

THE ARCTIC: AN UPSIDE-DOWN OCEAN

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FRESHWATER

Water that has no salt in it. Rivers, rain, snow, and melted sea ice are the key sources of freshwater in the Arctic.

The Arctic Ocean is located at the North Pole, sometimes considered the top of the world. Yet this ocean has been called an “upside-down” ocean by famous oceanographer Fridtjof Nansen. Around most of the globe, the surface ocean is warmed by the sun and loses freshwater through evaporation, making it warmer and saltier than the waters below. In the Arctic, cold, fresh water lies above warmer, saltier water that comes from the Pacific and Atlantic Oceans. We explain why the Arctic Ocean waters are layered in this way, how climate change is affecting these layers, and why it matters to us all.

WHY THE ARCTIC OCEAN IS UPSIDE-DOWN

The oceans cover 70% of the globe and most of this water is found at latitudes where it receives sunshine all year around. All this sunshine warms the surface ocean and also drives evaporation which removes **freshwater** from the ocean’s surface, leaving behind the sea salts. This means that, in most oceans, we expect to find warm, salty water at the surface, while deeper water tends to be cooler and less salty. So, when the Norwegian explorer Fridtjof Nansen froze his ship *Fram*,

Figure 1

Map of the Arctic Ocean showing the drift of the Nansen's ship *Fram* during his expedition traced in yellow. Blue arrows show the major sources of cold, fresh water from Arctic rivers, while red arrows show the sources of warm, salty Atlantic water through the Fram Strait and Barents Sea opening. The drift track of the MOSAIC expedition aboard the *Polarstern* is shown in orange, note that the *Polarstern* left the ice pack for a crew changeover in June 2020 in Svalbard and will return to ice pack to continue the drift. Sea floor depth map courtesy of IBCAO [2].

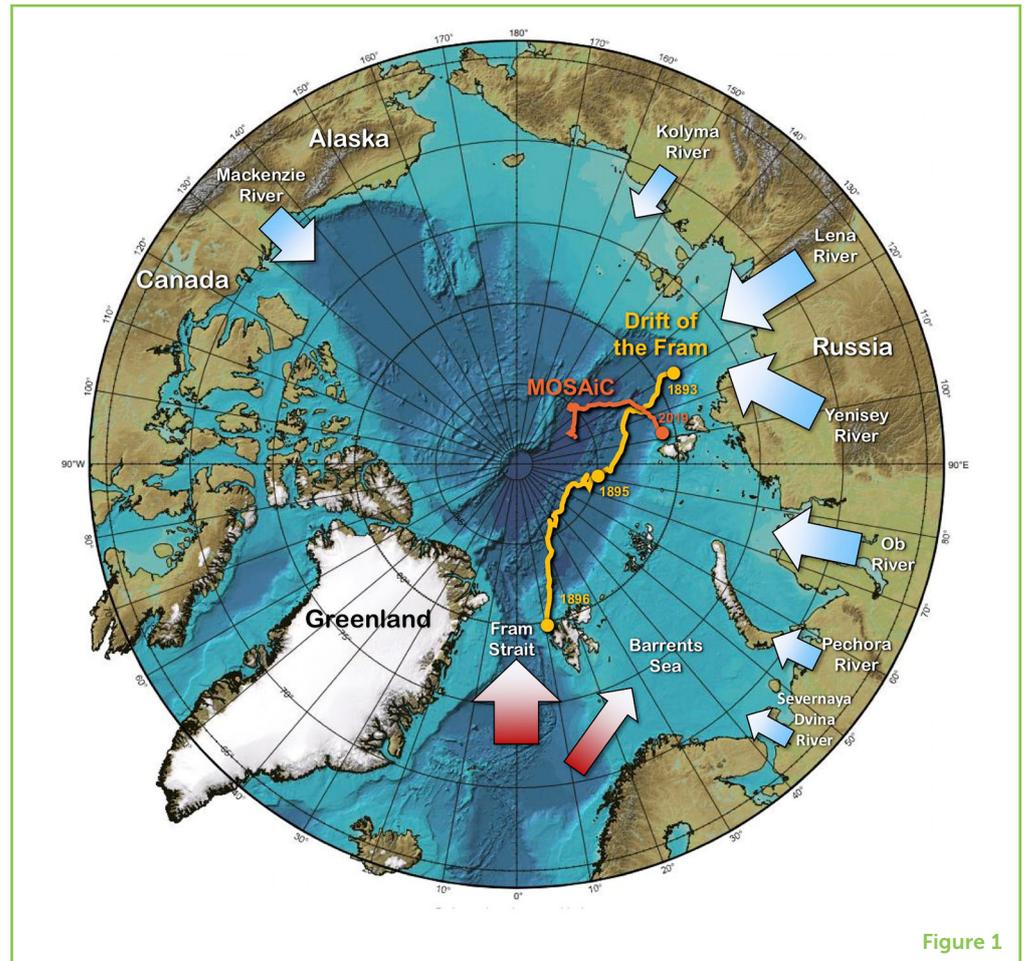


Figure 1

into the Arctic ice, in 1893–1896 (Figure 1) and found cold, fresh water at the surface with warmer, saltier water below, he described the Arctic as an “upside-down” ocean [1]. This early observation of the Arctic Ocean’s water structure has been confirmed by numerous oceanographers since Nansen’s discovery. Nansen knew that the Arctic Ocean was covered by sea ice, and that the direction the sea ice was drifting could carry his expedition from Siberia, across the North Pole, and back toward Norway. While they missed the Pole by only a few hundred kilometers, the expedition generated a wealth of new findings and provided important knowledge for modern-day Arctic Ocean science.

Since Nansen’s time, the Arctic has experienced climate change at twice the rate experienced by other areas of the earth, and the Arctic Ocean has lost a lot of old sea ice. Climate change in the Arctic does not only affect the sea ice. Warming temperatures also affect the water that lies below the ice surface. The MOSAIC expedition, which stands for Multidisciplinary Drifting Observatory for the Study of Arctic Climate, was launched in October 2019 and will hopefully provide some answers about how climate change is affecting the modern-day Arctic sea ice, the Arctic ocean, and the Arctic ecosystem. Today, in

¹ <https://follow.mosaic-expedition.org/>.

DENSITY

The ratio of a substance's mass to its volume. A cubic meter of dense water mass will be heavier than a cubic meter of less dense water. So density of water masses will determine which water mass is found at the surface and which is found at the bottom.

SALINITY

Concentration of salt in seawater. This is usually measured in grams per kilogram. So a salinity of 35 means that in a kilogram of seawater, there are 35 grams of salts.

HALOCLINE

Sub-surface layer of water partially formed through the mixing of the cold fresh Arctic surface waters above it, and the warmer saltier Atlantic or Pacific waters below it. Salinity increases steeply from the top to the bottom of the halocline.

BRINE

A solution of very salty water. Some canned fish comes stored in brine.

June 2020, the MOSAiC expedition is 7 months into its campaign to follow Nansen's intended path (Figure 1)¹ In the meantime, to understand how climate change might affect the Arctic Ocean, we must consider why there are layers of different water types (or water masses) in the Arctic Ocean and think about where they came from.

THE STRUCTURE OF THE ARCTIC OCEAN

The **density** of seawater depends on both its salt concentration, or **salinity**, and its temperature. As water temperature increases, the water expands and its density decreases, making it lighter. Dissolved salts add mass to the water and increase its density. In warmer waters, which make up most of the world's oceans, the temperature effect on density is more important than the salt effect. So, you will typically find warm water overlying colder water, regardless of the water's salinity.

In cold waters, such as those of the Arctic Ocean, the salt effect on density dominates over temperature. In the Arctic Ocean, you will find cold, fresh water at the surface. This freshwater comes from melting sea ice and from Arctic rivers that empty into the ocean (Figure 2). Below the very cold, fresh surface layer is saltier, denser, but warmer water that has come from the Pacific or Atlantic Oceans. When these warm, salty water masses mix with the cold, fresh surface layer above, they form an intermediate layer known as the Arctic **halocline** (Figure 2). This halocline layer acts as a barrier to heat transfer, preventing the warm, deep waters from melting the sea ice. Below the warmer, saltier water layer, the Arctic Ocean is filled with a slightly saltier, cold water mass, known as Arctic deep water.

WHERE DOES ARCTIC OCEAN WATER COME FROM?

Arctic rivers are the major source of freshwater flowing into the Arctic Ocean. There is so much freshwater run-off from Arctic rivers that the Arctic Ocean is the freshest of all the global ocean basins. Fresh river water is spread through the ocean by winds, tides, and ocean currents, with a lot of freshwater ending up piled at the surface in the middle of the Canada Basin. Some of the river water mixes with saltier seawater in the shallow coastal seas, gains density and ends up in the Arctic halocline, rather than at the ocean surface.

Another source of freshwater for the central Arctic basins is the very low salinity sea ice that drifts over from the shallow coastal seas where it is formed. When sea ice forms, ice crystals form from seawater and most of the salt is rejected as a dense **brine**. The dense brine sinks through the ocean water and eventually slips down the continental slope to fill the deep Arctic Ocean.

Figure 2

Measurements of water temperature and salinity in the upper 700 m of the Arctic Ocean, taken in October 2008 north of Siberia. The different layers of water are shown with alternating white and gray shading. You can see that the surface layer is very cold and fresh, while both temperature and salinity increase across the halocline below. Atlantic water is easy to spot as the warmest water layer (big bulge to the right) and bottom layer of Arctic deep water is cooler again, and marginally saltier.

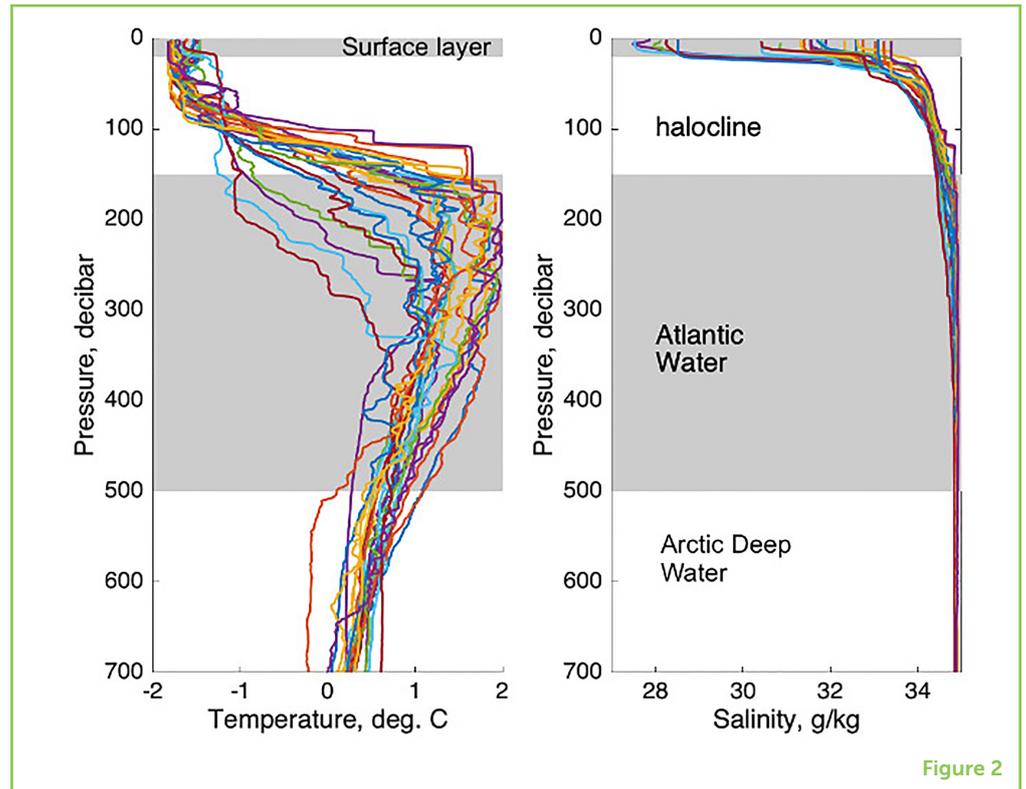


Figure 2

The warmest water in the Arctic comes from the Atlantic Ocean. Atlantic water enters the Arctic through Fram Strait, between Greenland and Svalbard, as well as through the Barents Sea Opening, between Svalbard and mainland Norway (Figure 1). Due to the rotation of the earth, Atlantic water moves to the right after leaving Fram Strait, and follows the continental slope around the Arctic in a counter-clockwise manner. When warm, salty Atlantic water first enters the Arctic Ocean through Fram Strait it is near the surface, but it rapidly sinks below the lighter, fresh, cold Arctic surface waters as it flows east. Slightly fresher warm Pacific water joins this counter-clockwise circulation when it enters the Arctic through the Bering Strait. The Pacific water settles just above the Atlantic water.

THE ARCTIC OCEAN INFLUENCES GLOBAL CLIMATE

As the Pacific and Atlantic waters circulate around the Arctic, they mix with the other Arctic water masses becoming cold and fresher, and lose more heat to the sea ice, and the atmosphere above. Water from the Arctic Ocean eventually exits the Arctic through the Canadian Archipelago, or as a deep, cold, fresh current in the western Fram Strait. In this way, the ocean carries solar energy absorbed as heat in the tropics and subtropics, to the Arctic where it acts as a heat source for northern hemisphere weather. Furthermore, the dense deep Arctic outflow water is replaced by the surface inflow of Atlantic and Pacific

Figure 3

Map of the Arctic Ocean showing the average area covered by summer sea ice in September 1980 (white) and September 2019 (blue). There has been a massive decline in summer sea-ice extent over the last 40 years (Image courtesy of the National Snow and Ice Data Centre, University of Colorado Boulder).

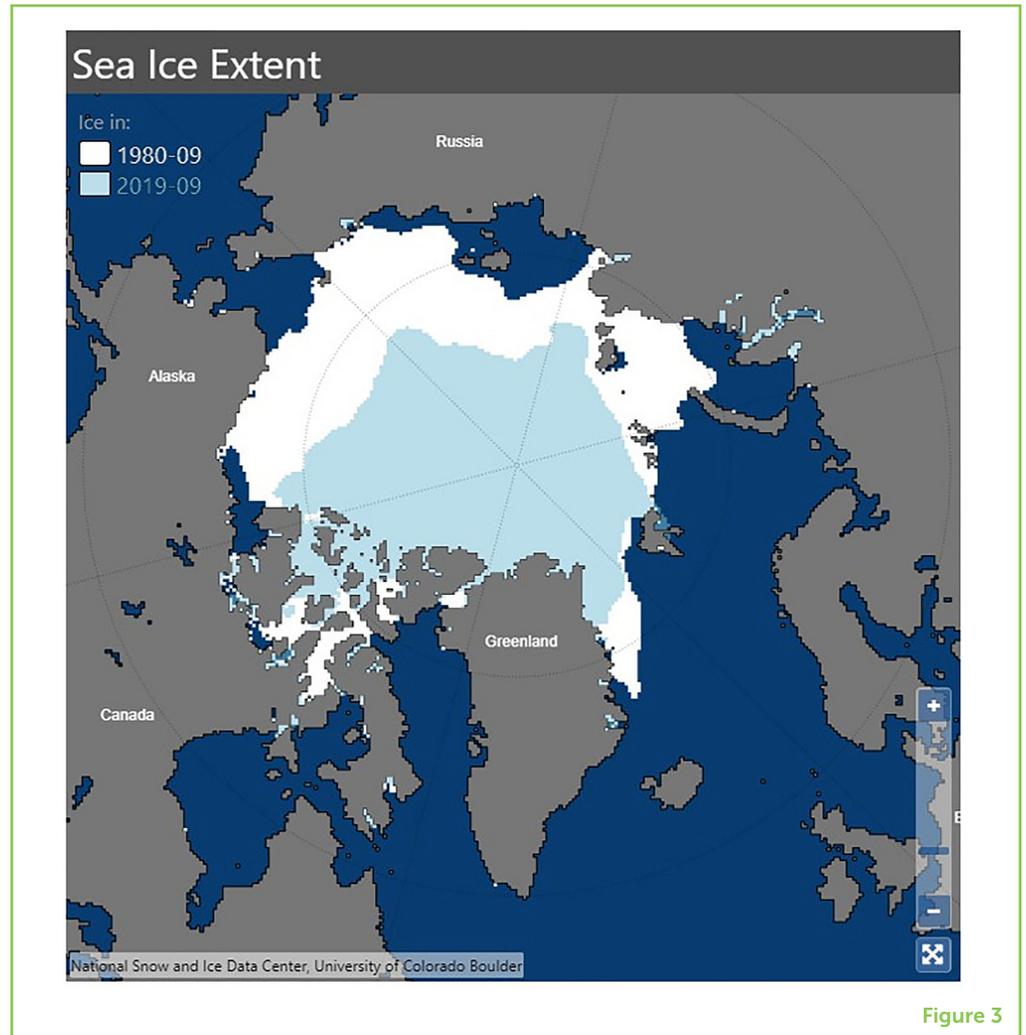


Figure 3

waters ensuring that this exchange between the tropics and polar latitudes continues like a giant conveyor belt.

CLIMATE CHANGE IMPACTS THE ARCTIC OCEAN, ITS ICE, AND ITS ECOSYSTEMS

MULTI-YEAR ICE

This is sea ice that has not melted during summer and has lasted for several years, getting thicker every winter.

Satellite measurements over the last few decades have shown that Arctic sea ice has experienced a steep decline (Figure 3) [3]. New sea ice forms every winter, but in recent years, the melt season has arrived earlier and lasted longer. This increased melt has shrunk the sea-ice coverage as measured in September which is the time of year with the least ice. As the extent of sea ice has decreased, the ice has also lost thickness, as the older, **multi-year ice** has melted or been blown out of the Arctic through Fram Strait.

Recent research shows us that there are multiple causes of sea-ice loss. Because ice is white, it reflects a lot more of the sun's energy back out into space, as compared with the darker, ice-free water, which absorbs solar energy. Therefore, as more water is exposed by sea-ice

melt, more heat is stored in the ocean. This extra stored heat then further melts the ice, creating a dangerous cycle of warming [4].

More open water also means greater areas over which the wind can mix up the different ocean layers. This mixing may allow more of the subsurface Atlantic/Pacific heat to reach the ocean surface. At the same time, the temperature of the inflowing Atlantic water has been rising, and the ocean is carrying more heat northward. In summary, there is more heat arriving in or absorbed by the Arctic Ocean, creating more opportunities to bring that heat in contact with the sea ice.

Disappearing sea ice results in larger areas of seawater, where the ocean and atmosphere can exchange heat and freshwater directly. Since the seawater temperature is typically warmer than the air, the ocean is an increasingly important source of heat for the atmosphere. Air temperatures near warm ocean waters have been seen to increase in response to rising ocean temperatures. Disappearing sea ice also means more light penetrates the ocean for longer periods, providing more energy for **photosynthesis** by sea-ice algae and tiny plant-like organisms called **phytoplankton**. Satellite measurements have seen increases in these organisms at the base of all Arctic Ocean food chains [5]. As ocean conditions change in the Arctic, we have also seen a change in the phytoplankton species living there, with an increase in smaller species that thrive in the nutrient-rich conditions caused by the mixing of Pacific and Atlantic waters with the Arctic water [6].

WHY DOES ALL OF THIS THIS MATTER?

From reading this article, you now know that the very cold temperatures and lots of freshwater make the Arctic Ocean an unusual upside-down ocean. These low temperatures mean that solar energy absorbed gained by the ocean in the tropics and carried north is lost in the Arctic, providing heat to the northern hemisphere climate. As the Arctic experiences global warming, the sea ice is melting and the numbers and types of organisms living in the Arctic Ocean may change impacting every part of the food web. Sea-ice loss is beginning to affect ice-dependent hunters, such as polar bears, seals, and walrus. Fish species from warmer waters are also migrating to the Arctic in increasing numbers, because the Arctic Ocean is warming up. Scientists should continue to study how the changes in the Arctic affect marine life and our global climate because these changes will impact many people far beyond the Arctic circle.

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PHOTOSYNTHESIS

A sunlight-powered chemical reaction between water and carbon dioxide that produces sugars and oxygen. This reaction is carried out by plants and plant-like organisms to make fuel to support life.

PHYTOPLANKTON

Tiny microscopic organisms that can photosynthesize like plants. There are many types of phytoplankton including some bacteria and some single-celled plant-like organisms, many of which can form shell-like exoskeletons.

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YOUNG REVIEWERS

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We are a group of enthusiastic Year 9 students that volunteered to review the paper because of our interest in science. We enjoyed learning about how science and the review process for scientific papers works from our Science Mentor, Dr. Chapman. We are: Aneura, Anya, Victoria, Izzy, Tanzeena, Daisy, Rowan, Martha, Charlotte, Imogen, and Naomi.



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AUTHORS



YUENG DJERN LENN

I am a scientist who studies how different layers of the ocean can move heat and salt around the planet, how these layers mix with each other in the polar oceans and where the energy for mixing comes from. I also teach oceanography at Bangor University in Wales, UK and enjoy hosting visiting schoolchildren who want to know more about the marine sciences. My own children (age 7 and 9) are sometimes forced to help me plan and practice new experiments and demonstrations for these visits. *y.lenn@bangor.ac.uk



BENJAMIN LINCOLN

I am a scientist at Bangor University who makes measurements in the ocean to understand how the wind and tides generate ocean currents, turbulence and mixing. I use these measurements answer questions, such as; What supplies nutrients for plankton and fish? How does deep warm water melt sea ice; How can we build reliable renewable energy devices in the ocean? To make these measurements I go to sea on large research vessels, such as icebreakers. If I am lucky there is 24 h daylight and amazing marine life, if I am unlucky it is, there is 24 h darkness and the ocean is a windblown sheet of ice.



MARKUS JANOUT

I am an oceanographer and work in a Polar Research Center in Germany to study the water masses and currents in the Arctic Ocean as well as in the ocean around Antarctica. I often join icebreaker expeditions to study how the polar oceans change and how this impacts the ecosystem and the animals that live on the sea ice and in the ocean beneath.