Warm Gulf Stream and Arctic Sea Ice: *what's the connection ?* The Thermohaline Circulation

Earth science is constantly finding surprising connections between distant parts of the globe. A good example is the mutual influence of warm tropical ocean currents, such as the Gulf Stream flowing by the East coast, and the frozen Arctic Ocean. Their influence on each other may have played a role in causing the abrupt climate changes that have plagued Europe and North America.

The best example of a major change is the advance and retreat of the massive ice sheets that covered Canada and part of the United States, as well as Europe and Russia, five separate times during the era when humans lived on Earth. The Little Ice Age from 1350 to 1850 is another example of a cool period that began and ended rather quickly. We have included several articles on the theme of abrupt climate change in this issue.

So what do the Gulf Stream and the Arctic ice sheet have to do with climate change? Let's cover some basics:

The tropics warm up a great deal. The excess heat in the tropics naturally flows into colder regions around the Poles. The oceans transport about a half of this energy, while the Atmosphere carries the rest. If we look at a globe, we see that the Indian Ocean has no connection with the Arctic, and the Pacific Ocean connects with the Arctic only at the narrow Bering Strait. This Strait is quite shallow; it is believed that Asian peoples walked across it to Alaska when the sea level was lower, and begat Native American peoples. Only insignificant amounts of water get through the Bering Strait. That leaves the Atlantic Ocean as the only ocean with a broad, deep channel to the Arctic.

Warm water is lighter than cold water, so it floats on top. Fresh water is lighter than salty water, so it also floats on top of brine. Very warm water in the tropics (85°F) spreads northward to the polar latitudes. In the Atlantic, this warm current is the Gulf Stream, which provides northern Europe with a milder climate than that of Canada. While releasing its warmth to the atmosphere, the waters of the North Atlantic are chilled by frigid air in the region between Norway, Greenland, Iceland, and the Arctic ice pack. The chilled water sinks and fills the deep basin of the Atlantic, flowing over the bottom all the way to the tropics and even farther, into the South Atlantic. “And so the cycle is complete.” This cycle is called the thermohaline circulation.

If the chilled water is salty, it will sink because salty water becomes heavier as it cools to the freezing point. BUT fresh water is different: as it cools to 4°C (39°F), it becomes heavier; but when it cools even more, it starts to become lighter – until it freezes into ice, when it becomes lighter still. This is why ice floats. Fresh water that is colder than 4° C floats on top of water right at 4° C; and the two layers do not mix easily.

When ice forms from fresh water, the ice layer cuts off almost all the heat flow from the ocean to the air. Salty water, though, would rather sink than freeze. So where the cold ocean is salty, the sinking of cold water drives the thermohaline circulation; but where the cold ocean is not-so-salty, ice forms, and little or no circulation ensues in the ocean.

Four large rivers drain from the Russian mainland into the Arctic Ocean, and the Mackenzie River drains from Canada. All this fresh water spreads over the top of the Arctic sea water, and readily freezes into the Arctic ice pack. A large fraction of the ice melts every summer. It does not require much atmospheric warming to melt the ice pack and reduce its area significantly.

A large amount of melt water, or fresh water from rivers, is thought to inhibit the thermohaline circulation in the Oceans, because it tends to remain on the surface of the Arctic Ocean instead of sinking, as salty water does.

There is evidence that a complete shutdown of the circulation has happened in the past. Model simulations give circumstantial evidence that it might be possible in the future, with some of the larger projected temperature increases. The National Research Council concluded that a complete shutdown of the thermohaline circulation was "unlikely" in the next 100 years, but could not rule out the possibility.

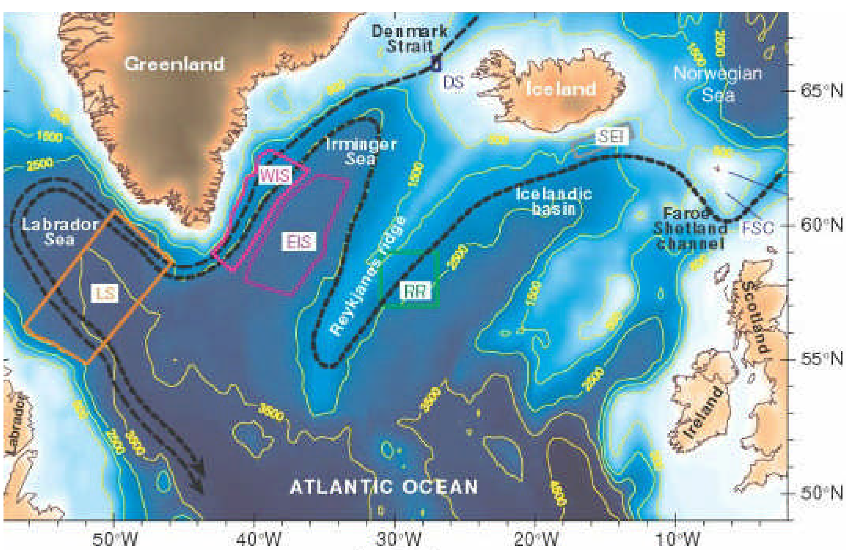
CLIMATE SCIENCE CLASSROOM

FAIR WARNING?

How Arctic Climate Change Has Rapidly Freshened Deep Atlantic Waters

In the last Climate Science Forum, we explained how the entire circulation of Atlantic Ocean water was forced by cold air over Arctic waters. Large amounts of fresh water in the Arctic could inhibit this process that mixes the shallow water with the deep Atlantic water. Since our last issue, Bob Dickson and others have announced that the deep waters of the North Atlantic Ocean have become notably more fresh (less salty) as a result of observed freshening of surface water in the Arctic Ocean ("Rapid freshening of the deep North Atlantic Ocean over the past four decades," *Nature*).[2]

To reach the Atlantic, cold subsurface water in the Arctic regions must flow over submerged "ledges" 800 meters deep, before it sinks into the deep Atlantic. One ledge is the Faroe-Shetland Channel between Scotland and Iceland (see map), and the other ledge is in the Denmark Strait between Iceland and Greenland. The path that the cold water follows is shown by dark dashed lines. In the last 40 years, observations show this overflow water has become noticeably less salty.



Topography of the bottom of the North Atlantic ocean and the cold currents flowing over ledges between Greenland and Scotland, and their subsequent pathways to and through the Labrador Sea (heavy dashed lines).

The Labrador Sea – comprising Atlantic waters east of Labrador and south of Greenland – plays a pivotal role in the Earth's climate. Through its deep layers passes all water that circulates in the deep Atlantic; through its surface layers passes the main flow of fresh water from the Arctic to the Atlantic. The authors write that "over the last 3 to 4 decades, the entire water column of the Labrador Sea has undergone radical change."

The explanation: Water upstream has become much more fresh in the top one kilometer of the Norwegian Sea. The far northern waters must pass through two channels and over the two ledges mentioned above. Dickson assembled observations from many locations along this "conveyor belt" of sinking water that show the water has steadily freshened at roughly the same rate over 25 years. They claim to have found a way that Arctic climate change has affected the deep abyssal water of the Atlantic Ocean. The stage is set for a possible slowdown of the entire thermohaline circulation of this Ocean (discussed in our last issue).

Although it's clear that the water of the far northern Atlantic is now less salty than it was 40 years ago, a number of factors could have caused the change, as Dickson points out. For example, the Arctic Ocean is exporting more ice to the Atlantic; precipitation has increased over northern Europe; and the East Icelandic current is bringing in more fresh water – all of which are tied to the North Atlantic Oscillation, an atmospheric see-saw that has amplified in these same years. Whether this is a natural or a human-induced change remains to be seen.

[2] *"Rapid freshening of the deep North Atlantic Ocean over the past four decades,"* Nature *v. 416, 832–837, 25 April 2002. Online at www.nature.com/cgi-taf/DynaPage.taf?file= /nature/journal/v416/n6883/abs/416832a_fs.html.*