Retentive structures, transport and connectivity in coastal ecosystems: using a quantitative particle tracking metric to describe spatio-temporal patterns

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Roadmap
An introduction to what we are doing and why.

Methods

Conclusions/Summary
August 2000 Survey

From Batchelder et al. (2002)
Mesoscale Structures

- 10's to 100's of kilometers
- Persistence of weeks to months
- Have strong energetic interfaces; physical energy augments trophic energy of biological system (Bakun)
  - Biological production
  - Life cycle closure (larval retention sensu Sinclair)
- Associated biological structures on similar spatial and temporal scales
- Types: upwelling fronts, river plume fronts, shelf break fronts, eddies
Focus on this

Delta x = 20 km  Delta x = 10 km  Delta x = 3 km  Delta x = 1 km
# Implementation

## RCCS

**Domain:** 41 - 45.5N, -126.7 - 123.5E

**ROMS:** 166 x 258 x 42 gridpoints (~1 km res.)

COAMPS wind forcing; Blended product using 9-27 km resolution, but mostly 9 km over RCCS domain

Initial/boundary conditions provided by NEP model simulation from 2002.

Forward run for 2002

Daily averaged physical snapshots of velocity, temperature, etc.

## NEP

**Domain:** 20 - 73N, 115 - 210E

**ROMS:** 226 x 642 x 42 gridpoints (~10 km res.)

Subdaily (6 hr) T42 CORE wind and fluxes (Large and Yeager)

Initial/boundary conditions provided by CCSM-POP hindcast model

Forward run for 1958-2004—includes multiple El Nino’s, Regime Shifts, and 2002 cold intrusion

Daily averaged physical snapshots of velocity, temperature, etc.
Typical horizontal velocity field
This one is from 5m on 1 July 2002

Alongshore upwelling jet
Large offshore eddy
Sluggish flow

Note: only every 3rd vector is plotted in both LON and LAT directions.
50,000 initial locations randomly selected

70 <= Bottom depth <= 500 meters

Latitude = 42-45N

(Averages ~ 1-2 indiv/km²)

Depth of particle was randomly assigned to be within 10-100m

Beginning on 2 Jan 2002, each particle was 3D-advedted for 15 days based on trilinear spatial & linear temporal interpolation of velocity fields with dt=1 hr; a new simulation (same starting locations) was begun every 7 days for all of 2002 (total of 53 simulations)
Subset of 50 of 50,000 particles selected for plotting

Circle (start loc); Blue (ET=0-7.5d); Magenta (ET=7.5-15d); Grn circle (grounded)
Untangling spaghetti . . .

Retention Indices and Metrics

• Displacement distance at some elapsed time
• e-flushing time for a specified control volume (distance)
• retentive vortices (size, location, persistence)

Connectivity Indices and Metrics

• Transition Probability Matrix Plots
• Sources and Destinations
Retention Indices and Metrics

Calculation Basics

Indices and Metrics require gridding of continuously distributed data.

For this domain, the 3° of Latitude and 1° of Longitude were gridded into 5’ bins, producing a display grid of 12 x 36. (432 cells total)

Displacement: Straight-line distance from origin to location at some later fixed $\Delta t$; median, mean, std; usually eliminate particles with boundary interactions from statistics ($\Delta t$ dependent)

E-flushing time: Time for a fixed fraction of particles within a control volume (or distance) to be lost from the volume ($\Delta d$, $\Delta V$ dependent)
E-flushing Time ($F_e$)

- select a distance (r) or control volume
- track fraction (f) remaining within r of initial location as function of time (t)
- note time when f declines to < 1/e (~0.368)
Start: 2 Jan 2002; Period of N flow; Particle counts are higher for initloc in south and lower velocity regions.
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Displacement distances have spatial biases when the boundaries of the domain are encountered (drifter-boundary bias).

Low particle count reflects loss of particles to boundary interactions—may lead to displacement underestimates.

Less boundary bias in local distance based metrics.
Well behaved “flushing” with single transition through threshold

Number of threshold crossings not ONE; rather 0 or >1; zero = slow, but regular flushing; >1 indicates substantial recirculation
RCCS
19 Jun 2002 start

ET = 7 days

Strong Upwelling; southward transport
Probability that an indiv starting in grid cell (Y-axis) will be located in grid cell (X-axis) after 7 days. Numbering of grid cells is by row from lower left (SW) of domain to upper-right (NW). This shows southward movement of particles.
Comparison of 1 km and 10 km grids

12 Jun 2002

Hi-resolution RCCS shows recirculation on shelf whereas low-resolution fields show alongshore flow only.

Blue traj = 15 d

Blue + purple traj = 15 d

10 km grid

RCCS

NEP

1 km grid

Coos Bay

Cape Blanco

Newport

Delta x = 20 km
Delta x = 10 km
Delta x = 3 km
Delta x = 1 km
NEP 10 km simulation shows greatest e-flush times nearshore, likely due to boundary effects.

RCCS 1 km simulation shows greatest e-flush times near center of Heceta Bank—not immediately adjacent to shore; does a better job resolving coastal upwelling.
Now for something different...

**Ant Algorithm**

- based on the behavior of social insects (like ants, bees)
- social insect interactions are self organized and based on local information
- Ant algorithms have been used to solve large combinatorial optimization problems (e.g., traveling salesman and similar)
- recently used to identify retentive structures in hydrodynamic fields (Segond et al., 2004)
Ant Algorithm – basics

• Ants move iteratively from one cell to one of 8 neighbors

• direction of stream ($\alpha$); ants are allowed a maximum 45° deviation from stream direction (max of 3 destination cells)

• velocity of the flow in destination cells ($\mu$)

• pheromone concentration ($\phi$) in destinations (by population/colony/ant)

• individual ant bias ($\beta$)

• my Ant algorithm is derived from, but not identical to Segond et al (2004)

• fitness of 3 destination cells is determined by:

$$F_i = f(\alpha, \beta, \mu, \phi)$$

Scale F so $\Sigma F = 1$,

Generate $UV(0,1)$ to determine destination.
Ant Assessment of “Potentially” Retentive Regions

Depth = 15 m

RCCS

22 Initial Colonies of 16 ants/colony
Retention regions matter for productivity and recruitment processes, but also for sink processes. Retention regions may indicate regions susceptible to hypoxia and/or anoxia.

http://www.piscoweb.org/research/oceanography/hypoxia
Summary and Conclusions

• Various metrics for retention and connectivity are available; some have fewer biases than others (boundary encounters in particular can create biases)—e-flushing time has less bias than displacement distance.

• Destination maps and source maps are useful for identifying regions that should be high priority for protection (in a MPA sense) and regions that might withstand higher harvest impacts, respectively.

• EOFs of e-flushing time series identify regions of strong co-variability (not shown).

• Retention and connectivity matrices are resolution (scale) dependent (comparison of patterns from 10 km and 1 km resolution models).
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