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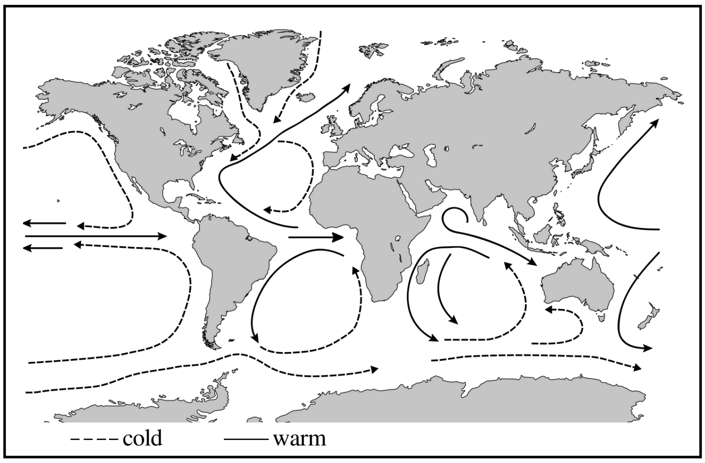
The Gulf Stream and Global warming

The oceanic circulation is a global system of surface and deep currents. These currents are powered by two quite different "engines".

1. Surface ocean currents

Those in the top few hundred metres are caused by winds. The dominant pattern of surface ocean currents (known as **gyres**) is roughly circular flow; clockwise in the northern hemisphere and anticlockwise in the southern hemisphere (Fig.1).

Fig 1. Ocean currents

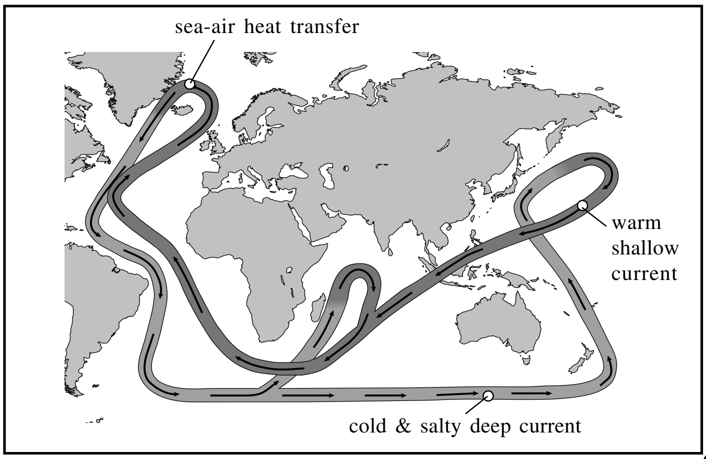


Within the circulation of the gyres, water piles up into a dome. The rotation of the Earth causes water in the oceans to push westward and to pile up on the western edges of ocean basins. The return flow is often narrow, fast-flowing currents such as the Gulf Stream.

2. The vertical circulation of water

Is driven by cold, salty, hence dense water sinking at high latitudes. This then returns towards the equator at depth and is replaced by the warm water moving towards the poles at the surface. Because this sinking is controlled by a combination of temperature (thermo) and salt-content (salinity), it is known as the thermohaline circulation (Fig.2) and is sometimes referred to as the great ocean conveyor.

Fig 2. Thermohaline circulation

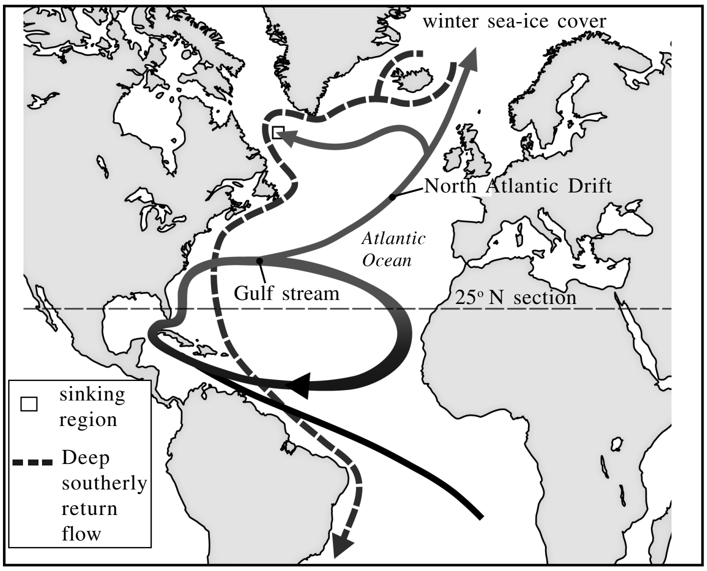


Key principles:
- cold water is denser than warm water
- salty water is denser than fresh water
- so cold, salty water is very dense! (and that's why it sinks)

The Gulf Stream

The Gulf Stream is a warm surface current that is driven northwards by the wind. After emerging from the Caribbean, the warm Gulf Stream splits in two; one part heads north-east to Europe and the other circulates back through the tropical Atlantic (Fig.3).

Fig. 3 The Gulf Stream



As the north-eastern branch flows across the North Atlantic, it gives off heat to the atmosphere. The northern extensions of the Gulf Stream - the Mid Atlantic Drift and the Norwegian current - continue to release heat and In turn, this makes the climate in regions bordering the eastern North Atlantic warmer than at similar latitudes elsewhere. This is the main reason why the British Isles, for example, have mild winters and relatively cool summers and why we can see palm trees growing in the west of Scotland.

The results of this warm Gulf Stream flow can also be seen in the extent of Arctic Sea ice, which is much less than that in the Pacific region of the Arctic. The effect of this Atlantic heat conveyor is most noticeable in winter.

As it moves northward, the Gulf Stream becomes cooler – as it passes heat to the atmosphere – and saltier, as moisture evaporates. As its salinity increases, so too does its density. By the time the Gulf Stream reaches Greenland and Iceland, the water has become sufficiently cool and dense that it sinks towards the ocean floor. This cooler water then heads back south towards the equator, forming the return stream of the giant ocean conveyor belt.

Summary

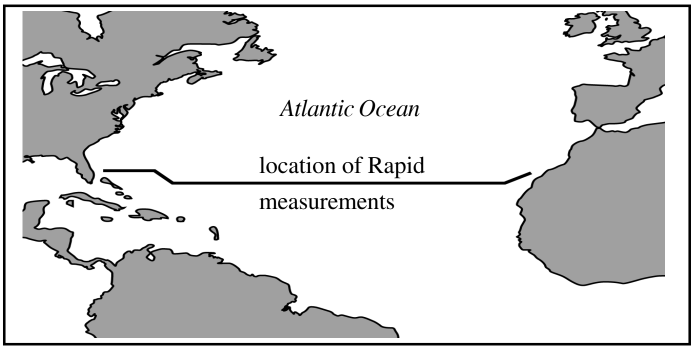
Ocean currents are generated by winds, temperature differences and by the sinking of cold, salty (and therefore denser) waters in the North Atlantic Ocean. That creates a void that pulls warm, salty surface waters northward. The ocean heats the atmosphere above the North Atlantic Ocean, and prevailing winds carry the heat eastward to warm Europe. Thus, the Gulf Stream raises Europe's winter temperatures by about 5 - 8°C.

The changing Gulf Stream

All governments need to plan for climate change but this is no easy matter. In the UK, for example, we need to try to understand how a general warming via the enhanced greenhouse effect will be **counterbalanced** by any cooling if the Gulf Stream weakens. The science is complex!

In order to try to understand how rapid climate change might affect us the Natural Environment Research Council (NERC) are coordinating the Rapid Climate Change programme. Using instruments stretching from the Bahamas to Morocco on the west coast of Africa (Fig.4), UK and US scientists are continuously monitoring both the warm, northward and cold, southward flow of the North Atlantic conveyor.

Fig.4 Monitoring the N. Atlantic conveyor

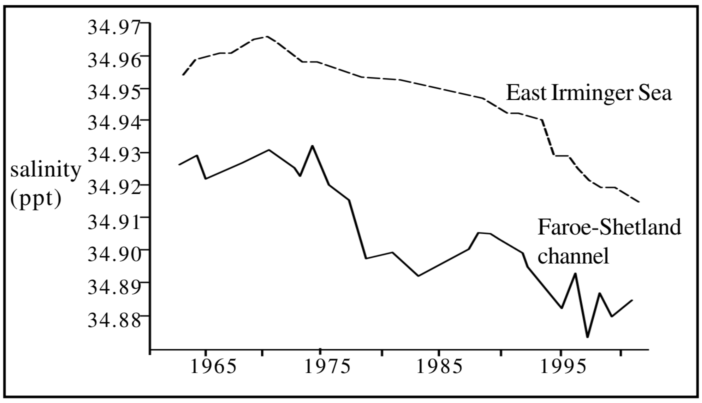


By combining data from past records with the new data, the scientists have learned that, around 8,000 years ago, Newfoundland, the UK and northern Europe experienced extreme cold and dry conditions. The temperatures in Greenland were almost 6°C colder than at present, for example. The shift to colder temperatures took only a few decades and lasted for about 160 years. This rapid cooling is believed to have been caused by a rush of melt-water into the North Atlantic which then caused the slowdown of the Atlantic conveyor, leading to the colder conditions.

The main conclusions from the programme so far:

- since the mid-1960s, the sub-polar seas feeding the North Atlantic have steadily become less salty, especially in the last decade (Fig 5) and to depths of 1,000 to 4,000m
- the flow of cold, dense water from the Norwegian and Greenland Seas into the North Atlantic has diminished by at least 20% since 1950
- since 1992 there has been a 30% reduction in the warm currents that carry water north from the Gulf Stream

Fig.5 Salinity changes in sub-polar seas



Many scientists believe that these changes may be a consequence of **atmospheric warming**:

- Increased rainfall, melting Arctic sea ice and Greenland ice sheets have added a lot of freshwater to the northern oceans
- Thus, their salinity has decreased and there has been less sinking
- As a result, the southern conveyor has weakened

Whether these processes are a direct consequence of human-induced warming isn't certain, but it is clearly a possibility and the programme is expected to run for at least another ten years.

Impacts of a weaker Gulf Stream and Conveyor

If the southern conveyor weakens, this will, in due course, weaken the returning northward flow. Heat-bearing Gulf Stream waters would no longer flow into the North Atlantic, and European and North American winters would become more severe.

One possibility is that Europe will freeze; another is that the slowing of the Gulf Stream may keep Europe cool as global warming heats the rest of the world - but with more extremes of weather.

Computer models that simulate ocean-atmosphere climate dynamics indicate that the North Atlantic region might cool by between 3° - 5° C if Conveyor circulation were totally disrupted. Global warming could stop or slow down the thermohaline circulation, causing localized cooling in the North Atlantic and cooling, or lesser warming, in countries affected by the North Atlantic Drift, namely Iceland, Ireland, Britain and Scandinavia.

There are two key points:

1. If thermohaline circulation shuts down and induces a climate transition, severe winters in the North Atlantic region would probably persist for decades to centuries - until conditions reached another threshold at which thermohaline circulation might start up again.
2. Abrupt regional cooling may occur even as the Earth, on average, continues to warm.

A persistent string of severe winters, lasting decades to a century, can cause glaciers to advance, rivers to freeze, and sea ice to grow and spread. The disruption to agriculture and implications for e.g. energy demand could be immense.

Practice Questions

(a) The thermohaline circulation is generated by differences in the temperature and salt content of different parts of the ocean. Explain why water at high latitudes in the North Atlantic has a greater salinity than the seawater near the equator (2)

(b) At the end of the Ice Age, the ice sheet that had covered much of North America melted. There is evidence that the huge volume of fresh water that was produced flowed into the North Atlantic between 40°N and 60°N.
   (i) What effect would this have had on the flow of the Gulf Stream? (1)
   (ii) What is likely to have happened to the climate in the UK and Scandinavia at the end of the Ice Age?

Markscheme

(a) Water flows from warmer seas / equator; undergoes more evaporation than colder water at high latitudes;

(b) (i) Water would sink further south/ the current would not flow so far north;
   (ii) Remain cool because the warming effect of the current would be lost;

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