What is pack ice?

"Now we are in the very midst of what the prophets would have had us dread so much. The ice is pressing and packing round us with a noise like thunder. It is piling itself up into long walls, and heaps high enough to reach a good way up the fram's rigging; in fact, it is trying its utmost to grind the fram into powder."

This frightening description of the awesome power of the ice was written by the Norwegian Fridjof Nansen on Friday, October 13, 1893, as his robust ship, the *Fram*, became stuck in the Arctic pack ice. Together with 12 other adventurers, he was at the beginning of an epic three-year voyage to traverse the Arctic Ocean. During the journey they would be exposed to conditions that would test their seamanship and survival skills to the absolute limits. Nansen, arguably the greatest polar explorer, knew that there was nothing he or his crew could do to combat the extreme physical forces that dominate moving fields of pack ice. He recognized that their survival was down to the strength of their ship and having enough provisions to last the long frozen winter months.

Nansen's Fram expedition.

This can be taken as the point at which scientific investigations of pack ice opened up and understanding of its complexity, and its role in the functioning of the global environment, began to develop and useful practical information in navigation, fishing and climate forecasting was made available. Before this the 'civilized' world had mostly looked on pack ice as a nuisance, unpredictable, obstructive, unproductive and a potential destroyer and wrecker. But at the same time in the Arctic but not in the Antarctic, there was a race of people, Eskimos or, more properly, Inuit, who had knowledge and deep understanding of pack ice. They had lived with it, travelled on it and hunted their food from it for thousands of years. Mostly these people with their natural wisdom were ignored until comparatively recently.

Even with all the developments in shipbuilding that have produced immensely strong metal-hulled ice-breaking ships crammed full of the latest satellite-based navigation aids, pack ice just a few centimeters thick can hinder modern day seafarers just as much as the early polar explorers in their wooden vessels. The pack-ice regions of the world are hostile, and only inhabited by man at the very fringes of their extent. They are places of extreme low temperatures, darkness for long periods of the year and severe winds.

Most people's first impression of the Antarctic pack ice is actually one of extreme beauty. The tranquility they feel is a complete contrast to the buffeting ocean that had been their lot as their ship travelled many days from either the African continent or the South American continent to the Southern Ocean. But a closer inspection of the huge ice floes, up to several meters thick, effortlessly moving on the ocean surface, rafting on top of each other and forming massive ridges of ice blocks twice the height of man is a humbling experience that inspires a healthy caution. The pack ice is not a silent place, and when a ship slowly negotiates a passage between ice floes there is a constant creaking and grinding of ice, almost a haunting groaning that emphasizes the alien nature of the frozen landscape.

Icebergs are not pack ice

Pack ice is mostly frozen seawater. In simple terms, the surface of the ocean is cooled down and ice crystals form. These crystals rise to the surface and coalesce to form a frozen layer on the surface of the water. This layer can become thicker, break open and refreeze. Slabs of ice can raft on top of each other and deform, as in Nansen's description. Ice formed from seawater, or sea ice, therefore varies from loose aggregations of ice crystals through to structures that are tens of meters thick.

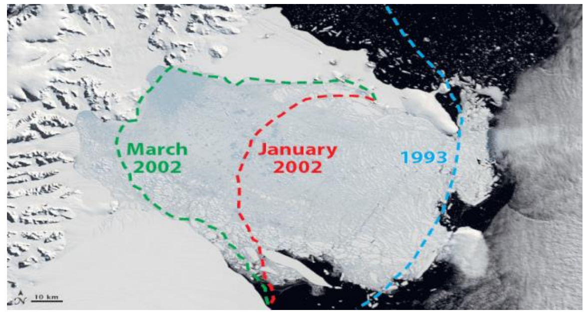
However, when most people think of the polar oceans and seas they picture huge floating icebergs that have broken off from coastal glaciers or ice shelves. There is no doubt that icebergs are a distinctive feature of many pack-ice regions, but they are produced from outside of the pack ice, and are only a small part of a much larger frozen seawater system. Icebergs are not made in the sea, but are large chunks of freshwater ice that have been built up over thousands of years by the gradual freezing of snow and ice on glaciers covering land.

Icebergs are sculpted into spectacular shapes as they gradually melt in the open ocean.

Nevertheless, one of the most striking sights for anyone who ventures into polar waters is the wonderful array of iceberg shapes. Wind and wave action combine to create bizarre forms, from cathedral-like spires and pinnacles, to caverns and other improbable structures. Icebergs also come in a spectacular range of colors, from the familiar blues and whites through to dark green and even black.

Ice shelves and glaciers

Many of the 'ice stories' that hit the news headlines are in fact talking about icebergs and the breaking up of ice shelves (the thick plates of ice, fed by glaciers, that float on the ocean around much of the Antarctic continent.) One of the most dramatic ice-shelf events in recent years was the collapse and breakup of the Larsen B ice shelf on the eastern side of the Antarctic Peninsula in 2002. Within just over a month 1255 square miles (3250 km squared) of the shelf broke off from the continent and disintegrated into thousands of icebergs that drifted off into the Weddell Sea. The shelf was estimated to be in the order of 12,000 years old, and was 722 feet (220 m) thick in places. The amount of ice released in this short time was in the order of 720 billion tons. The largest iceberg to calve in recent years was iceberg B-15, which calved from the Ross Ice Shelf in 2000. It was a massive 183 miles (295 km) long and up to 16 miles (25 km) wide, a total area of 4247 square miles (11,000 km squared). Since 1974 it is estimated that seven ice shelves around the Antarctic Peninsula have shrunk by a total of about 5212 square miles (13,500 km squared).



During the period January to March 2002, the Larsen B ice shelf broke up into thousands of smaller icebergs. The extent of the shelf in 2002 was already very much less than in 1993.

Icebergs are not just a feature of the Antarctic, although there are far fewer icebergs in the Arctic because of the less extensive ice shelves and large glaciers. Most of the icebergs in the north Atlantic come from about 100 iceberg producing glaciers along the coast of Greenland, while a few originate in the eastern Canadian Arctic islands. The Jakobshavn glacier on the western shore of Greenland, which flows up to 66 feet (20 m) per day, produces 10% of the Greenland icebergs (approximately 1350 annually). The annual yield of icebergs in the Arctic is estimated to be up to 40,000 medium to large icebergs, although only 1-2% or so of these are of sufficient size to reach the open ocean intact.

What happens to icebergs?

Once in the ocean the fate of the iceberg depends on many factors. In shallow waters icebergs can ground on the seabed, sometimes for several years. Collections of grounded icebergs can reach such numbers that they are known as iceberg graveyards. Some 90% of an iceberg is actually under the water line, and this mass of ice forms a huge keel that is caught by surface currents. The upper part of a berg, which can tower to over 328 feet (100 m), 'catches' the wind very effectively and the passage of an iceberg is therefore determined by a combination of winds, waves and currents. Bergs can move anywhere up to 3 feet (1 m) per second and are estimated to travel up to 25 miles (40 km) per day. It is intriguing that pack ice may drift in one direction, propelled by the wind, whereas icebergs may move in a quite different direction propelled by deep water currents.

In shallow coastal areas iceberg graveyards can form when icebergs become stuck on the seabed below, sometimes for many years.

In fact, oceanographers track icebergs by satellite to gain valuable information about the movement of surface waters. Some of the biggest bergs, with areas of several thousand square miles, last for many years before eventually melting, and are therefore very useful tools for measuring long-term trends in the movement of the surface waters. Iceberg B-9, which broke free from the Ross Ice Shelf in 1987, split into two smaller icebergs, B-9A and B-9B, which were still being tracked half-way round the Antarctic continent 13 years later.

As icebergs melt they may calve off smaller bergs, eventually disintegrating into even smaller bergs. Categories of iceberg sizes range from very large (greater than 10 million tons and hundreds of square miles in surface area) to large, medium, and small bergs. Then there are 'bergy bits' and 'growlers,' which are the size of a grand piano. The rate of melting depends on the water temperatures and the amount of wave action; a berg in water around 32°F (0°C) may deteriorate at a rate 10% slower than the same berg in 50°F (10°C) waters.

Eventually icebergs disintegrate to form ever-increasing lumps of ice.

In Arctic waters icebergs can prove a hazard to the offshore drilling platforms, and there are programs to monitor iceberg production and trajectories b various groups including coastguard agencies. In certain circumstances the towing of icebergs to deflect them from their path is the only course of action remaining to protect offshore structures.

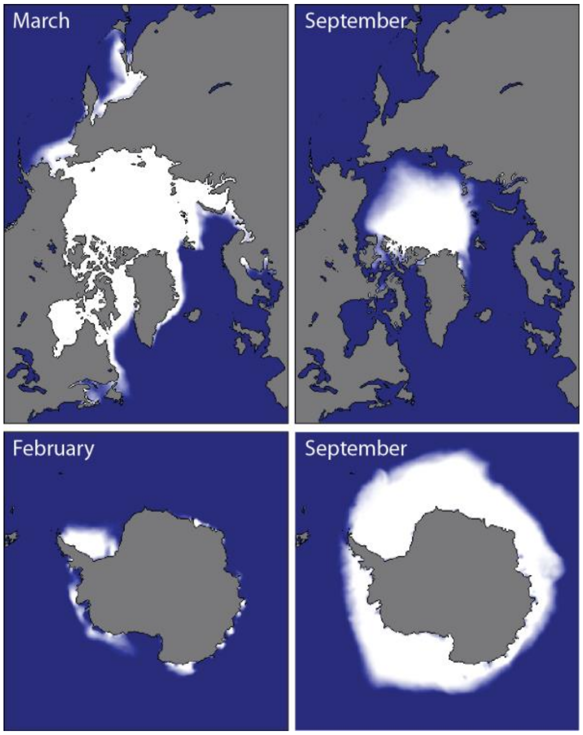
Icebergs in the pack ice and as a freshwater source

The massive icebergs clearly also affect the distribution patterns of the pack ice, sometimes on a massive scale of many hundreds of square miles. Over a 10-year period a massive floating glacier, the Ninnis glacier tongue in east Antarctica, had gradually broken up to produce hundreds of icebergs, the largest of which had a surface area of around 309 square miles (800 km squared). Bergs such as these, especially if grounded, affect the strength and direction of ocean and pack-ice flow, forming a huge physical barrier akin to an island. The breakup of the Ninnis glacier and the numerous icebergs it had produced over a 10-year period was closely monitored by sea-ice researchers using satellite monitoring techniques. They reported clear links between profound changes in average sea-ice thickness, density, and distribution with the numbers and movements of these icebergs.

Since icebergs are made of freshwater several schemes have suggested towing icebergs to warmer climes to use the meltwater as a freshwater source. This is not as far-fetched as it may at first seem. There is colossal water reserves locked up in the polar icecaps, and the water contained within the icebergs could go a long way to combating the severe water shortages that many people in the world suffer. The largest northern hemisphere iceberg on record was encountered near Baffin Island in 1882, with an estimated mass in excess of 9 billion tons of water. The Antarctic icebergs contain orders of magnitude more; the Ross Sea icebergs B-9 and B-15 are estimated to contain trillions of tons of water each. At time of writing the population of the world is around 7 billion. Therefore just one of these giant icebergs would be enough to meet the whole of the world's water needs for a considerable time. It seems that in the future, ideas for harnessing the freshwater source will increase. On a much smaller scale, ice from icebergs in Newfoundland is collected for both bottled water and vodka production.

Sea ice is just frozen water, isn't it?

Despite the colossal amounts of water contained within floating icebergs, the numbers pale into insignificance compared to the huge areas covered by frozen seawater, the pack ice. In the Southern Ocean alone, up to 8 million square miles (20 million km squared) are covered by sea ice. This is an area as big as North America and Canada combined. The estimated average thickness is around 3 feet (1 km), and so there are approximately 4800 cubic miles (20,000 cubic km) of sea ice. To put this in perspective, a household chest freezer has a volume of approximately 9 cubic feet (0.25 cubic m). The total world human population is around 7 billion, and so to contain all of the Antarctic sea ice, each person on Earth would need roughly 12,000 chest freezers.



Top row shows Arctic sea ice at the end of a northern hemisphere winter (left) and at the end of summer (right). Bottom row shows Antarctic sea ice at the end of a southern hemisphere summer (left) and at the end of winter (right).

Of all of the ice presently on the Earth's landmasses (most of it lying over the Antarctic continent) melted, the sea level would rise by about 262 feet (80 m), flooding huge areas of coastal regions. Since sea ice is less dense than seawater, when it floats on the ocean surface it displaces only its own weight of seawater, so if all the sea ice melted the meltwater would simply replace the volume preciously occupies by the ice. That is why there are no sea-level changes with the annual formation and melting of the millions of square miles of sea ice each year.

Pack ice has many names

Frozen seawater at first may be considered to be simply ice. However, it is not quite so easy, and even a cursory glance into the literature dealing with sea ice turns up a bewildering collection of ice-terms: frazil ice, slush ice, rafted ice, columnar ice, granular ice, grease ice, ice floe, porridge ice, bottom ice, infiltration ice, nilas ice, ice ridges, pancake ice, consolidated ice, pack ice, fast ice, multiyear ice, rotten ice, brown ice, anchor ice, platelet ice, ice brine, ice flowers, snow ice, superimposed ice, grey ice, black ice, white ice… to name just a few.

This collection of names pales into insignificance when compared to the range of words the Inuit have to describe the state of sea ice. Studies of the Inuit knowledge of sea ice reveal a profound understanding of the relationships between ice, water currents, tides, and winds. This understanding is reflected in a rich vocabulary to describe ice-related features. In studies conducted by the Hudson Bay Program, Inuit and Cree communities had over 80 terms relating to sea ice. Inuit hunters often link astronomical and biological observations to their own experience to exploit moving ice fields. For example, Inuit hunters have been known to predict a wind to tide change of observing mammals: in the spring a reduction in the numbers of basking seals indicates that the water is no longer freezing, since the seals will stop going onto moving ice when the thinning ice cannot support their weight.

The Inuit of Iglooik in Nanuvut, in the eastern Canadian Arctic, have an extensive ice vocabulary. For example, *ivuniraarjuruluk* is an outstanding ice formation that is used for navigation and to obtain freshwater; *uiguaq* is a thin layer of newly-formed ice that attaches to the edge of an ice floe; and *ukkuartinniq* is a strip of ice that runs from the moving ice to the edge of land-fast ice. The links between animals and ice are also intriguing: *sikutuqqijuq* is floating young ice where walrus are usually found, or the verb *tijjatuliqiyug* describes hunting walrus from the solid ice. There are, of course, many hunting terms such as *mauliq* or hunting seals through snow-covered breathing holes. Even the noise of sea ice is used by some Inuit to describe ice, such as *ivaluktaktok*, a word describing the noise of piling ice.

Sea ice that isn't pack ice

Ice attached to the land is referred to as land-fast ice, or frequently just fast ice.

Some frozen seawater is attached to the land, floating ice shelves, or even large icebergs. The land-fast ice is not subject to the same processes as the pack ice, which is free floating and moved by wind and water currents. Land-fast ice is virtually a static structure, so the development and form of the two types of ice are quite different. This study is mostly concerned with pack ice, although as far as the frozen oceans are concerned, land-fast ice is of great consequence. Therefore, throughout this study mention will be made of land-fast ice and, where pertinent, the differences between land-fast ice and pack ice highlighted.

Land-fast ice is important as a transition between the land and the open ocean pack ice, since its relative stability is a refuge for migrating, hunting, and breeding mammals, and even humans who may travel on it. It is also difficult to separate the two types of ice, since land-fast ice can break from its anchor point and drift away to form an integral part of the pack ice. Often land-fast ice is cracked and deformed by the tidal rise and fall of the underlying water. This can result in tidal cracks within the ice that are important regular openings for marine mammals and birds.