Arctic Ocean

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The Arctic Ocean is the smallest of the Earth's four major oceans (the Pacific, Atlantic, Indian, and Arctic), covering 14×10^6 km^2 located entirely within the Arctic Circle (66° 33′N). It is a major player in the climate of the north polar region, has a variable sea ice cover, and is home to a multitude of plant and animal species. Its temperature, salinity, and ice cover have all undergone changes in the past several decades, although it is uncertain whether these predominantly reflect long-term trends, oscillations within the system, or natural variability.

The Arctic Ocean is surrounded largely by the land masses of Eurasia, Greenland, and North America (Figure 1). Its principal connection to the rest of the Earth's oceans lies between Greenland and Scandinavia, where it connects to the North Atlantic. Smaller connections include the narrow (85 km wide) Bering Strait, linking it to the North Pacific, and the passageways within the Canadian Archipelago and between the Archipelago and Greenland, leading to Baffin Bay and thence to Davis Strait and the North Atlantic.

The Arctic Ocean has an unusually broad and shallow continental shelf on the Eurasian side, extending more than 1000 km northward from Scandinavia and approximately 800 km northward from Siberia. The deeper portion of the Arctic is divided by the Lomonosov Ridge into two main basins, the Canadian Basin and the smaller and deeper Eurasian Basin, which has a maximum depth exceeding 5000 m.

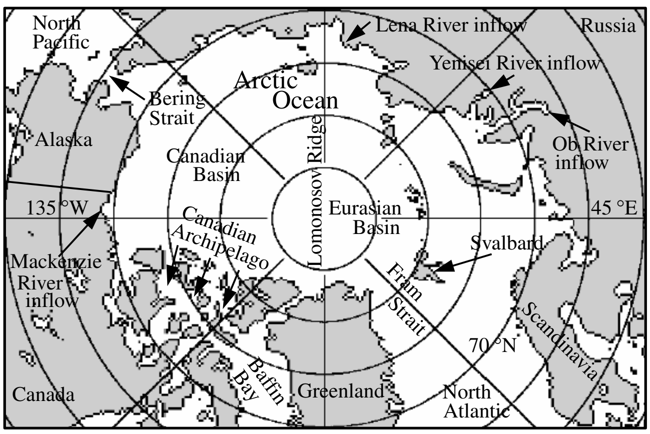

Figure 1 The Arctic Ocean and its surroundings

Water flows into the Arctic principally from the Atlantic as a warm, salty undercurrent. There are also smaller oceanic inputs through the Bering Strait and cold, freshwater inputs from many rivers, most significantly the Lena, Yenisei, and Ob rivers in Russia and the Mackenzie River in Canada. A large part of the outflow from the Arctic is through the Fram Strait between Greenland and Svalbard. Surface currents in the Arctic tend to be clockwise in the Canadian Basin, with occasional reversals to this flow, and more linear along the Transpolar Drift Stream flowing from north of Russia, across the Eurasian Basin and the vicinity of the North Pole, and out through Fram Strait (*see* **Ocean Circulation**, Volume 1).

The water inflows and outflows play a major role in the temperature and salinity structure of the Arctic (*see* **Salinity Patterns in the Ocean**, Volume 1). The warm, salty Atlantic layer from the Atlantic inflows is most prominent closest to the entrance regions but is also apparent throughout the Arctic at depths exceeding 200 m. Overlying the Atlantic layer, the Arctic surface water, in contact with the cold Arctic atmosphere and subject to the freshwater inputs from the surrounding rivers, is colder and less saline. The upper 30–50 m of the surface water tends to be fairly well mixed vertically, with temperatures near the freezing point and salinities ranging from highs exceeding 34 parts per thousand (ppt) near the North Atlantic to lows below 29 ppt near river inflows. Surface salinities in the Bering Strait are approximately 31 ppt. Vertically, salinities tend to increase with depth from the bottom of the mixed layer down to the Atlantic layer, with this vertical variation forming a prominent halocline, especially in the Eurasian Basin. The resulting stable density stratification hinders the warm Atlantic layer waters from upwelling to the surface.

Importantly, the Arctic Ocean is largely capped by a thin, broken layer of sea ice, generally less than 6 m thick and covered by snow (*see* **Sea Ice**, Volume 1). The sea ice restricts exchanges of heat, mass, and momentum between the ocean and the overlying atmosphere and, due to its high reflectivity, also tremendously restricts the input of solar radiation to the ocean. Ice covers almost all of the Arctic Ocean in winter, to an ice concentration (percent areal coverage) of at least 90%, and most of the Arctic Ocean in summer. Sea ice is considerably less saline than the ocean water from which it forms and tends to decrease in salinity over time, as more of the salt content is washed downward through the ice during periods of summer melt.

The Arctic ice cover is in constant flux, being melted by solar radiation, augmented by additional freezing, and moved by winds, waves, and currents. As ice floes separate, openings appear, called *leads* when linear and *polynyas* when large and non-linear. In contrast, when the forces acting on the ice result in floes colliding forcefully together, the ice breaks and piles of ice rubble form. The above-water portions of these are called *ridges*, and the more massive underwater portions are called *keels*. A ridge/keel combination can have an ice thickness of 30 m or more, far exceeding the level-ice thickness.

Despite the cold temperatures, the Arctic is home to a host of plant and animal life, including algae colonizing the sea ice, sometimes at a concentration of millions in a single ice floe, and protozoans, crustaceans, and nematodes, most of which are smaller than 1 mm in length, also living in the ice and feasting upon the algae. Although biomass tends to be low under the permanent ice pack, high phytoplankton and zooplankton concentrations are frequently found in the ice-free waters. The resulting availability of food makes the ice-free waters popular for numerous species of birds and marine mammals. Amongst the larger animals, polar bears and Arctic foxes roam over the ice, and seals, walruses, and whales live in the ocean waters.

The Arctic has received considerable attention during the late 20th century and the start of the 21st century because of various changes reported to be occurring in it and the sense that these could be related to a possible global warming. Among the changes are the following:

1. A warming and spatial expansion of the Atlantic layer, at depths of 200–900 m, determined from ship-based conductivity–temperature–density (CTD) measurements in the 1990s versus data from 1950–1989 (Morison *et al.*, 2000; Serreze *et al.*, 2000).
2. A warming of the upper ocean in the Arctic's Beaufort Sea (north of Alaska) from 1975 to 1997, found from *in situ* measurements (McPhee *et al.*, 1998).
3. A considerable thinning, perhaps as high as 40%, of the Arctic sea ice cover in the second half of the 20th century, found from submarine data (Rothrock *et al.*, 1999).
4. A lesser and uneven retreat of the ice cover, averaging approximately 3% per decade between late 1978 and the end of 1996, found from satellite data (Bjørgo *et al.*, 1997; Parkinson *et al.*, 1999), and a related shortening of the length of the sea ice season throughout much of the region of the Arctic Ocean's seasonal sea ice cover, also found from satellite data (Parkinson, 2000).
5. An increase of 5.3 days per decade in the length of the melt season on the perennial ice cover, found from satellite data for 1979–1996 (Smith, 1998).
6. A decrease in the salinity of the upper 30 m of the central Beaufort Sea from 1975 to 1997, found from *in situ* measurements. This freshening of the water has been attributed largely to sea ice melt (McPhee *et al.*, 1998) and to increased runoff from the Mackenzie River (Macdonald *et al.*, 1999).
7. A mixed pattern of salinity increases and decreases through the expanse and depth of the rest of the Arctic Ocean (Morison *et al.*, 2000). This includes an increase in the salinity of the surface waters in the mid-Eurasian Basin during the 1990s, found from submarine data, and a thinning of the halocline separating the surface from the warm Atlantic layer waters (Steele and Boyd, 1998; Morison *et al.*, 2000).

In view of the highly coupled nature of the Arctic climate system, many of the changes occurring within it are likely connected. In particular, the freshening of the upper ocean in the Beaufort Sea is likely a response in part to the thinning of the ice, as ice melt adds freshwater to the upper ocean which consistently is much less saline than the ocean average. Similarly, the reduction in the sea ice cover and warming of the upper ocean are probably both connected to the Arctic surface air temperature increases reported, for instance, by Serreze *et al.* (2000).

The causes of the late-20th century changes in the Arctic system remain uncertain, although it is likely that several factors are involved. The increase in carbon dioxide and other greenhouse gases in the global atmosphere, is believed to cause atmospheric warming, although some human influences, such as the increase in particulate matter in the atmosphere, tend to offset a portion of the warming (*see* **Arctic Climate**, Volume 1). Atmospheric warming contributes to oceanic warming, sea ice melt, and upper ocean freshening, all observed in recent decades in portions of the Arctic.

Other potential influences, however, are more oscillatory in nature, such as the impacts of the North Atlantic Oscillation (NAO) and the Arctic Oscillation (AO), two major decadal-scale oscillations in atmospheric pressure patterns, or the impacts of El Niño/La Niña cycles. The NAO and AO in particular have received attention because many of the patterns of change in the ocean and ice cover of the Arctic can be explained by changes in the NAO and AO in recent decades (e.g., Parkinson *et al.*, 1999; Morison *et al.*, 2000). It remains uncertain, however, whether the changes in the NAO and AO are exclusively natural fluctuations in the climate system or are related to long-term, perhaps anthropogenically induced climate change (*see* **Arctic Oscillation**, Volume 1; **El Niño**, Volume 1; **North Atlantic Oscillation**, Volume 1).

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