Drake Passage Effect Without the Drake Passage

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Background

A global-scale circulation carries about 10 or 20 million tons per second of relatively warm water northward into the top kilometer of the North Atlantic Ocean. The water cools off, sinks, and returns southward as a relatively dense flow of "North Atlantic Deep Water" (NADW, see **Fig. 1**). This NADW "overturning" circulation may have an important influence on the climate of Europe, and has been implicated in abrupt climate changes at the end of the last ice age.

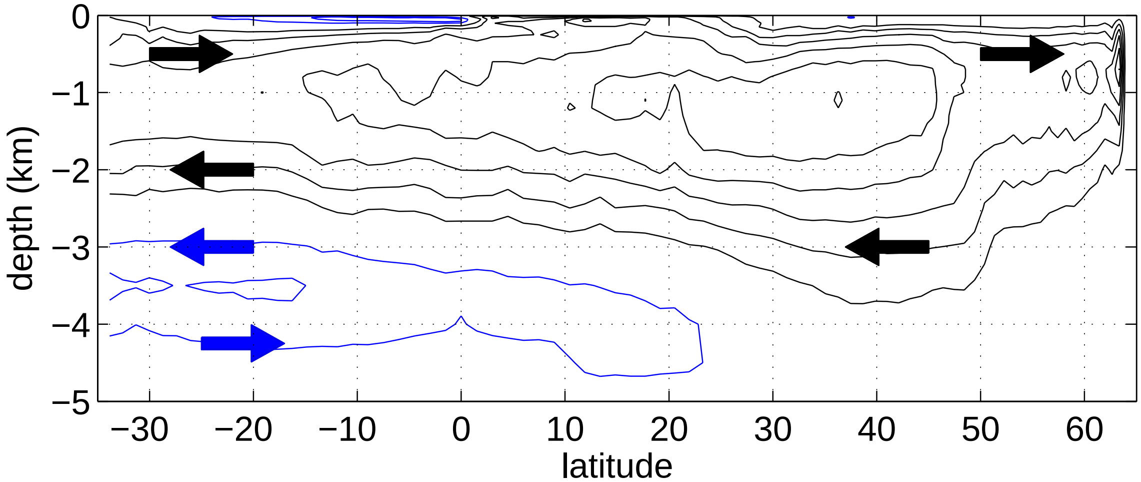

Fig 1: Overturning streamlines for Atlantic Ocean from numerical simulation; arrows show direction (north or south) of flow at selected locations.

What determines the strength of the overturning? Computer simulations of global ocean circulation (Toggweiler and Samuels, 1995) suggest that at least some of this circulation is driven by winds far from the North Atlantic. The behavior is linked to some surprising features of fluid flow on a rotating object such as the Earth. Because of the Coriolis force

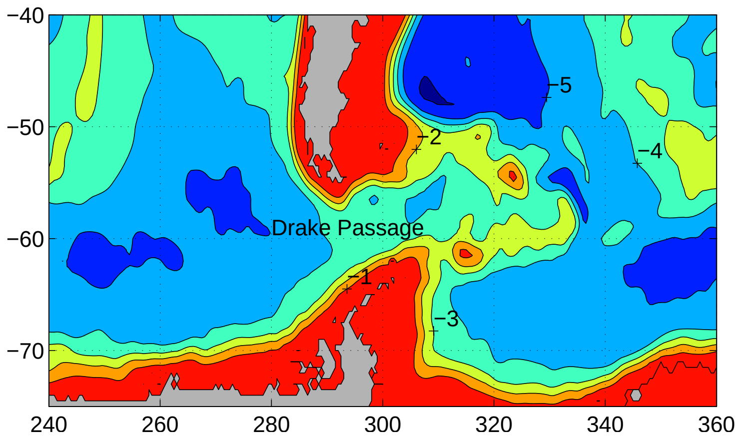

Fig. 2: Bottom depth (in kilometers) in vicinity of Drake Passage.

associated with the Earth's rotation, wind creates a surface ocean flow at right angles to the wind. **Westerly** (that is, blowing from the west) winds of the Southern Ocean (the region surrounding Antarctica) produce a **northward** ocean flow, which must return **southward** in some deeper layer. The amount of return flow is proportional to the pressure difference between the eastern and western edges of the ocean. Again, this is an effect of the Coriolis force. However, between the southern tip of South America and the northern tip of Antarctica--the Drake Passage--the ocean has **no** eastern or western boundaries at the surface (**Fig. 2**). The only "boundaries" occur deeper down, where there are submarine ridges. Therefore, the return flow must occur at great depth. Since this water is much colder and denser than the surface water, and since it is difficult to change the density of water far below the surface, Toggweiler and Samuels argued that the water must take a long detour, via the North Atlantic, to close the circuit. The water cools by heat loss to the atmosphere, and is then able to sink near Iceland. The ability of the wind to drive such a large-scale overturning circulation is the **"Drake Passage Effect."**

Other, more idealized simulations show that Southern Ocean wind can drive the NADW flow even when there are eastern and western boundaries at all latitudes: the Drake Passage Effect **without** the Drake Passage (Tsujino and Suginohara, 1999). This raises some interesting questions. What role does the Drake Passage actually play in the Drake Passage Effect? Why does the Southern Ocean wind drive flow into the North Atlantic even when there is no Drake Passage?

Experimental Procedure

Klinger *et al* (2003) simulated an ocean with a simplified geometry: a flat bottom and walls that are latitude circles and lines of longitude. Two pairs of experiments were run. Each pair has one experiment with no wind and one experiment with westerly wind over the southern part of the southern hemisphere. In one experiment pair, the boundaries are all solid, while in the other, the eastern and western boundaries have a gap at around 55 S and down to a depth of about 2500 m (**Fig. 3**). The gaps are "periodic": water flowing eastward through the eastern gap immediately emerges from the western gap. This represents the Southern Ocean at the latitudes of the Drake Passage.

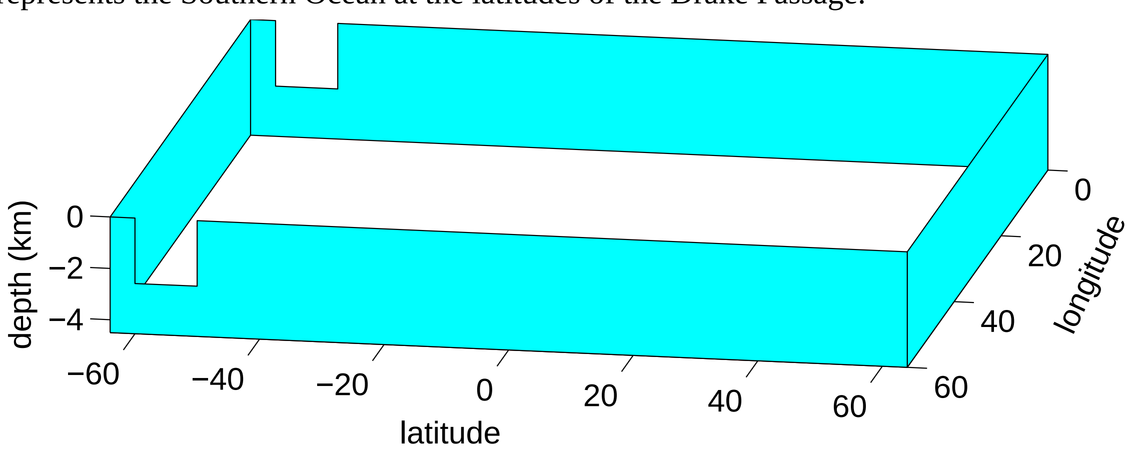

Fig. 3: Geometry of “Channel” experiments with periodic gaps in walls.

Results

For each pair of experiments, we examined the wind-driven flow by subtracting velocities in a no-wind experiment from velocities in the corresponding wind-driven experiment. The experiments confirm that the "Drake Passage Effect" exists with and without east/west walls. In both cases, there is a strong, wind-driven flow at around 55 S (**Fig 4**). Some of this flow circulates locally (sinking just to the north, flowing southward, and rising to complete the circuit), and some takes a much longer route via the northern hemisphere. However, the experiments show that the gaps in the eastern and western walls **doubles** the amount of flow taking the long route. Thus the "Drake passage" greatly enhances the effect of the wind on NADW flow.

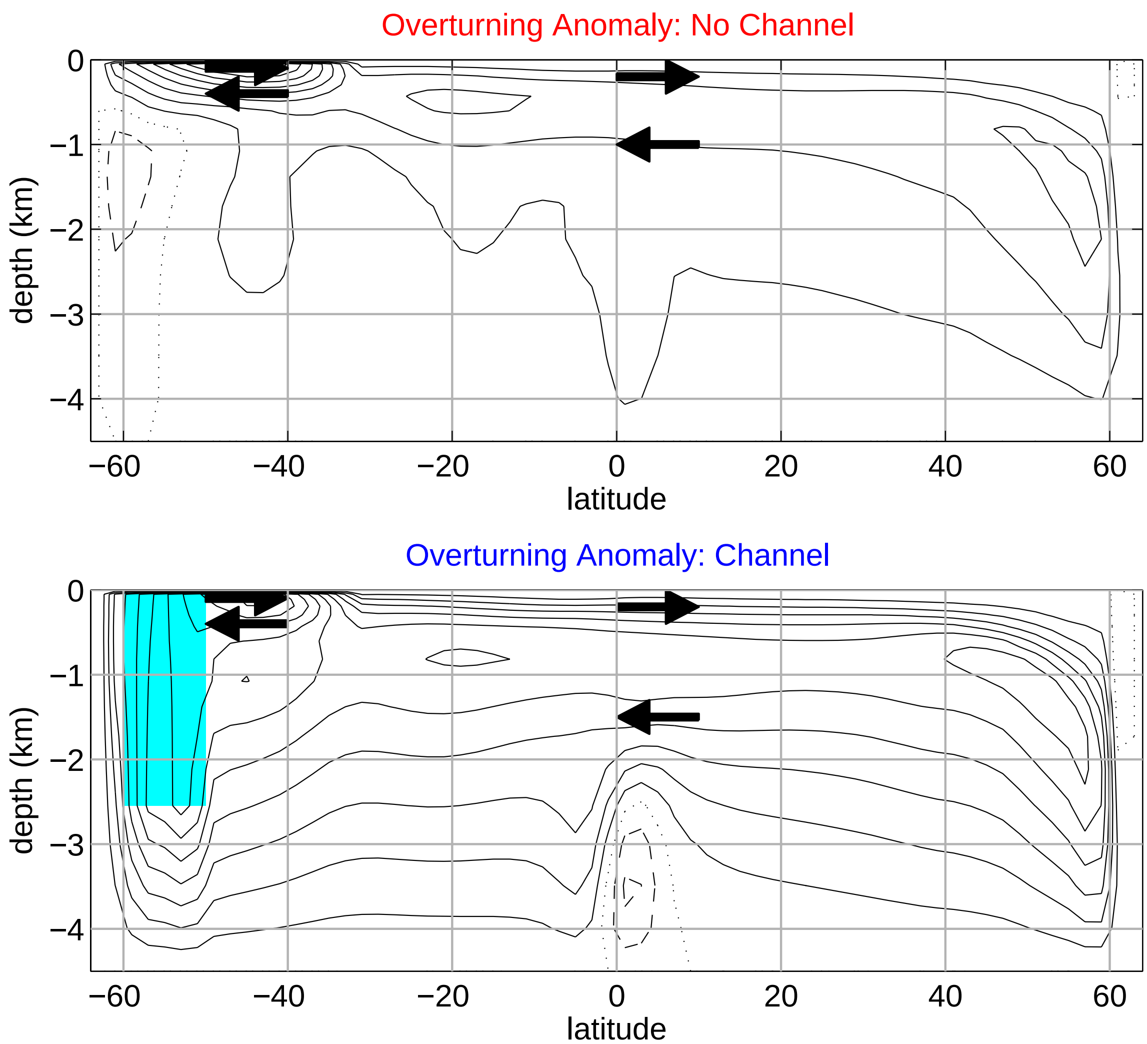

Fig. 4: Overturning streamlines (wind-driven relative to no-wind experiment) for no-channel and channel experiment pairs. Light blue shade marks location of gap in eastern and western boundaries.

Why do both geometries produce circulation far from the wind forcing? Our analysis of the equations governing the flow suggests that even when there is no Drake Passage, the return flow must occur in a relatively deep layer. Therefore, both cases have similar behavior for the same reason: the wind-driven northward surface flow in the far south must go far to the north in order to cool down enough to flow southward again in a deep layer (**Fig. 5**). When there is a Drake Passage, the water must sink even deeper than in the closed-wall case, which is harder to do locally (due to the difficulty of cooling the deep water), and hence more of the water takes the longer route via the North Atlantic.

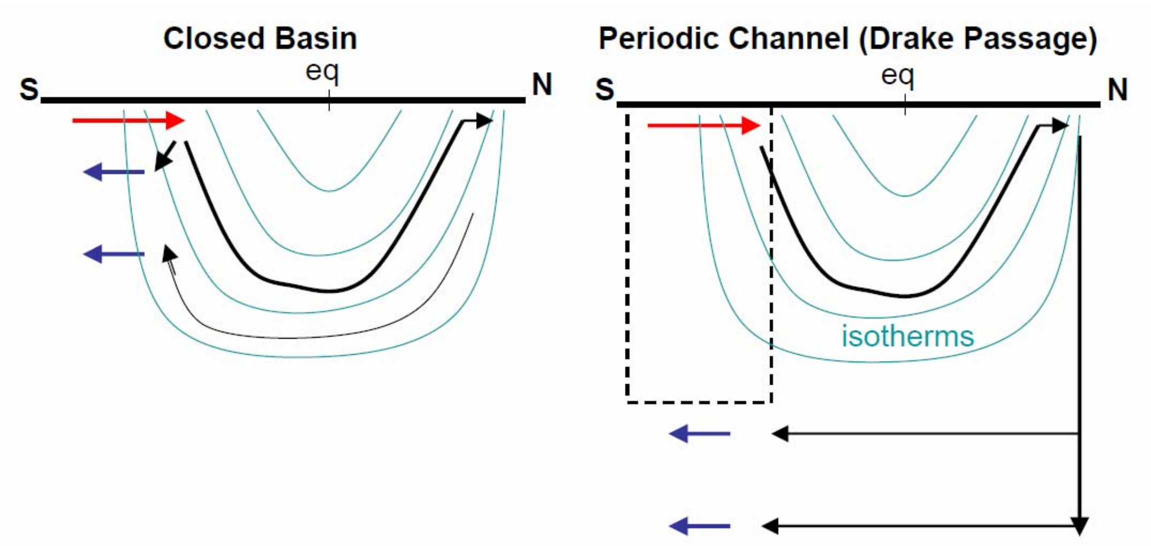

Fig 5: Schematic of flow for closed basin (left) and basin with gaps (dashed lines) in eastern and western boundaries (right). Light blue curves show contours of constant density (deeper contours represent colder and denser water), red arrow shows current directly driven by wind, blue arrows show deep return flow, and black curves/arrows show paths of water connecting surface currents to deep currents.

Significance

The experiments address a fundamental question of how the circulation of the ocean works. Since the global overturning circulation is apparently sensitive to wind even in regions where the ocean has eastern and western boundaries, it may be influenced by wind outside the Drake Passage latitudes. However, our results indicate that the unique geometry of the Drake Passage latitudes does make the global circulation—and perhaps the climate of the North Atlantic--especially sensitive to wind there.

References

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