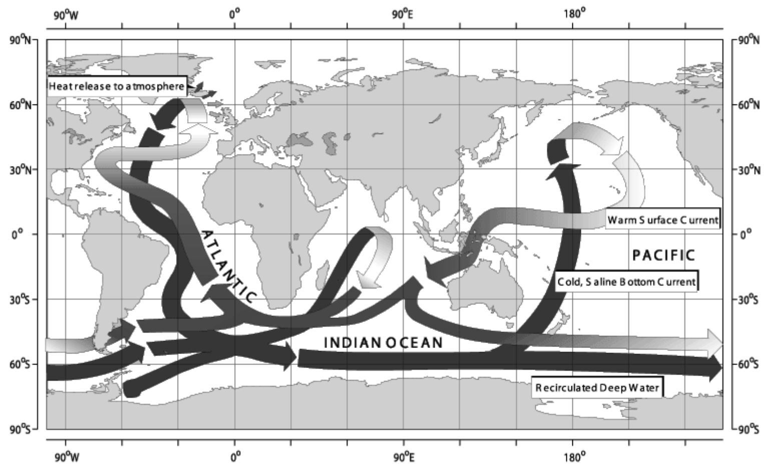

Figure 1: The thermohaline circulation. Data from *clivar.org*.

1 Origin of the oceans

Cometary water may have contributed as much as 50% of the Earth's water (Javoy, 2005).

The distribution of rare gasses favours the idea of direct participation of comets, mixed with mantle-outgassed water, which is poor in deuterium.

Terrestial water has a D/H ratio of $D/H \sim 1.56 \cdot 10^{-4}$, while comets have values about $2\times$ that, $D/H \sim 3 \cdot 10^{-4}$.

These two sources were homogenized by outgassing and mantle recycling in the first 100 Myr. The solar system formed 4 566$\cdot 10^6$ a ago, and the Earth's was about 95% completed in the first 30$\cdot 10^6$ a (Javoy, 2005).

2 Ocean Circulation

The thermohaline circulation, Figure 1, brings warm ocean to northern lattitudes. The temperature in the northern hemisphere is about 10°C warmer due to ocean water heat transport (Rahmstorf, 2002).

Since the last glacial maximum (LGM), 30 ka to 19 ka ago, about 50 million km^3 has melted from land based ice sheets, raising the sea level by $\sim$ 130 m (Lambeck and others, 2002).

3 Sea Ice

Polar sea ice is one of the most variable features of the Earth's climate, changing considerably from summer to winter and from one year to another. At any given time, global sea ice covers

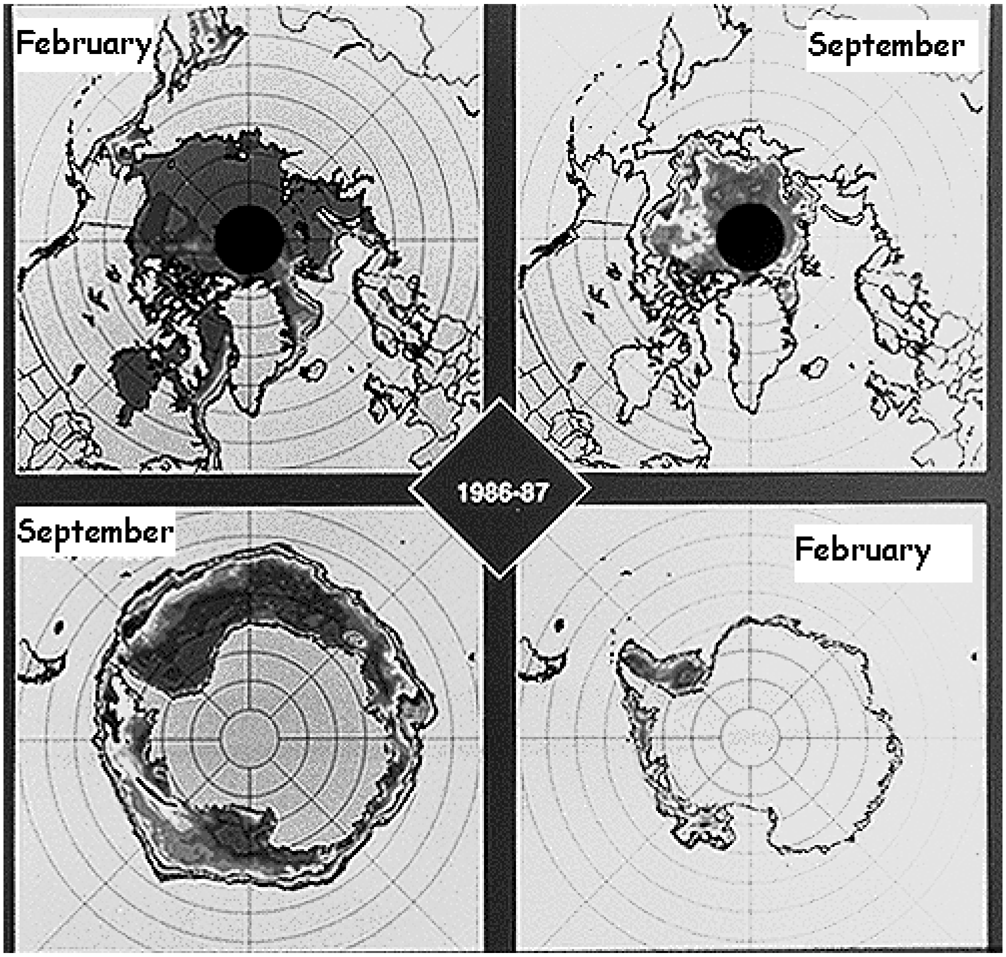

Figure 2: These four images constructed using data from the Scanning Multichannel Microwave Radiometer (SMMR) on the Nimbus-7 satellite show the amount of polar sea-ice coverage for September 1986 and February 1987.

an area approximately the size of the North American continent. Sea ice cover is one of the largest unknowns in predictions of future climate (Laxon and others, 2003).

The top two images of Figure 2 show the Arctic ice cover and the bottom two images are of Antarctic ice cover. Late in the Arctic summer (September), sea-ice coverage is at a minimum-approximately 9 million square kilometers in 1986. In the Arctic winter (February) sea-ice coverage reaches a maximum about 15 million square kilometers in 1987. By comparison, the area of the continental United States is 9.5 million square kilometers, while Canada's area is 10 million square kilometers.

The third and fourth images, for the Antarctic region, show a much greater difference in sea-ice coverage between summer and winter. In the late winter/early spring (September in the southern hemisphere), sea ice covered 19 million square kilometers in 1986. In the summer (February), however, Antarctic sea-ice cover shrank to only 4 million square kilometers. A comparison of the areas surrounding each pole reveals the reasons for these differences.

The area at the Arctic pole is ocean, bounded by the continents of the Northern Hemisphere. The continental boundaries, therefore, limit the extent to which sea ice can grow during the cold months. In contrast, sea ice in the southern hemisphere has no "land boundaries" to the north to limit the winter's sea-ice growth.

In the summer, geography again plays a role in sea-ice coverage. At both poles, the coldest region is directly over the pole. In the Arctic, the coldest region is covered by water. Arctic sea ice thus shrinks less in summer because it lies in an area that stays very cold.

The continent of Antarctica, on the other hand, covers the Earth's south pole. Sea ice extends from the coast of the continent, which is further away from the extreme cold of the pole. The sea ice therefore lies in a relatively warm climate, causing greater melting during the warm summer months.

Future plans for studying the dynamics of sea-ice coverage include the use of data from the Special Sensor Microwave/Imager (SSM/I), currently on board Defense Meteorological Satellite Program (DMSP) satellites, and data from the European Space Agency's Multifrequency Imaging Microwave Radiometer (MIMR), scheduled for flight on the EOS satellites.

Surface and satellite-based observations show a decrease in Northern Hemisphere sea ice extent during the past 46 years (Vinnikov and others, 1999).

Sea Ice Formation

The maximum density of pure water is at $T = 4°\text{C}$, and the freezing temperature $T_{sl} = 0°\text{C}$. Salinity lowers the freezing temperature, and the temperature of maximum density even more (Figure 3).

Figure 4 shows an example of salt-water with a salinity of 2%, at an initial temperature of $T_0 = 1°\text{C}$. The air temperature is $T = -2°\text{C}$, and the maximum density is at $T_\rho = -0.3°\text{C}$. The whole column will thus cool down to T_ρ, and after that only the top layer will cool; there sea ice can form.

If the salinity is greater than 2.47% the temperature of maximum density T_ρ is greater than the freezing temperature T_{sl}. In such cases sea ice will only form after long periods of very cold weather.

Sea ice does though form, and the reason is that the ocean is strongly layered (Sigtryggsson and Stefánsson, 1969). That results in vertical mixing being limited to the uppermost layer, above the *halocline*, see Figure 5.

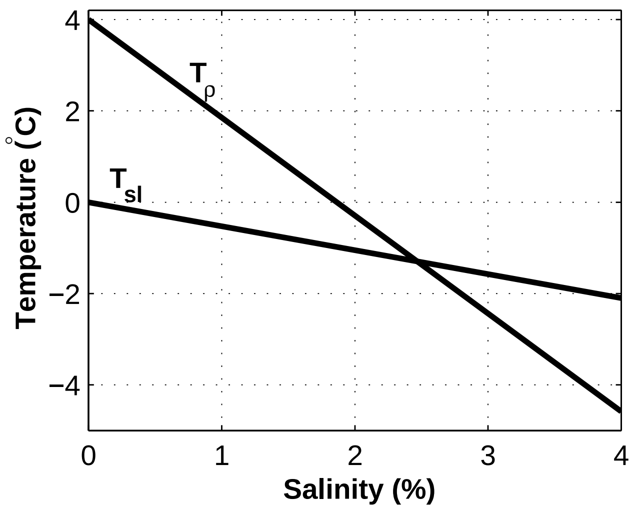

Figure 3: Freezing temperature (T_{sl}) and temperature of maximum density (T_ρ) as a function of salinity. The temperature of maximum density is equal to the freezing temperature at a salinity of 2.47%.

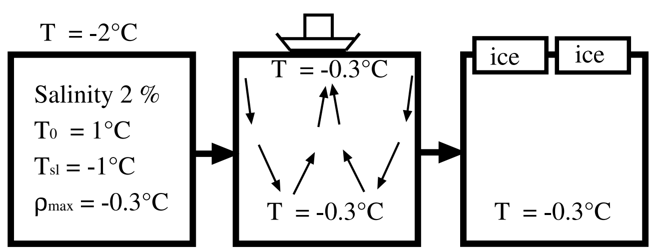

Figure 4: Vertical mixing in an ocean with salinity of 2%. The maximum density of the salt water is at $T = -0.3$°C. The initial temperature of the ocean is $T_0 = 1$°C, while the air temperature is $T = -2$°C. There will be vertical mixing until all the ocean is at $T = -0.3$°C. The freezing temperature is $T_{sl} = -1$°C.

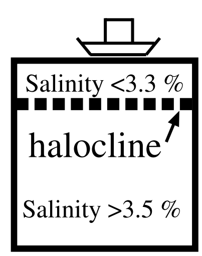

Figure 5: The halocline layer limits mixing to the upper 40 - 70 meters in the North-Atlantic ocean.

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