Coastal retention in upwelling currents: Mechanisms and sensitivity to wind forcing

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The Setting: Eastern Boundary Currents (EBCs)

From The Sea v. 11, Hill et al. 1998
Motivation: Benthic Larval Transport
Larval Transport Paradigms in Eastern Boundary Currents

Older:
- The well-mixed larval pool
- Upwelling relaxation => high settlement

Newer:
- Linear, diffusive, alongshore advective transport
- Gaussian dispersion kernel

Newest:
- Eddy-driven intermittent dynamics
- Stochastic/packet model
- Lagrangian coherent structures map transport pathways

The Tattered Curtain
Roughgarden 1988
Largier 2003
Siegel et al. 2008
Harrison et al. MEPS 2013
The Tattered Curtain Hypothesis

Physical Hypothesis:

- Curtain is the upwelling front billowing in the wind, interacting with eddies
- Tattered by eddies and filaments, esp. at headlands
- Convergence at front
- During relaxation front collides with coast

Roughgarden et al. 1988, 1991
Harrison et al. MEPS 2013, Mitarai et al. 2008, Siegel et al. 2008
Particle “Larvae” Model

Harrison et al. MEPS 2013, Mitarai et al. 2008, Siegel et al. 2008, Har

Coastal jets: A mechanism for retention

Retention/settlement tends to be semi-coherent along the coast, moderated by a tattered upwelling jet

Settlement Diagram: alongshore settlement through time
A quasi-retentive upwelling jet

- Material in interior of jet
- Jet controls retention and settlement patterns
- Some jet segments linear and coherent
- Some tattered by filaments
Jet Transects

- Material concentrated within high shear zones
- Near the core of the jet
- On either side of the upwelling front
Retention (settlement) and Wind

“Settlers” = 20-40 days old and < 10km offshore
Wind & Settlement Statistics
(single run)

- Settlement shows a strong correlation ($r = 0.75$) with a 20-day integrated wind product.
- Some settlement patterns better predicted by 2-5 day wind product.
- Lack of settlement more predicted by long bouts of upwelling favorable winds, “tattering” the upwelling jet.

Note: wind and settlement normalized.
Wind & Settlement Statistics (Ensemble Results)

• In the CCS-box model, extended, strong upwelling completely tatters the upwelling jet and moves potential settlers far offshore.

• There is a positive correlation between 20-40 PLD settlement and the integrated alongshore wind, peaking at $r = 0.63$ for a 20-day integrated wind ($W$).

Correlation of lagged wind (left) and integrated wind (right) and settlement as a function of window size for the 28 run ensemble.
The Tattered Curtain Hypothesis Revisited

Physical Hypothesis:

Harrison and Siegel, submitted to LO:FE

• Curtain is the upwelling front jet billowing in the wind, interacting with eddies
• Jet is tattered by eddies and filaments, esp. at headlands
• Convergence at front Retention in jet core
• During relaxation front collides with coast Moderate upwelling keeps jet at coast regionally
Moving beyond the Bakun upwelling index

- The tattered upwelling jet is an emergent feature in upwelling systems
- There is **LOCAL** reduction of upwelling by coastal velocity shear:

\[ \text{Bakun: } f u_E = \frac{T_y}{\rho} \]

\[ u_E \frac{\delta v_G}{\delta x} + f u_E = \frac{T_y}{\rho} \]

\[ u_E = \frac{T_y}{\rho}(f + \frac{\delta v_G}{\delta x}) \]

= reduction of Ekman transport

Brink 1987, Woodson et al. 2013
Land of the upwelling jet

Broitman et al., 2008, Ecol. Mono
Coastal Retention in Iberian EBC

Domingues et al. 2012 PloS ONE

Crab larvae
Conclusions

• The upwelling jet partially retains material released over the shelf, broken up by filaments.
• Strong upwelling winds tatter this jet, moving material offshore in complex patterns.
• The response of the jet to wind is nonlinear, making predictability limited in this high energy region.

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