The Upwelling of Downwelling Currents

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1. The problem: The term "downwelling currents" refers to currents with a downslope mass flux in the bottom boundary layer (BBL hereafter). Paradoxically, many of these currents generate the same kind of highly productive ecosystems usually associated with upwelling regimes. An outstanding example of this biological abundance are the spring blooms of the Malvinas Current, which show surface peaks of chlorophyll-a of 25-30 mg/m3, values an order of magnitude larger than those observed in typical offshore locations (Fig. 1). The food supply in the Malvinas region is so plentiful and reliable that elephant seals, which breed and molt on the Argentinean shores, cross the wide Patagonian shelf (~400 km) to feed there (Fig. 1). Unsurprisingly, this region hosts one of the largest fisheries in the southern hemisphere. Nighttime satellite pictures, for example, routinely show a dense conglomerate of squid fishing vessels whose illumination rivals the Buenos Aires and Montevideo urban centers (Fig. 1). The chlorophyll blooms of the Malvinas Current are symptomatic of the upwelling of nutrient-rich waters to the surface, but the mechanisms that may drive such upwelling are still unknown. The winds in the Patagonia region are not upwelling favorable, it is unlikely that tidal mixing is significant since the blooms occur far away from the coast, and the Malvinas Current does not generate the eddy shedding and meandering that drives the upwelling of other western boundary systems. In this poster we present a new theory to explain the development of these upwelling regions.

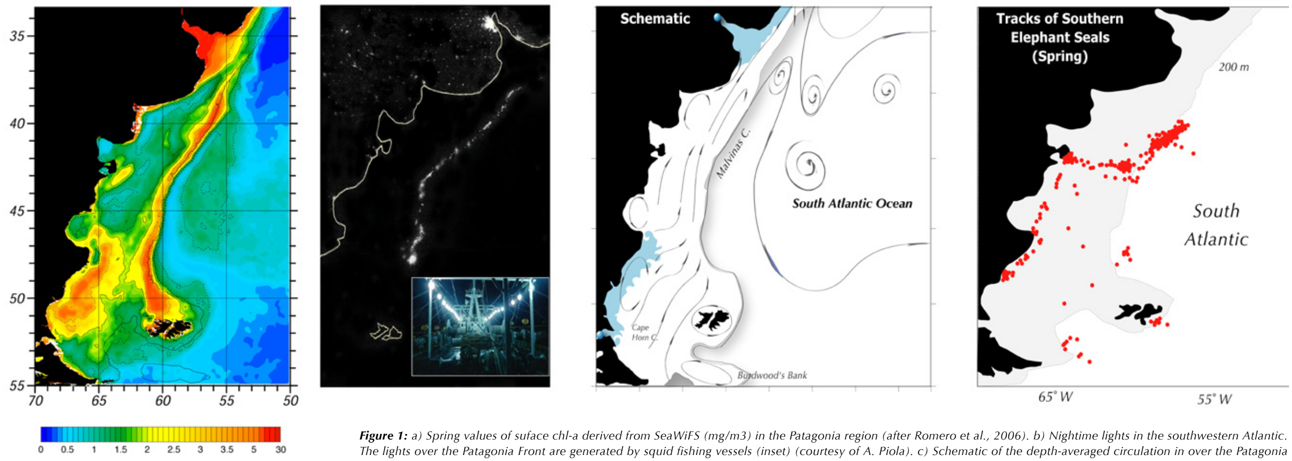
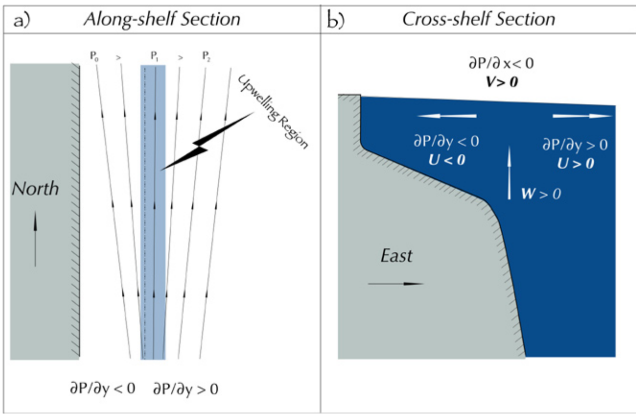


__Figure 1:__ a) Spring values of suface chl-a derived from SeaWiFS (mg/m3) in the Patagonia region (after Romero et al., 2006). b) Nightime lights in the southwestern Atlantic. The lights over the Patagonia Front are generated by squid fishing vessels (inset) (courtesy of A. Piola). c) Schematic of the depth-averaged circulation in over the Patagonia shelf and continental slope. d) Postions of radio-tracked elephant seals in the Patagonia shelf.

2. The Hypothesis: Downwelling currents travel in the direction of the coastally trapped waves. Based on the arrested topographic wave theory of Csanady (1978, JPO), we hypothesize that as these currents move along continental slopes they spread out in the cross-shore direction with one portion extending onto the shelf while its axis shifts towards deeper waters (Fig. 2a). These displacements generates alongshelf pressure gradients of opposite signs at each side of the shelfbreak, $\partial P/\partial y < 0$ over the shelf and $\partial P/\partial y > 0$ over the slope (Fig. 2a). Through quasi-geostrophic equilibrium, this pressure field generates horizontal velocities of opposite signs at each side of the shelfbreak and hence, by continuity, shelfbreak upwelling (Fig. 2b).



3. Testing: To test the proposed hypothesis we present the results of a series of highly idealized, process-oriented, numerical experiments using the Princeton Ocean Model (Fig. 3). We initialized our first experiment with a vertically uniform inflow of 0.1 m.s-1 extending over the continental slope of the upstream boundary (50 km<x<100 km, and *y*=0). The experiment was started from rest and run for 300 days. The steady state was defined as the time average of the last 30 days of the numerical integration; to corroborate the steadiness of the solutions we extended the integration to 5 years but found no significant differences with the 300-day simulation.

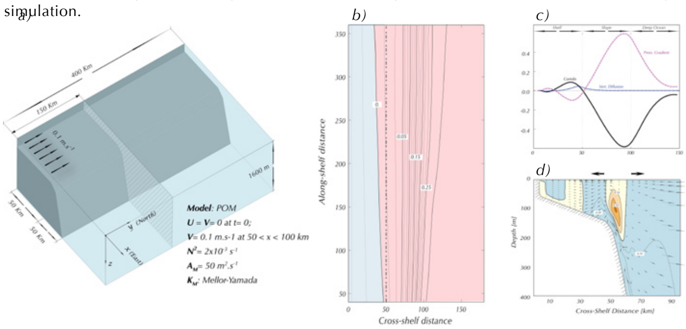


__Figure 3:__ a) Model set-up. b) Steady state stream function distribution c) Alongshelf momentum balance. Note the change of sign of the pressure gradient at the shelfbreak. d) Cross-shelf section showing vertical velocities (color and contours) and cross-shelf velocities. Note the similarity between Fig. 3b and 2a and Fig. 3d and 2b.

4. Sensitivity study: We performed an ancillary set of experiments to test the sensitivity of the shelfbreak upwelling to the inflow, bottom topography, density stratification, bottom friction, horizontal diffusion, and the presence of a shelf current.

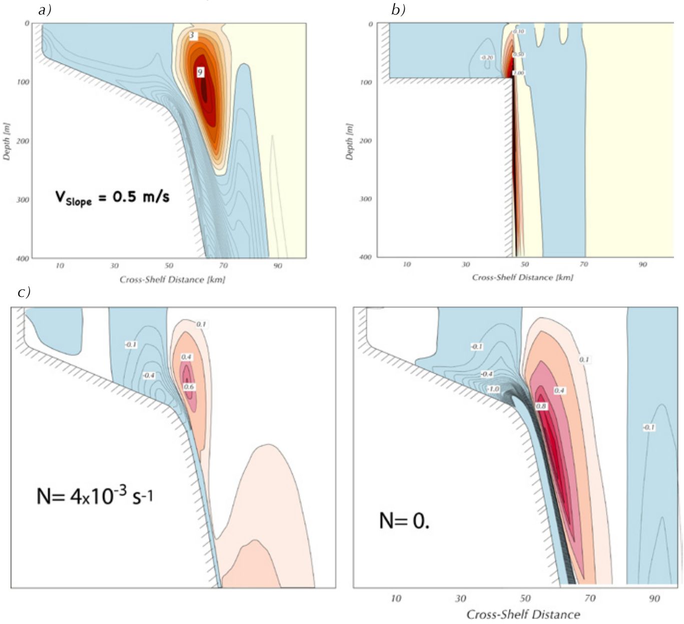


__Figure 4:__ Sensitivity of the shelfbreak upwelling to: a) magnitude of the inflow; b) the slope of the bottom topography; c) density stratification. The discussion of further sensitivity studies can be found in Matano and Palma (2007, JPO, submitted)

5. Reality check: To further assess the robustness of the proposed mechanisms we analyzed the results of a highly-realistic 3-D simulation of the southwestern Atlantic and compared it with observations.

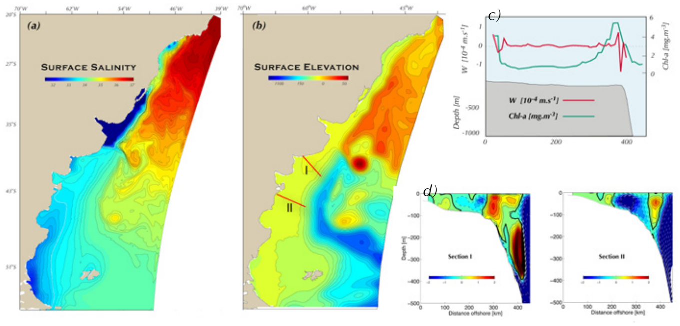


__Figure 5:__ a and b) Snapshots of surface salinity and elevation in a 3-D simulation of the southwestern Atlantic; c) comparison of vertical velocities in the model (red) and chl-a observations (green line); d) cross-sections I and II of vertical velocities in the model