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On the asymmetry between cyclonic and anticyclonic flow in basins with sloping boundaries

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We present results from laboratory experiments and numerical simulations of the barotropic circulation in a basin with sloping boundaries forced by a surface stress. We focus on flows with large-scale Rossby numbers that are always significantly smaller than unity. The results of the laboratory experiments and simulations show that the cyclonic circulation follows the isobaths and the flow pattern is invariant for different strength of the forcing. For the anticyclonic circulation, the flow pattern changes with forcing strength, being similar to the cyclonic topographically steered pattern for weak forcing, and developes strong cross slope flows for strong forcing. Linear dynamics are symmetric between cyclonic and anticyclonic circulation and gives a good description of the cyclonic and weakly forced anticyclonic circulation. The analysis of the non-linear dynamics show that topographically steered cyclonic flows are all stable and steady solutions to the inviscid non-linear equations, while anticyclonic flows are not. This implies that the non-linear terms (advection of relative vorticity) are always small for topographically steered cyclonic flow. For anticyclonic flow, the non-linear terms are important when the Rossby number is larger than the Ekman number, which is the case for the anticyclonic experiments with strongest forcing. For these experiments the advection of relative vorticity prevents the flow from following topography, creating locations with strong relative vorticity and separation of the flow from the slope. The development of cross slope flow can be understood from the conservation of potential vorticity in basins with irregular topography.

The separation of anticyclonic flow from steep topography in our lab experiments and our theoretical analysis is in agreement with features like the Gulf Stream separation from the continental slope at Cape Hatteras.