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Realistic Modelling of the Gulf Stream Using Brinkman Penalization

The advantage of a smooth representation of bathymetry in terrain-following σ-coordinate ocean models is compromised by the need to avoid numerical errors on steep slopes associated with horizontal pressure gradient discretization. Geopotential z-coordinate models avoid these errors, but greatly underrepresent the interaction of flow with a topographic slope, especially when the bathymetry is underresolved. Hybrid coordinate models are also deficient because it is difficult to find a satisfactory compromise between z and σ coordinates. With volume penalization, we do not seek a compromise, but rather a correction to the usual coordinate systems that realistically recovers continuous and steep bathymetry. We derive and apply a new volume penalization method to the Gulf Stream separation problem that has puzzled modellers for decades. The method improves the representation of the flow-topography interaction and achieves realistic separation of the Gulf Stream at resolutions as coarse as 1/8 degrees. In addition, it provides a tool to separate the effect of eddy activity and topographic slope when changing grid resolution. Our results show that realistic bathymetry is more important than eddy activity in ensuring realistic Gulf Stream separation. We anticipate that a successful topographic slope correction will be valuable to climate models, as their current resolution is far from sufficient to represent western boundary currents (WBCs) using traditional coordinate systems. Our results suggest that a climate model using penalization with 1/4 degree resolution would represent ocean circulation much more realistically.