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Better forecasts of sea-ice change? Melt puddles and melt models

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Several reasons make it essential to have good forecasts of future sea-ice* area in the Arctic. Arctic sea ice is linked to extreme weather events across Europe, America, and the far East, from intense droughts to "snowmaggedon" winters. Evidence suggests that changing sea ice will have repercussions on patterns of extreme weather over the coming decades. Ongoing sea-ice change will also determine the range over which Arctic animals thrive. Whilst a few species will benefit from future ice loss, like the orca, which is extending its range into the new open water areas in the Arctic, loss hurts other top predators, particularly the iconic polar bear. Ongoing sea-ice change will determine the range over which each Arctic animal thrives.

Over the last forty years, Arctic sea ice has declined rapidly (Fig. 1). This is a key part of the climate change picture. To predict how climate will evolve in the future, scientists use "global climate models": sophisticated computer models that can simulate conditions everywhere on the planet. These models mostly do a good job at representing the climate correctly. However, while there is variation between individual model results, most models don't quite predict the amount of sea-ice decline that we know is actually happening. This is a problem for politicians, scientists, and engineers, because it limits confidence in the forecasts from climate models.

Human actions over the coming years, particularly total carbon emissions, will make a real difference to the extent of these changes in the Arctic and beyond. However, we would also like to have more confidence in our climate model-based forecasts of sea-ice change to understand how our climate-related actions will affect Arctic sea ice. Recent model results suggest that if we continue to emit carbon dioxide at our current level, the Arctic Ocean could be free of sea ice during summer within twenty years – or as late as in eighty years. If we do not know when it will occur, it is difficult for Arctic communities and governments to plan for the consequences of a sea ice-free summer in future.

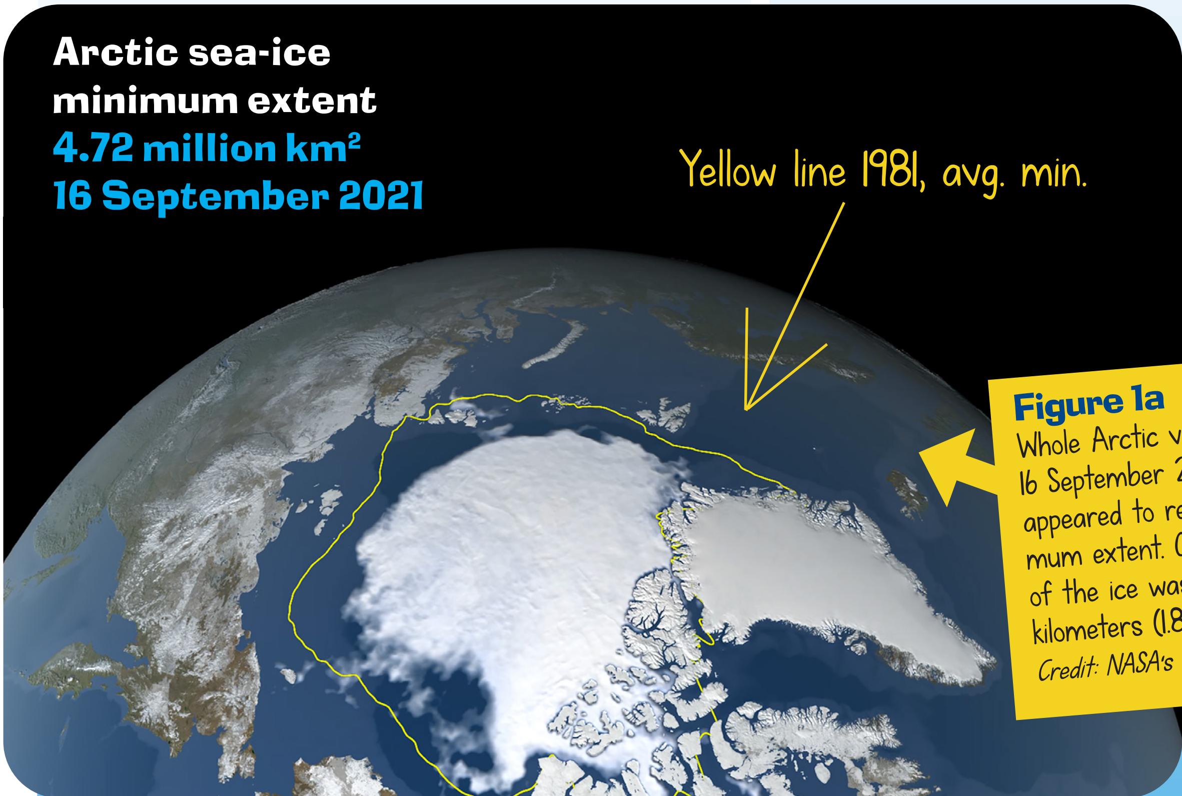


Figure 1a
Whole Arctic view of sea ice on 16 September 2021, when the ice appeared to reach its yearly minimum extent. On this date, the extent of the ice was 4.72 million square kilometers (1.82 million square miles).
Credit: NASA's Scientific Visualization Studio

This means that it is crucial for climate scientists to test the equations that shape the model calculations, by studying how well models represent past sea-ice changes when the climate was warm and sea ice was reduced.

To address this problem, we investigated the physics and causes of sea-ice change, concentrating on Arctic changes during the most recent warm past climate period: the Last Interglacial*- from 130,000 to 115,000 years ago. The Arctic was about 4°C (7°F) warmer than today during the Last Interglacial. This is known thanks to many valuable records of past air temperature, especially from pollen recovered from lake bottoms and peat cores. The focus on this warm period, and on how sea ice reacted, gives insight on how the Arctic will respond to future warming. It also allows us to check our climate models against measured Last Interglacial temperatures and sea-ice changes so we can find out if they do a good job of forecasting how sea ice changes during warm climates.

Ice cores are a great source to know about past climate conditions. One item of interest in Greenland ice cores is the ratio of water isotopes*: versions of water with more or less neutrons. It is easier for versions with less neutrons to evaporate from the open sea surface, and inversely. Depending on the sort of isotopes we find and in what quantity, we can estimate how close or how far the sea ice was from Greenland at different times during the past, and we can say with high certainty that the amount of sea ice in summer was much lower during the Last Interglacial than today.

The latest climate models reveal one of the key reasons there was so little Last Interglacial summer ice: puddles of melted ice. Today, in spring and early summer, shallow puddles of water form on the surface of the ice. These puddles, or "melt ponds", determine how much sunshine is absorbed by the ice and how much is reflected back into space (Fig. 2).

Figure 1b
Regional view of Arctic sea ice in early summer, with extensive melt ponds.
Credit: Don Perovich

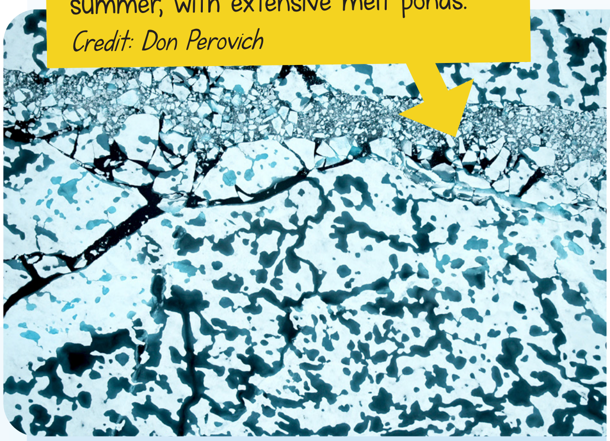


Figure 1c
Close up view of Arctic sea ice in early summer, with melt ponds.
Credit: Don Perovich

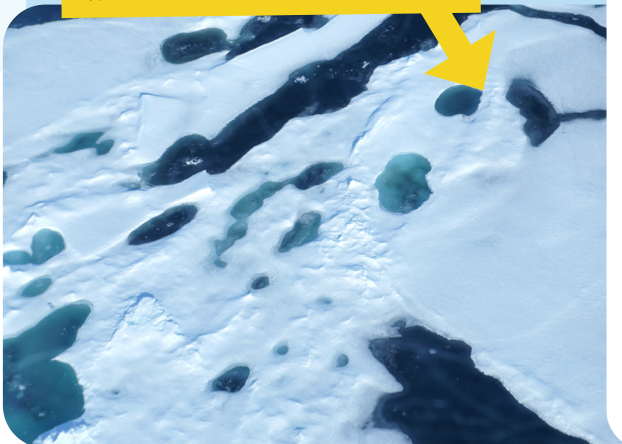
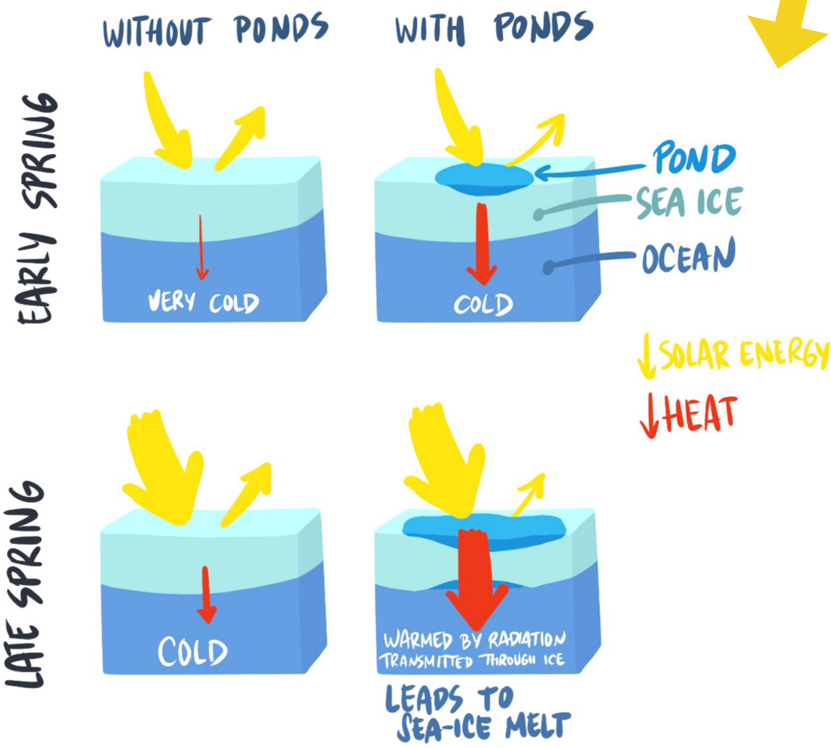


Figure 2
How melt ponds work: in early spring (April-May), most energy from the sun (gold arrow) is reflected by the reflective sea ice so very little heat (red arrow) is passed through to the sea. If a darker melt-pond forms on the ice, it absorbs heat that warms the surrounding sea ice and the sea below, melting more of the sea ice above and around. This kicks off a positive feedback process through the rest of spring and into the summer: now that the sea ice is thinner, solar warmth can pass more easily through the melt pond and into the sea ice and sea, so the sea ice thins even more, and so on.



During the Last Interglacial, there was much more intense springtime sunshine than now. This created many melt ponds, which absorbed a lot of this extra sunshine and completely melted the sea ice. This exposed the ocean surface, which absorbed even more sunshine and heated up, explaining how the Last Interglacial Arctic was 4°C (7°F) warmer in summer than today. Unlike older models, the UK's new weather and climate forecast model has melt ponds built in. And also unlike older models, this new model simulated a fully ice-free Last Interglacial Arctic in summer. We know we can likely trust this result because we found a very close match between the model's simulated temperatures, and those inferred from Last Interglacial summer pollen, which suggests the model represented well the most important Last Interglacial climate processes (Fig. 3).

This says two important things. Firstly, the Arctic was probably ice-free in summer. Secondly, we can use this new model to check how well climate models do during warm climates with little or no Arctic sea ice left.

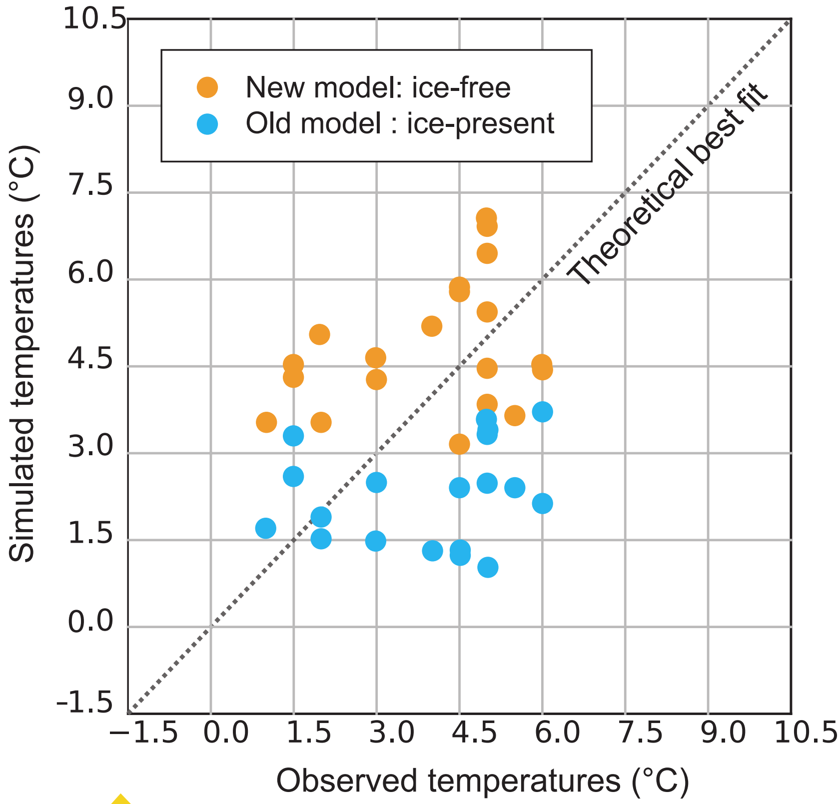


Figure 3
The temperature data from pollen and from the model match! The x- and y-axes represent the modeled and actual temperature increases that occurred during the Last Interglacial in degrees Celsius. There is a better correlation for the new model results, compared to the older model, and they are closer to the theoretical best fit line.

Studying sea ice during the Last Interglacial was technically and scientifically challenging. We continue to work on it to gain better insight into what happened and why. In particular, we want to understand whether other models – from all climate modeling groups around the world – show the same response to Last Interglacial changes. If they show a similar response, this tells us about the reliability of our models. Already, by uncovering this Arctic sea-ice change during this period, and crucially finding out why it became ice-free, we have helped politicians, scientists, and engineers have greater confidence in model forecasts of our future.

Related publications:

Diamond R et al. (2021) Cryosphere 15: 5099-5114

Guarino MV et al. (2020) Nat Clim Chang 10: 928-932

Malmierca Vallet I et al. (2018) Quat Sci Rev 198: 1-14