Guide to the Science of Climate Change in the 21st Century

Chapter 8
Global Circulation of Water in the Ocean

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8.0 Global Circulation of Water in the Ocean

8.1 Introduction

The oceans contain 97 per cent of the water on the Earth. They cover 70 per cent of the Earth's surface. They interact with and significantly impact the global circulation of the atmosphere. Oceans are very important elements in the energy budget, carbon cycle and hydrologic cycle. The oceans are slow to warm and to cool and store considerable energy and dissolved greenhouse gases such as carbon dioxide.

8.2 Ocean currents

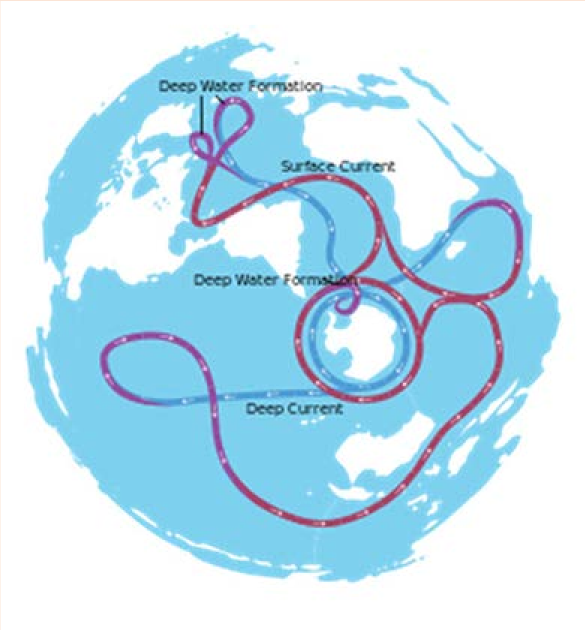
Circulation of water in the oceans is the result of a complex system of continuous directed movements of seawater known as ocean currents. Ocean currents mix ocean water, transport nutrients and influence the climates in the regions in which they travel.

There are two major types of ocean currents, surface water currents and deep-water currents. Of course, there are many intermediate currents between the surface and deep-water currents of varying significance depending on location. Surface water currents are driven by winds and tides. Deep water currents are driven by differences in water density resulting from differences in temperature and salinity and are known as thermohaline circulation.

The combination of several surface water currents, which experience warming and changes in salinity due to evaporation and the deep-water currents, connect the oceans of the world in what is known as the global ocean conveyor belt as shown in Figure 8.1. Surface currents are shown in red and deep currents are shown in blue. Another name for the global ocean conveyor belt is the meridional overturning circulation or MOC.

The dynamics of the global ocean conveyor belt are illustrated in Figure 8.2 which identifies the Atlantic portion in greater detail. Atlantic meridional overturning circulation is known by its acronym, AMOC. Sea water is warmed and evaporated near the equator in the vicinity of the Gulf of Mexico and the Caribbean Islands (See Figure 8.3). The resulting water is warmer and more saline but still less dense than adjacent water and remains a surface stream. A portion of this water, the Gulf Stream, flows north. As it nears Greenland it is cooled by the local air mass and some freezes. The remaining water is cold and has a higher salinity. It becomes denser than the adjacent water mass and sinks to form the North Atlantic Deep-Water Current in a process known as deep water formation. The sinking water is replaced by the warm water of the Gulf Stream. The flow of the Gulf Stream is determined by the rate of deep-water formation.

A full circulation of the global ocean conveyor belt, Figure 8.4, takes approximately 500 years to complete according to https://education.nationalgeographic.org/resource/ocean-conveyor-belt/ though others estimate the full circulation to take 1000 years or more. https://oceanservice.noaa.gov/education/tutorial_currents/05conveyor2.html#:~:text=It%20is%20estimated%20that%20any,River%20(Ross%2C%201995) . Not really known.



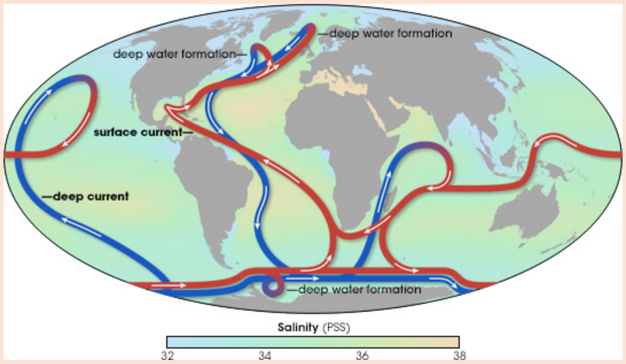
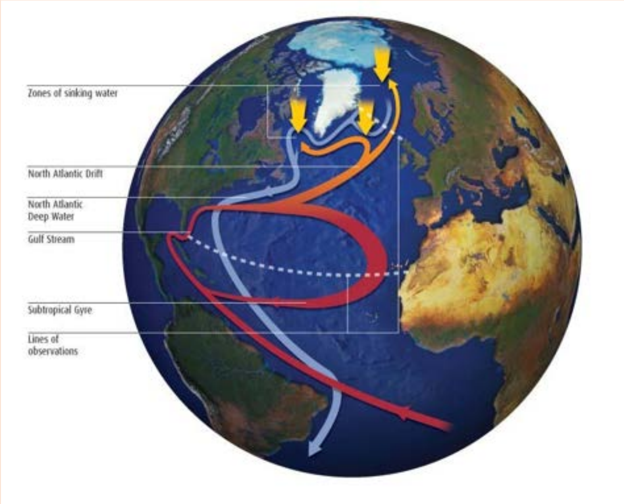


Figure 8.1 Two views of the thermohaline circulation or 'global ocean conveyor belt' https://en.wikipedia.org/wiki/Thermohaline_circulation



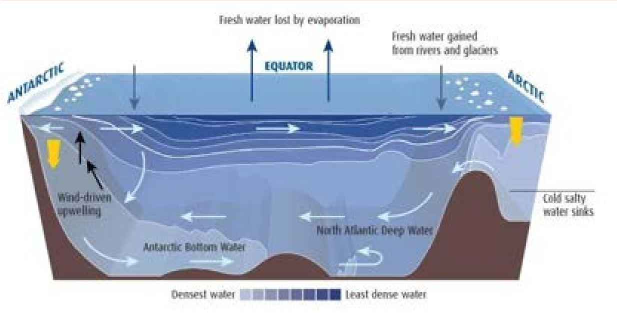


Figure 8.2 Atlantic portion of the global conveyor belt, AMOC.

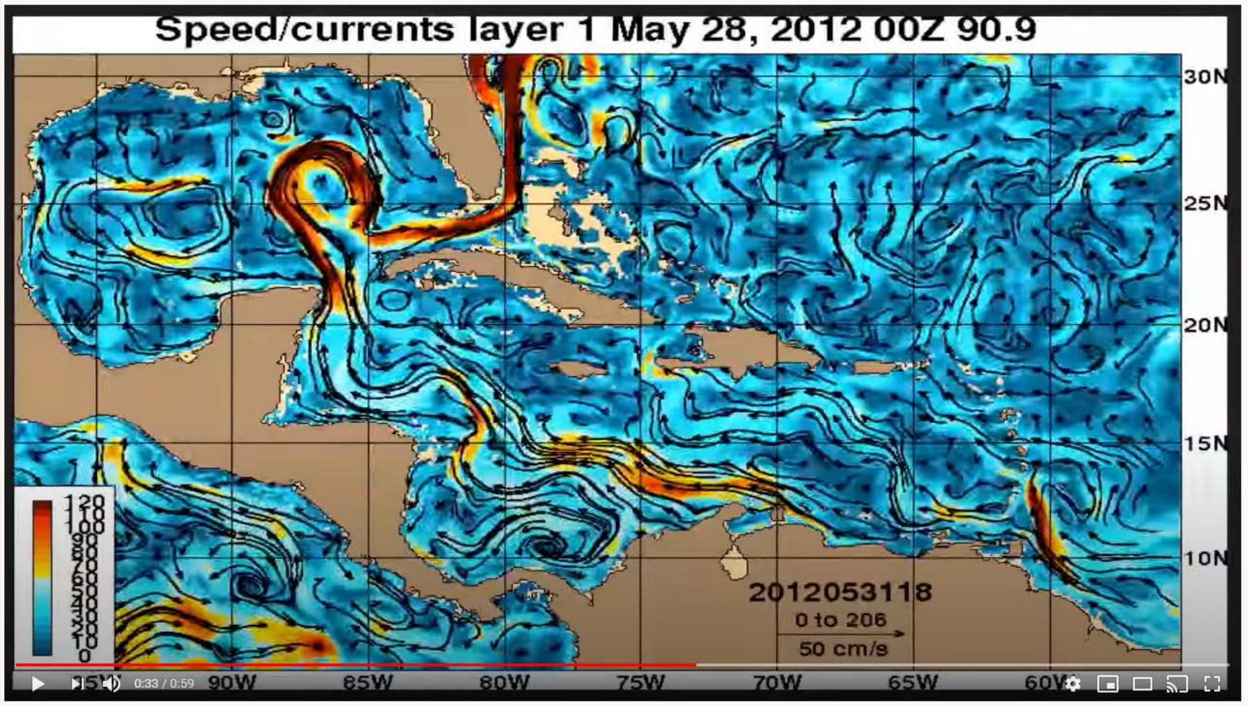


Figure 8.3 Ocean currents in the vicinity of the Gulf of Mexico and the Caribbean Islands.
https://www.youtube.com/watch?v=eg3UFr8WjWc

Figure 8.4 illustrates global surface water ocean currents. Warm currents are shown in red and cold currents are shown in blue. The climate of regions adjacent to the currents will be significantly affected by their temperature. A clearer version of ocean surface currents is shown in Figure 8.5.

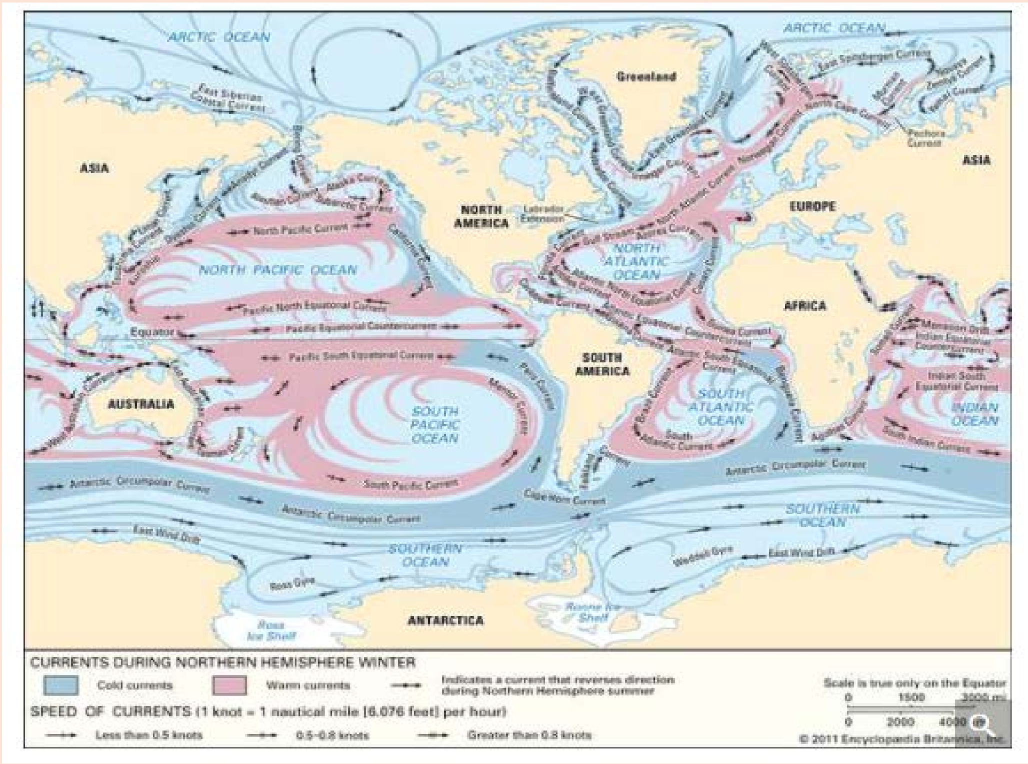


Figure 8.4 Global surface water ocean currents during northern hemisphere winter.

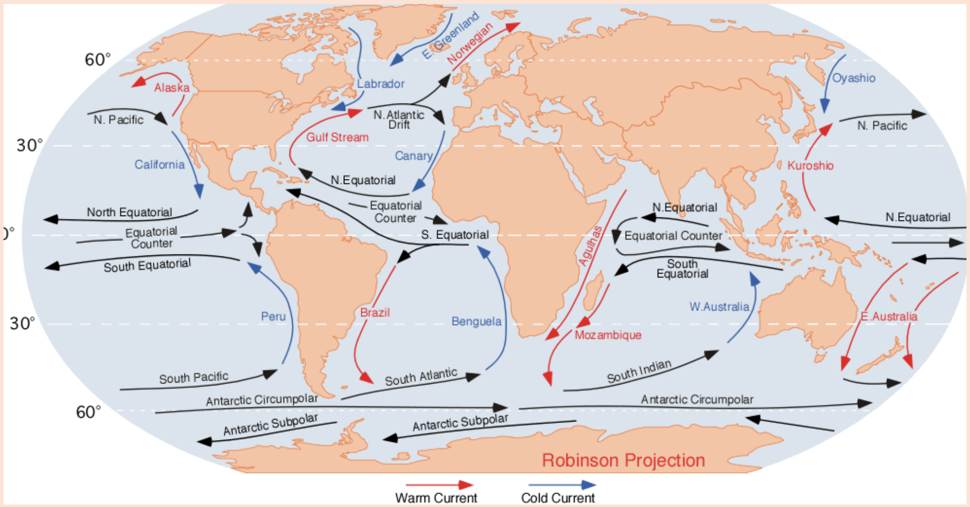
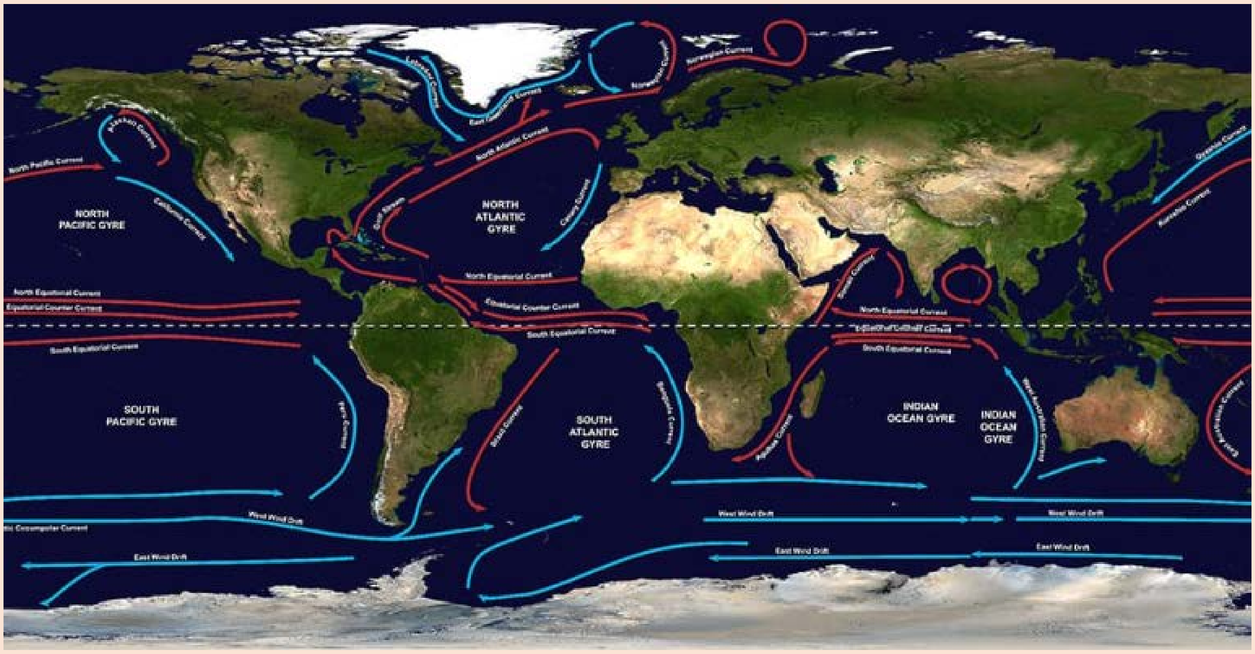


Figure 8.5 Global ocean surface currents https://en.wikipedia.org/wiki/Ocean_current .

A gyre is a large system of rotating ocean currents. There are five major gyres as shown in Figure 8.6.



Figures 8.6 Gyres
https://oceanservice.noaa.gov/facts/gyre.html#:~:text=The%20ocean%20churns%20up%20various,of%20currents%20known%20as%20gyres.

Garbage accumulates in gyres as shown in Figure 8.7. The web site, Garbage accumulation in North Pacific gyre https://marinedebris.noaa.gov/discover-marine-debris/garbage-patches#:~:text=Garbage%20patches%20are%20large%20areas,whirlpools%20that%20pull%20objects%20in describes the NOAA marine debris program and is well worth reviewing.

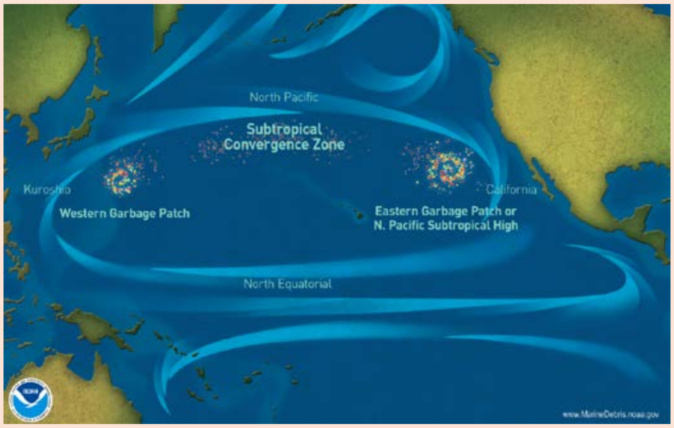
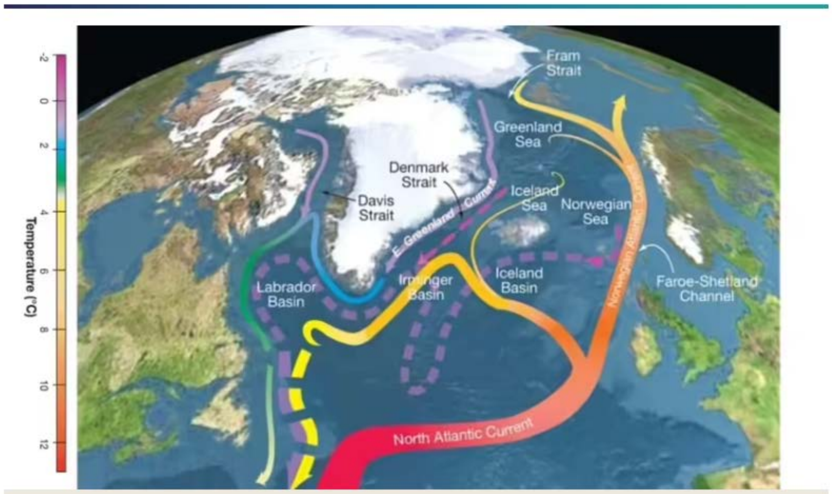


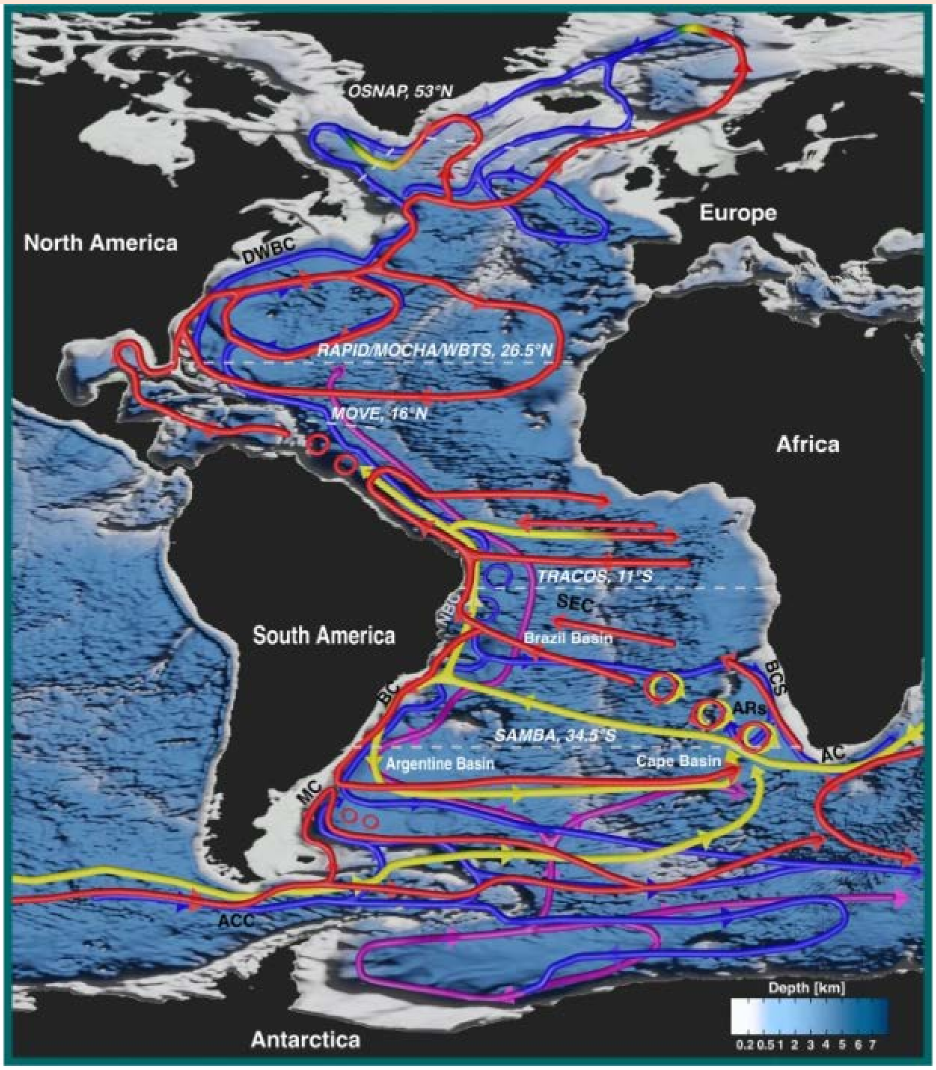
Figure 8.7 Garbage accumulation in North Pacific gyre https://marinedebris.noaa.gov/discover-marine-debris/garbage-patches#:~:text=Garbage%20patches%20are%20large%20areas,whirlpools%20that%20pull%20objects%20in.

Details of the surface currents and deep currents of the north Atlantic Ocean are shown in Figures 8.8 and 8.9.



This topographic map shows the schematic circulation of surface currents (solid curves) and deep currents (dashed curves) of the Atlantic Ocean, which form a portion of the Atlantic Meridional Overturning Circulation (AMOC). The colors of the curves indicate approximate temperatures. WIKIMEDIA COMMONS (CC BY 3.0)

Figure 8.8 Ocean currents in the North Atlantic Ocean
https://science.howstuffworks.com/environmental/earth/oceanography/amoc-news.htm .



The schematic represents the pathways of surface (red), intermediate (yellow), deep (blue), and abyssal (purple) waters over the bottom topography (blue shading). Transitions between these colors indicate water mass transformations. Important currents and topographic features mentioned in the text are labeled, and dashed white lines indicate the nominal latitudes of the five Atlantic Meridional Overturning Circulation (AMOC) monitoring arrays (Box 1). AC Agulhas Current, ACC Antarctic Circumpolar Current, ARs Agulhas Rings, BC Brazil Current, BCS Benguela Current System, DWBC Deep Western Boundary Current, MC Malvinas Current, NBC North Brazil Current, SEC South Equatorial Current.

Figure 8.9 Idealized schematic of the overturning circulation in the Atlantic Ocean https://www.nature.com/articles/s43247-022-00644-x .

8.3 Gulf Stream

A very good description of the Gulf Stream may be found in https://scijinks.gov/gulf-stream/ . This web site is supported by NOAA and is provided as an educational resource. Excellent information on a variety of water, weather, climate related topics can be found using their search feature. Figure 8.10 illustrates the Gulf Stream.

Figure 8.10 Gulf Stream https://scijinks.gov/gulf-stream/ .

8.4 Potential impact of global warming on the Atlantic Ocean Meridional Circulation or AMOC

A recent study of the Gulf Stream and the larger Atlantic Ocean circulation (AMOC) suggests that there is evidence (approximately 1500 years of proxy data) that the circulation is weakening https://www.pik-potsdam.de/en/news/latest-news/gulf-stream-system-at-its-weakest-in-over-a-millennium . A very good description of the AMOC, with animation, was recently published by the New York Times, https://www.nytimes.com/interactive/2021/03/02/climate/atlantic-ocean-climate-change.html?utm_campaign=Carbon%20Brief%20Daily%20Briefing&utm_content=20210303&utm_medium=email&utm_source=Revue%20Daily . The complexity of the circulation and how little is actually known about it is emphasized. It is suggested that the melting of the Greenland Ice Sheet is a likely cause for the weakening, if it is in fact weakening. A weakening AMOC would change the climate of northern Europe, cause warming of southern regions of the Atlantic with the result of drier conditions in the Sahel region of Africa and more frequent severe hurricanes. Because the AMOC is a large part of the 'ocean conveyor' the effects of its weakening would be global. Also see a discussion of the AMOC from the UK Met Office https://www.metoffice.gov.uk/weather/learn-about/weather/oceans/amoc#:~:text=The%20Atlantic%20Meridional%20Overturning%20Circulation%20(AMOC)%20is%20a%20large%20system,northwards%20into%20the%20North%20At lantic. They state “Climate models suggest that the AMOC will weaken over the 21st Century as greenhouse gases increase. This is because as the atmosphere warms, the surface ocean beneath it retains more of its heat. Meanwhile increases in rainfall and ice melt mean it gets fresher too. All these changes make the ocean water lighter and so reduce the sinking in the ‘conveyor belt’, leading to a weaker AMOC. So, the AMOC is very likely to weaken, but it’s considered very unlikely that large, rapid changes in the AMOC, as seen in past times, will happen in the 21st Century.”

Melting of the permanent Arctic sea ice between Greenland and Ellesmere Island would result in water flowing south from the Arctic Ocean through the Nares Strait. (Presently not possible because it is blocked by sea ice.) This would impact the Greenland Current by allowing flow from the Arctic Ocean directly into the Labrador Basin instead of around the northern portions of Greenland. The effect would be to change the flow patterns of northern portions of the AMOC. See Figure 8.11. Effects might be similar to increased melting of the Greenland Ice Sheet.

Figure 8.11 Nares and Davis Straits.

8.5 Observation of ocean currents

8.5.1 Drifter Program

The ‘Global Drifter Program’ is managed by NOAA https://www.aoml.noaa.gov/global-drifter-program/ . They describe it as follows:
“The Global Drifter Program is a branch of NOAA’s Global Ocean Observing System and a scientific project of the Data Buoy Cooperation Panel. It has two components: the Global Drifter Center at AOML and the Lagrangian Drifter Laboratory (LDL) at Scripps Institution of Oceanography, UC San Diego. The LDL supervises drifter production, designs and tests new types of drifters, and manages the real-time data flow on the Global Telecommunications System.” The objective is to provide ‘an accurate and globally dense set of in-situ observations

of mixed layer currents, sea surface temperature, atmospheric pressure, winds, waves, and salinity.'

A description of the 'drifters' is provided by the web site, Ocean Tracks, https://oceantracks.org/library/drifters . See Figure 8.12 for sketch of a drifter. Ocean Tracks describes a drifter as follows:

- "Drifters" are freely-floating drifting buoys that are deployed in the ocean to measure currents.
- The drifter is composed of a surface float, a tether and a drogue. There are some variations on this design, but these are the basic components.
- The surface float contains a battery, instruments that measure things like temperature, barometric pressure, wind speed and direction, and ocean salinity, and a transmitter that relays the position of the drifting buoy and data collected by the instruments on the surface float to satellites.
- The tether connects the surface buoy to the subsurface drogue.
- The drogue is a canvas-covered cylindrical frame with holes in it that sits at about 15m below the ocean's surface. Because the drifter sits at this depth, its movement is influenced by processes occurring in the upper 15m of the ocean."

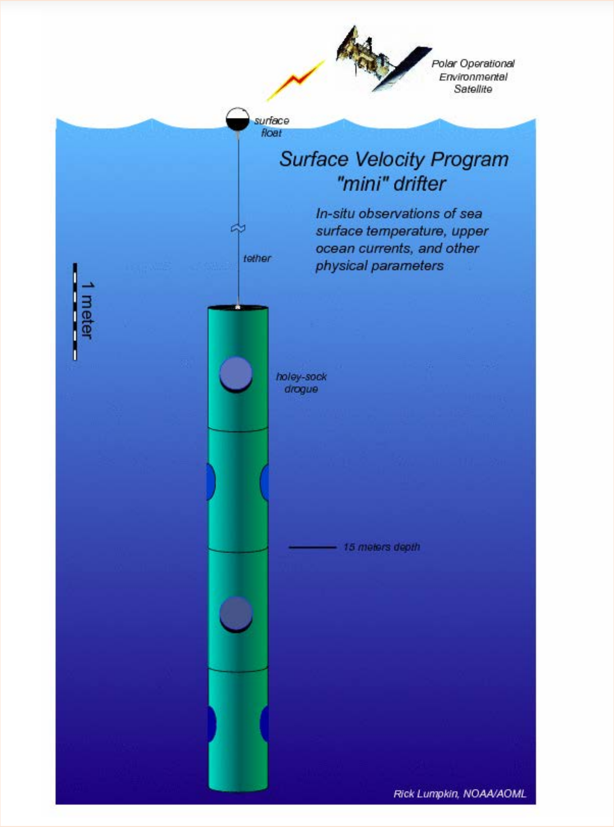


Figure 8.12 Sketch of an ocean drifter taken from https://oceantracks.org/library/drifters .

The data collected are used to calibrate and validate temperature measurements made from satellites, which can be thrown off by atmospheric particles or biased by the day-to-night changes in temperature sampled only while the satellite is passing overhead.

Figure 8.13 shows the location of drifters and the deploying country.

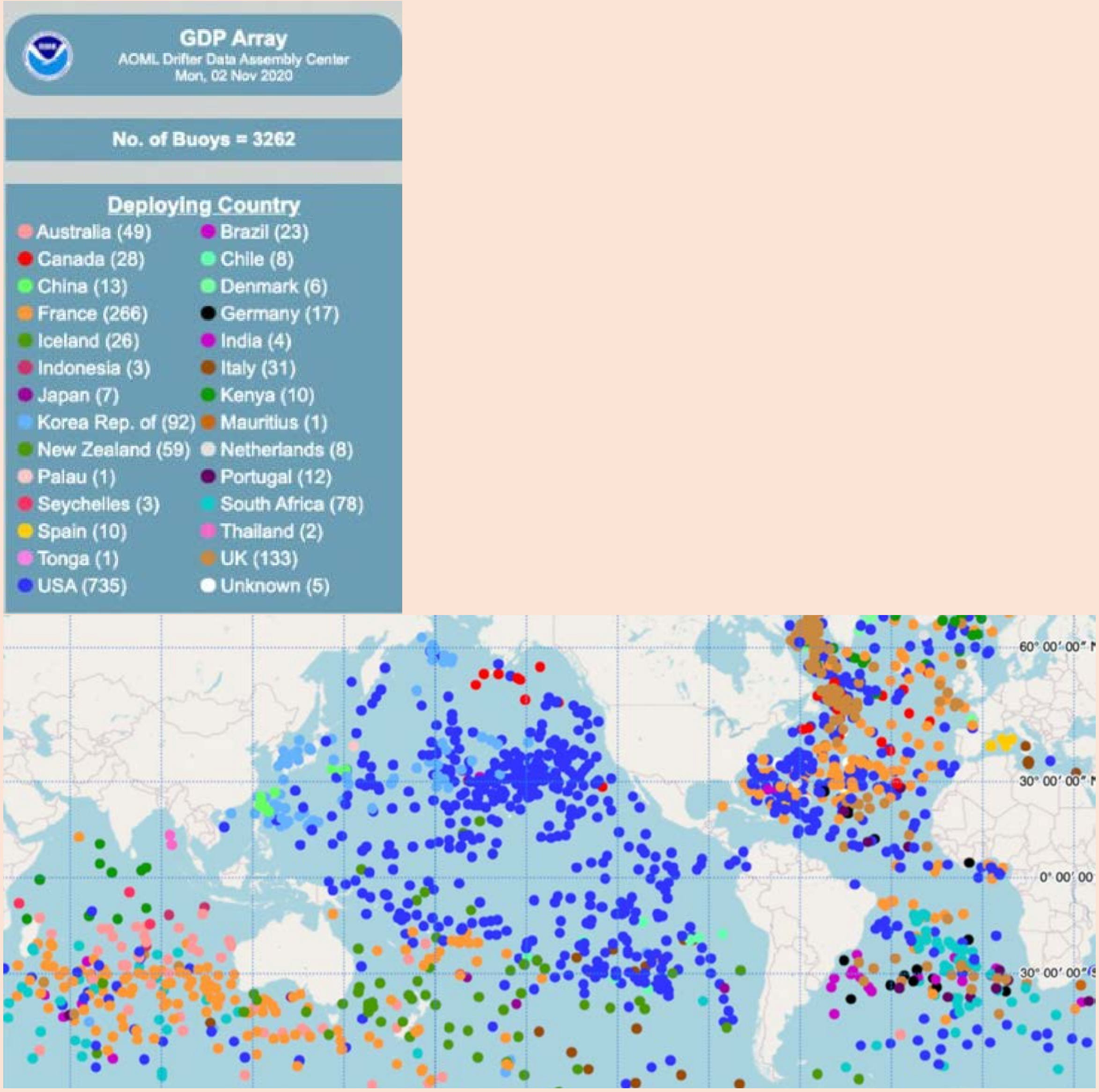


Figure 8.13 Location of drifters and deploying country, https://ldl.ucsd.edu/apps/projects/noaa/global-drifter-program.html .

8.5.2 Deep ocean drifters

As stated by NOAA , https://oceanservice.noaa.gov/education/tutorial_currents/06measure4.html , “The purpose of deep ocean drifters is to monitor ocean currents and ocean water characteristics far beneath the ocean surface, scientists use devices called profiling floats. While Davis drifters remain at the ocean surface during their deployment, profiling floats are programmed to sink to a particular depth and remain there for a specific period of time. At that depth, which scientists call a "parking depth", the profiling float drifts with the prevailing current. After the pre-programmed time period, the profiling float begins to rises to the ocean surface. As the profiling float ascends, it can be programmed to take a series measurement from the surrounding water, which may include the water's temperature, salinity, and pressure. When the profiling float reaches the surface, it transmits its data to an orbiting satellite to determine the profiling float's position, and begin to receive the profiling floats data. The satellite also receives information about the path the float has taken while it was drifting. When all of the float's data has been transmitted, the float sinks again to drift and the cycle is repeated. Floats are designed to make about 150 such cycles. Some floats, such as the one depicted in the image below, can sink and drift up to 2,000 meters (approximately 6,500 feet) beneath the surface of the ocean.”

A sketch of deep ocean drifter and how it operates is shown in Figure 8.14.

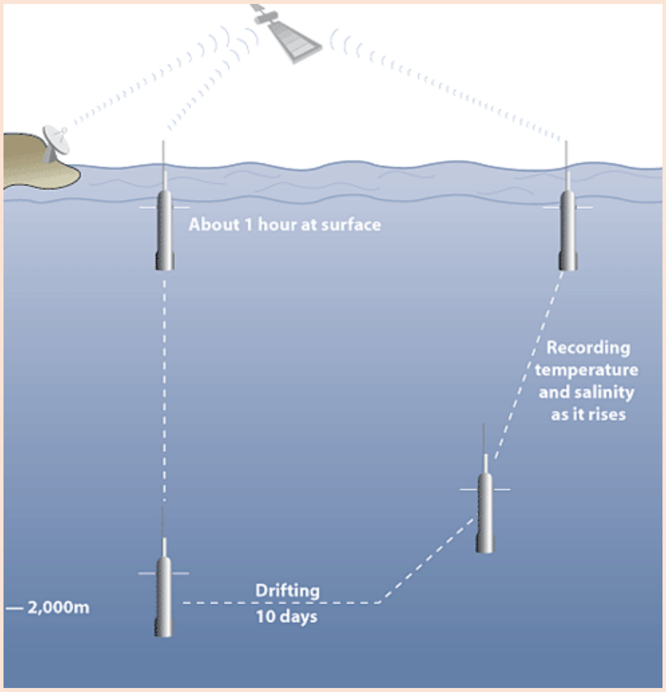


Figure 8.14 Sketch of deep ocean drifter, https://oceanservice.noaa.gov/education/tutorial_currents/06measure4.html .

8.6 Information support

Key web sites:

1. Ocean currents. https://www.noaa.gov/education/resource-collections/ocean-coasts/ocean-currents

2. The global conveyor belt. https://oceanservice.noaa.gov/education/tutorial_currents/05conveyor2.html

3. Ocean current. https://en.wikipedia.org/wiki/Ocean_current

4. Ocean conveyor belt, National Geographic. https://education.nationalgeographic.org/resource/ocean-conveyor-belt/ .

5. Circulation of global conveyor belt, NOAA. https://oceanservice.noaa.gov/education/tutorial_currents/05conveyor2.html#:~:text=It%20is%20estimated%20that%20any,River%20(Ross%2C%201995) .

6. Gyres https://oceanservice.noaa.gov/facts/gyre.html#:~:text=The%20ocean%20churns%20up%20various,of%20currents%20known%20as%20gyres.

7. Garbage accumulation in North Pacific gyre https://marinedebris.noaa.gov/discover-marine-debris/garbage-patches#:~:text=Garbage%20patches%20are%20large%20areas,whirlpools%20that%20pull%20objects%20in

8. Surface currents in the Atlantic Ocean. https://oceancurrents.rsmas.miami.edu/atlantic/gulf-stream.html#:~:text=The%20Gulf%20Stream%20transports%20significant,%2Fs%20(5%20knots).

9. Gulf Stream, NOAA. https://scijinks.gov/gulf-stream/

10. Atlantic Meridional Ocean Circulation, AMOC. https://www.pik-potsdam.de/en/news/latest-news/gulf-stream-system-at-its-weakest-in-over-a-millennium

11. Atlantic Meridional Ocean Circulation, AMOC. https://www.metoffice.gov.uk/weather/learn-about/weather/oceans/amoc#:~:text=The%20Atlantic%20Meridional%20Overturning%20Circulation%20(AMOC)%20is%20a%20large%20system,northwards%20into%20the%20North%20Atlantic.

12. Thermohaline circulation. https://en.wikipedia.org/wiki/Thermohaline_circulation

13. Details of the North Atlantic Ocean currents, https://science.howstuffworks.com/environmental/earth/oceanography/amoc-news.htm

14. Idealized schematic of the overturning circulation in the Atlantic Ocean https://www.nature.com/articles/s43247-022-00644-x

15. Description of AMOC with animation, New York Times. https://www.nytimes.com/interactive/2021/03/02/climate/atlantic-ocean-climate-change.html?utm_campaign=Carbon%20Brief%20Daily%20Briefing&utm_content=20210303&utm_medium=email&utm_source=Revue%20Daily

16. Discussion of the AMOC from the UK Met Office. https://www.metoffice.gov.uk/weather/learn-about/weather/oceans/amoc#:~:text=The%20Atlantic%20Meridional%20Overturning%20Circulation%20(AMOC)%20is%20a%20large%20system,northwards%20into%20the%20North%20Atlantic

17. Global Drifter Program is managed by NOAA https://www.aoml.noaa.gov/global-drifter-program/ .

18. Drifters, Ocean Tracks. https://oceantracks.org/library/drifters

19. Location of ocean drifters and deploying country. https://ldl.ucsd.edu/apps/projects/noaa/global-drifter-program.html .

Videos:

1. Fresh water in the Arctic. https://www.youtube.com/watch?v=FxXaT7yO4TQ

December 12, 2020 – Fifth Anniversary of the Paris Agreement
August 9, 2021 – Publication of IPCC AR6 WG1, Climate Change, The Physical Science Basis, February 28, 2022 IPCC AR6 WGII, Climate Change: Impacts, Adaptability and Vulnerability and April 4, 2022 IPCC AR6 WGIII, Climate Change: Mitigation