Physical Oceanography: Warming spins up the Southern Ocean

Andrew L. Stewart

Department of Atmospheric and Oceanic Sciences, University of California, Los Angeles, USA

Eastward flow in the Southern Ocean is the primary conduit between ocean basins. A comprehensive study of multi-decadal observational records and model experiments reveals that warming in the upper ocean is causing this flow to accelerate.
The circulation of the Southern Ocean is dominated by a latitudinally broad system of currents that flow from west to east. These currents include the Antarctic Circumpolar Current (ACC), which circumnavigates the Antarctic continent, and the southern limbs of the subtropical gyres, which circulate counter-clockwise around the Southern Hemisphere subtropical latitudes. These eastward currents are the primary agents via which oceanographic properties such as heat, salt and dissolved chemicals are transferred between the Atlantic, Indian and Pacific basins. The currents exist due to a combination of strong eastward winds and latitudinal variations in heat and freshwater exchanges across the sea surface. Much attention has been given to possible accelerations of these currents, particularly the ACC, due to the anthropogenically-driven southward shift and intensification of the Southern Hemisphere winds. However, observational and modeling studies consistently show that the ACC resists wind-driven acceleration. Writing in *Nature Climate Change*, Shi et al. show that the eastward flow of the Southern Ocean has, in fact, accelerated over the past several decades due to a latitudinal gradient in warming of the upper ocean. This finding highlights the need to consider both wind- and density-driven drivers of the Southern Ocean circulation in a changing climate.

The Southern Ocean exhibits patterns of large-scale circulation that are unique among Earth’s major current systems. Due to the absence of continental barriers, the strong mid-latitude westerly winds drive an uninterrupted eastward flow, the ACC, carrying volumes of water equivalent to 1000-2000 Amazon rivers. The ACC is abutted directly to its north and south by the eastward-flowing limbs of the subtropical and subpolar gyres, respectively, giving rise to a ~2000km-wide system of eastward currents across much of the southern hemisphere mid-latitudes.

A complete understanding of the controls on the strength of these currents, particularly the ACC, remains elusive. This stands in stark contrast with the subtropical gyre circulations, whose theoretical underpinnings have been developed and refined for over seven decades. These theoretical challenges arise, in part, because the Southern Ocean’s unique geometry requires that eastward wind forces be balanced by pressure forces at the sea floor, rather than at continental boundaries. Model experiments consistently indicate that this renders the transport of ACC insensitive to winds: instead, strengthening winds are compensated by an
intensified mesoscale eddy field, an effect referred to as “eddy saturation”\(^5\).

In contrast, processes controlling latitudinal gradients in seawater density have been shown to exert a strong control over zonal flow in the Southern Ocean\(^9\). The latitudinal density gradient is broadly a result of processes that create cold waters around the Antarctic continent, which are denser than the relatively warm, near-surface waters of the subtropics\(^1\). The eastward flow of the Southern Ocean is approximately proportional to the strength of this latitudinal density gradient, due to the action of the Coriolis force associated with the rotation of the Earth.

In the context of Southern Ocean climate change, both in the coming decades/centuries and in the deep past, the oceanographic community has focused on potential consequences of changes in the strength of the westerly winds\(^4\). This focus was warranted because southward shifting and intensification of the westerly winds are a well-established response to increased atmospheric CO\(_2\) concentrations. Yet observations have previously confirmed that the anthropogenically-driven southward shift and strengthening of the mid-latitude westerlies in recent decades did not appear to have accelerated the ACC\(^6\).

Shi et al.\(^7\) revise this finding via an analysis of multi-decadal changes in the flow of the Southern Ocean. The authors bring to bear a remarkably wide range of datasets and tools, drawing evidence from satellite and \textit{in situ} observations, historical reconstructions of ocean conditions, ensembles of couple climate model simulations, and idealized experiments using ocean simulations. The authors’ analysis consistently indicates that the core of the longitudinally-averaged eastward flow, around 52S, has accelerated over the past several decades (Fig. 1). In contrast, the northern flank of the eastward flow, around 35S, has decelerated and perhaps even reversed. The authors do not attribute the acceleration to changes in winds, but rather due to heat uptake in the surface ocean on the northern flank of the ACC, increasing the latitudinal density gradient and thus the strength of the eastward flow.

This study raises fresh questions about a much-studied aspect of anthropogenically-driven changes in the climate system. The evidence presented is compelling: the various different
observational and model datasets tell impressively consistent stories, and the authors have
taken care to quantify statistical significance in the diagnosed trends and to account for
potentially confounding effects of internal variability. However, it remains unclear how the
multi-decadal acceleration of the Southern Ocean zonal flow is partitioned between the major
current systems that comprise this flow. The authors’ results indicate that the eastward
acceleration is concentrated around the Sub-Antarctic Front, which approximately separates
the ACC from the subtropical gyres. Yet the observations indicate that there has been little
near-surface acceleration through Drake Passage, which is widely used in the oceanographic
community as a measure of the ACC transport. It therefore remains unclear to what extent the
diagnosed acceleration can be classified as a strengthening of the ACC, versus a southward
shift and strengthening of the eastward flow in the subtropical gyres.

Regardless of how the eastward acceleration maps onto major current systems, the findings of
Shi et al.7 highlight a climatically important shift in the large-scale circulation of the Southern
Ocean. Further work is required to establish the consequences of the eastward flow
acceleration identified in this study, for example due to more rapid transfer of heat, salt and
dissolved gases between ocean basins.

The author declares no competing interests.

References

492.

Research Papers, 36, 39–53.

10003–10020.

Journal of Climate, 19, 6382–6390.
Figure 1: Warming-induced acceleration of the Southern Ocean. Warming of the upper ocean (above 2000m depth) in the southern hemisphere midlatitudes increases the latitudinal temperature gradient between waters around the Antarctic continent and the subtropics. Via the action of the Coriolis force associated with Earth’s rotation, this strengthens the core of the longitudinally-averaged eastward flow of the Southern Ocean, centered around 52S.