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Thermohaline circulation induced by bottom friction in sloping-boundary basins

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We show that a velocity field in geostrophic and hydrostatic balance on the f-plane can be diagnosed from an arbitrarily prescribed distribution of buoyancy in a basin with closed depth contours. We emphasize the steady-state circulation associated with a large-scale horizontal buoyancy gradient, attained in the absence of wind forcing. For inviscid motion, the diagnosed field contains a free barotropic along-isobath flow which can be chosen arbitrarily, e.g.~in such a way that the buoyant "southern" pool of surface water essentially recirculates. Including bottom friction, we show that steady motion requires that the net Ekman transport across closed depth contours must vanish. This constraint determines the free barotropic motion and thereby the entire velocity field, which proves to be independent of the strength of the bottom friction. The barotropic flow component serves to create a "thermohaline" circulation, i.e.~a circulation which tends to spread the buoyant water horizontally. Analytical solutions and results from a numerical experiment are presented to illustrate the steady flow resulting in a basin where the upper-ocean density increases across the basin. An interesting aspect is that the depth-integrated flow forms two gyres: A cyclonic gyre harboring denser water and an anticyclonic one harboring lighter water, qualitatively resembling the circulation in the North Atlantic. Thus, the interaction between the sloping bottom and the ocean stratification serves to create a two-gyre circulation, even in the absence of wind forcing.