher than what our atmosphere contains now. However, there is no geologic evidence to support that much CO2 in the Cryogenian atmosphere, Sohl says.

Another problem for the hard snowball theory is the lack of a massive extinction event in the Cryogenian fossil record. One would expect a major hit to the ocean ecosystem when it presumably got cut off from the Sun by a thick layer of ice, but only relatively small extinctions have been found.

A further complication is evidence of an ongoing water cycle during the Cryogenian. Such precipitation runs counter to the dry atmosphere that would likely develop if the oceans were all capped with ice.

"The suggestion that the Earth was once entirely covered by ice—the continents by thick ice sheets and the oceans by thick sea ice—remains somewhat contentious," says physicist Richard Peltier of the University of Toronto.

In response to these concerns, an alternative theory has developed that goes by the name "slushball." In this case, the Earth becomes largely covered with ice, but open water remains near the equator. Sohl says that many of her geologist colleagues lean toward the slushball scenario, as it seems to better match observations.

That is not to say that a hard snowball never happened. Extensive glaciation took place around 2.2 billion years ago, in the Paleoproterozoic era, and it seems plausible that global ice cover occurred then, Sohl says. Compared to the Cryogenian, the Paleoproterozoic sun was even fainter (down 16 percent in brightness from now). The timing of the glaciation also seems to coincide with the evolution of photosynthetic life, which would have drastically reduced greenhouse gases through the release of oxygen.

Tuning for the past

To give a better understanding of the contentious Cryogenian period, Sohl's team has been developing climate models that recreate the conditions on Earth nearly a billion years ago.

They start with the NASA/GISS Earth System Model (ModelE2-R), which has been used to make the most recent climate assessments by the Intergovernmental Panel on Climate Change (IPCC). But they turn the clock back on the simulation, altering the parameters to what they were in the past. For example, the Sun's brightness is dimmed by 6 percent and the continents are arranged into a single supercontinent near equator.

"You need this flexibility when studying past climate conditions," Sohl says. "We are probably using one of the most sophisticated models available for our paleoclimate runs."

Some previous attempts at simulating Earth's history have focused on explicitly trying to produce a hard snowball, but Sohl and her colleagues have preferred to let the climate model suggest what the outcome of their runs should be. They have found that ocean currents, like the present-day Gulf Stream, have a large impact on how and where heat from the Sun ends up distributed across the Earth's surface.

"For us, the ocean circulation seems to help in preventing a full freeze-over," Sohl says.

The team's early results show that the ocean retains areas of open water in the tropics, even when glaciers cover much of the land mass. The implication seems to be that the slushball picture is more likely than the hard snowball, at least as far as the Cryogenian period is concerned.

Sohl and her colleagues are now exploring other aspects that could play a role in past climates. For example, the day was shorter during the Cryogenian (21.9 hours instead of 24), and that likely affected the atmospheric dynamics.

Peltier, who is not involved in this work, believes one of the most outstanding issues remaining in Snowball Earth studies is the effect of the topography (i.e., altitude variations). Higher topography could enable glaciation even when other factors work against it, he says.

Other ice worlds

These are not the first climate simulations to show that freezing a planet is not so easy, but "the message hasn't really gotten to the astrobiologists" Sohl says. The astrobiology community tends to think of the hard snowball as the cold edge of habitability. They are often unaware how "slushy" that edge can be.

The traditional definition of planet habitability is the presence of liquid water. And for convenience, scientists often assume that the state of water is determined by the distance a planet is from its star. In which case, the "habitable zone" is the region around a star where liquid water should exist. A planet outside this habitable zone should be in permanent snowball territory.

But those who study climate know that an awful lot of factors go into freezing besides just the star-to-planet distance. Through her current project, Sohl hopes to elucidate some of these factors.

"In the end, I think we'll come to realize that the habitable zone is broader than we originally thought," she says.

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