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The role of the complete Coriolis force in cross-equatorial transport of the Antarctic Bottom Water

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We investigate the equatorial crossing of the Antarctic Bottom Water using a shallow water model that includes the complete Coriolis force. Most theoretical models of the atmosphere and ocean neglect the component of the Coriolis force associated with the horizontal component of the Earth's rotation vector, the so-called traditional approximation.

This approximation is typically justified on the basis that ratio of the ocean depth to the Rossby radius of deformation is negligibly small, $H/R_d \ll 1$. However, the steep topography and weak stratification in the abyssal ocean magnify the role of the non-traditional component of the Coriolis force. This is most pronounced in equatorial regions, where the traditional component of the Coriolis force is weakest and the non-traditional component is strongest. The inclusion of the complete Coriolis force gives rise to a range of very long sub-inertial waves, whose frequencies lie below the inertial frequency, in the two-layer shallow water equations. These waves have a dramatically different structure to their traditional counterparts, particularly when the stratification is weak.

We focus on the flow of the Antarctic Bottom Water from the Brazil Basin in the western South Atlantic to the Guiana Basin in the western North Atlantic. In this region, the current traverses a deep channel directed westwards and very slightly northwards across the equator. Previous attempts to model this flow have struggled to explain why the cross-equatorial transport is so high, with around 2.0–2.2 Sv exiting at the northern end of the channel.

We present analytical and numerical solutions of the non-traditional shallow water equations for the cross-equatorial flow of the Antarctic Bottom Water. We obtain analytical solutions by considering the steady-state flow of a single layer of shallow water through a northwesterly channel with a simple geometry. We assume zero potential vorticity, as it may be shown that fluid whose potential vorticity q has sign opposite to that of the Coriolis parameter f is subject to symmetric instability, and measurements confirm that the potential vorticity is indeed close to zero near the equator. The solution reveals that the transport of fluid through the channel is strongly affected by the non-traditional component of the Coriolis force. The geometry of the channel and the position of the current are also found to have a substantial effect on the solution. The combination of non-traditional effects with the bathymetry of the channel through which the Antarctic Bottom Water flows can increase the cross-equatorial transport by 50% or more, for realistic parameters.

To determine how realistic equatorial topography might influence the transport of the Antarctic Bottom Water, we conduct large-scale numerical simulations of the two-layer shallow water equations, including the complete Coriolis force. The flow into the basin is prescribed at the southern boundary, and the time-dependent shallow water equations are integrated to a quasi-steady state. We discuss some of the computational complications associated with the additional Coriolis terms, and we compare the transports predicted by the traditional and non-traditional equations.