The Tattered Curtain Hypothesis Revisited

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The Tattered Curtain Hypothesis

In the 1980's a paradigm emerged to explain the observed larval distribution and settlement patterns off the California coast[1].

The upwelling front:

- Controls settlement
- Is broken up by squirts, filaments and eddies
- Is a convergence zone

Its location depends on wind:

- Strong upwelling winds move front offshore
- Wind relaxation moves front onshore, causing a settlement pulse

Explains observations:

- Spatial concentration of larvae
- Species distributions across upwelling front
- Large, discrete pulses of settlement

Expected in all eastern boundary currents where there is:

- A narrow shelf
- Coastal upwelling
- Larvae released during upwelling

Key
Green = yes
Red = no
Blue = maybe

CCS-in-a-Box Model

A ROMS 3D ocean model of an idealized California Current is forced by temporally-variable upwelling favorable winds[2]. Larvae are modeled as **passive surface drifters** released daily from the nearshore (< 10 km) on a 2km grid. Here we define potential settlers as 20-40 day old larvae (PLD) that have been transported back to the nearshore.

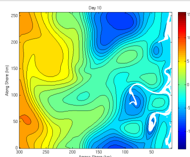

Fig 1. Model sea surface height and a single larval release after 10 days. The model is alongshore periodic (N/S) and open in the western boundary.

Lagrangian Coherent Structures (LCS)

Lagrangian coherent structures (LCS) are a type of transport boundary, identified by regions of high relative dispersion between particles advected in the model flow fields. The finite time Lyapunov exponent (FTLE) detects two types of LCS: **hyperbolic** and **shear**[3].

$$FTLE(\vec{x},T,t_0) = \frac{1}{|T|}\ln\left\| d\vec{x}(\vec{x},T)/d\vec{x}(t_0)\right\|$$

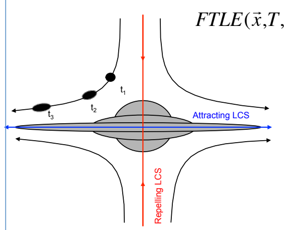

Fig 2. Hyperbolic LCS are associated with Lagrangian saddle points, where nearby particles diverge in forward time (blue) and backward time (red).

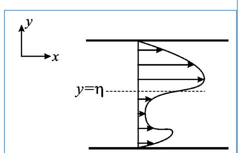

Fig 3. Shear-type LCS form where velocity gradients are maximal (here at η). Their sensitivity to perturbation is unknown.

Modeling the Tattered Curtain

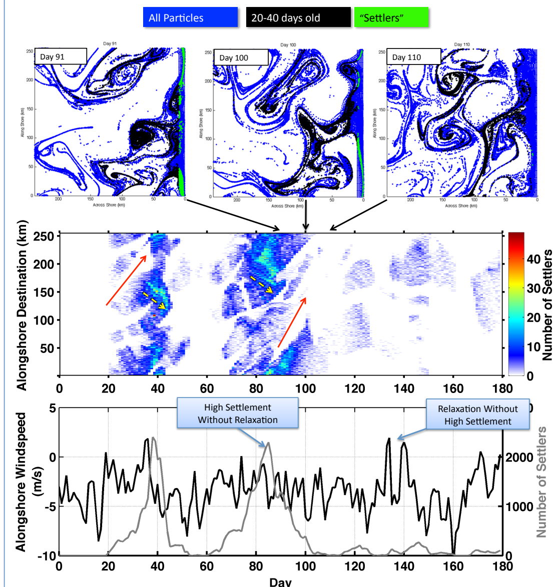

Fig 4.

Top: All raleases (blue), mature larvae (black), and settlers (green) on the model surface. Settlement is largely controlled by a nearshore jet broken up by squirts and moved on and off shore by meanders. This jet often breaks up, moving settlers offshore incoherently.

Middle: Settlement through one model run. Squirts and meanders propagate poleward (red arrows), while packets (and anti-packets) propagate equatorwards (yellow arrows). Spatial patterns are quasi-coherent across the model shoreline.

Bottom: Alongshore wind (black) and number of settlers (grey). Some settlement events correspond with wind relaxation events, with a 2-5 day lag (day 40). Other large settlement events occur during persistent upwelling (days 60-100), and some relaxation events do not lead to settlement

Conclusion: The upwelling jet moderates large spatial patterns of settlement, and has a complex relationship with wind. Dense packets[2,4,5] move equatorward within the jet while meanders and squirts move poleward. Settlement is high when the jet exists for sufficient time and is close to shore.

The Gaussian Jet

Oceanic jets tend to be Gaussian in shape (e.g. Kundu, [6]). In the case of a coastal upwelling jet, geostrophic balance predicts the maximum velocity will coincide with the maximum SST (and thus SSH) gradient, along the upwelling front. But where are the transport boundaries?

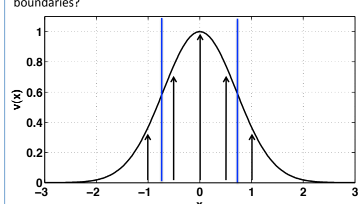

Fig 5. Gaussian Jet with A = L = 1.

The system
$$\begin{cases} \dot{x} = u = 0 \\ \dot{y} = v = A\exp(-x^2/L^2) \end{cases}$$

has the solution
$$\begin{cases} x(t) = x_0 \\ y(t) = y_0 + At\exp(-x^2/L^2) \end{cases}$$

and the maximum velocity gradient dv/dx occurs at x = ±L√2/2. These are effectively momentum barriers, where the change in momentum needed to move in or out of the jet is greatest. Note these barriers are on either side of the upwelling front (x = 0), not along it.

The relative dispersion, $\partial y/\partial x_0 = (-2Ax_0t/L^2)\exp(-x_0^2/L^2)$, is also maximized at x = ±L√2/2, and depends exponentially on the initial condition x_0. The FTLE metric will pick up this shear-type LCS boundary as a maximal curve in both forward and backward time.

Wind and Settlement

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 0.63 for a 20-day wind integration window.

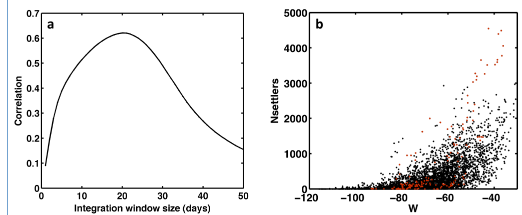

Fig. 6 Correlation of integrated wind and settlement as a function of window size for the 28-run ensemble **(a)**. 20-day integrated wind product (W) and number of settlers over the ensemble **(b)**, with model run 113 (outlier) in red.

Finding the Jet Boundary (in progress)

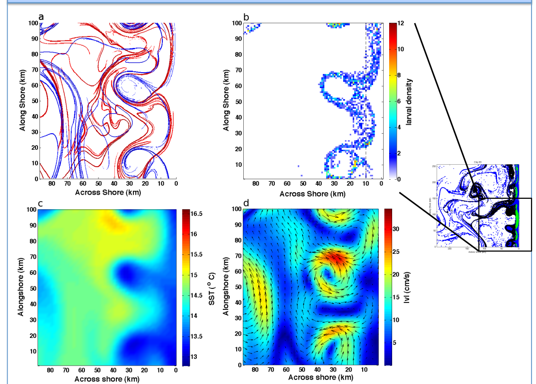

Fig 7. Dynamics of the coastal jet for day 81. LCS (a) trap settling-age larvae (b) into an up-welling jet (d). SST (c) shows the upwelling front is *inside* of the region of high larval abundance, not along it's boundary.

Preliminary results show that the outer jet boundary is offshore of the maximum SST gradient (the upwelling front) and coincides with the maximum velocity shear (not shown), as predicted by the Gaussian jet kinematic model.

Questions: Is this boundary structurally stable? Are shear-type and hyperbolic LCS mutually exclusive? Can we predict under what conditions this jet exists?

References

[1] J. Roughgarten, *AOE*, 1991
[2] S. Mitarai et al., *JMS*, 2008
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[6] P. Kundu, *Academic press*, 1990