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Separation of western boundary currents: New insights from barotropic models

ANDREW E. KISS[1]

[1] *RSES, The Australian National University, ACT 0200, Australia*
email: andy@rses.anu.edu.au

Ocean circulation models often display unrealistic western boundary current (WBC) separation, and better understanding of this process is needed. Separation can be induced by isopycnal outcropping, collision with another WBC, vanishing wind stress curl, or changes in topography or boundary curvature. However WBC separation also occurs in the absence of all these features, e.g. in a single barotropic wind-driven gyre on a beta-plane with a circular no-slip boundary. WBC separation in this model is explained by considering potential vorticity (PV) balance along streamlines[1]. Fluid parcels have their PV reduced by anticyclonic wind stress in the interior, and this PV is recovered via friction in the WBC. The WBC is mostly anticyclonic, but there is also a cyclonic region against a no-slip or limited-slip boundary. In an inertial WBC this relative vorticity distorts the PV contours, delaying PV recovery in the anticyclonic region and producing excessive recovery in the cyclonic sublayer.

Previous WBC studies focused on the recirculations driven by inadequate PV recovery in the anticyclonic region. The cyclonic sublayer has been relatively neglected, but it can be crucial to separation: it acquires a PV excess (controlled by viscosity, the current's inertia, and the degree of boundary slip) which must be dissipated by viscosity before the outflow rejoins the interior. Dissipation of a large PV excess requires the WBC to separate abruptly from the coast, and also involves an adverse streamwise pressure gradient. The cyclonic sublayer is absent with a free-slip boundary, yielding a very different outflow structure.

This separation process appears to be relevant to more realistic models, and observations suggest it may be relevant to the oceans. A numerical model must resolve the thin viscous sublayer at the western boundary to capture this mechanism, perhaps explaining the high resolution needed for realistic separation.

Keywords: western boundary current separation; Gulf Stream; OGCM

References

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