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

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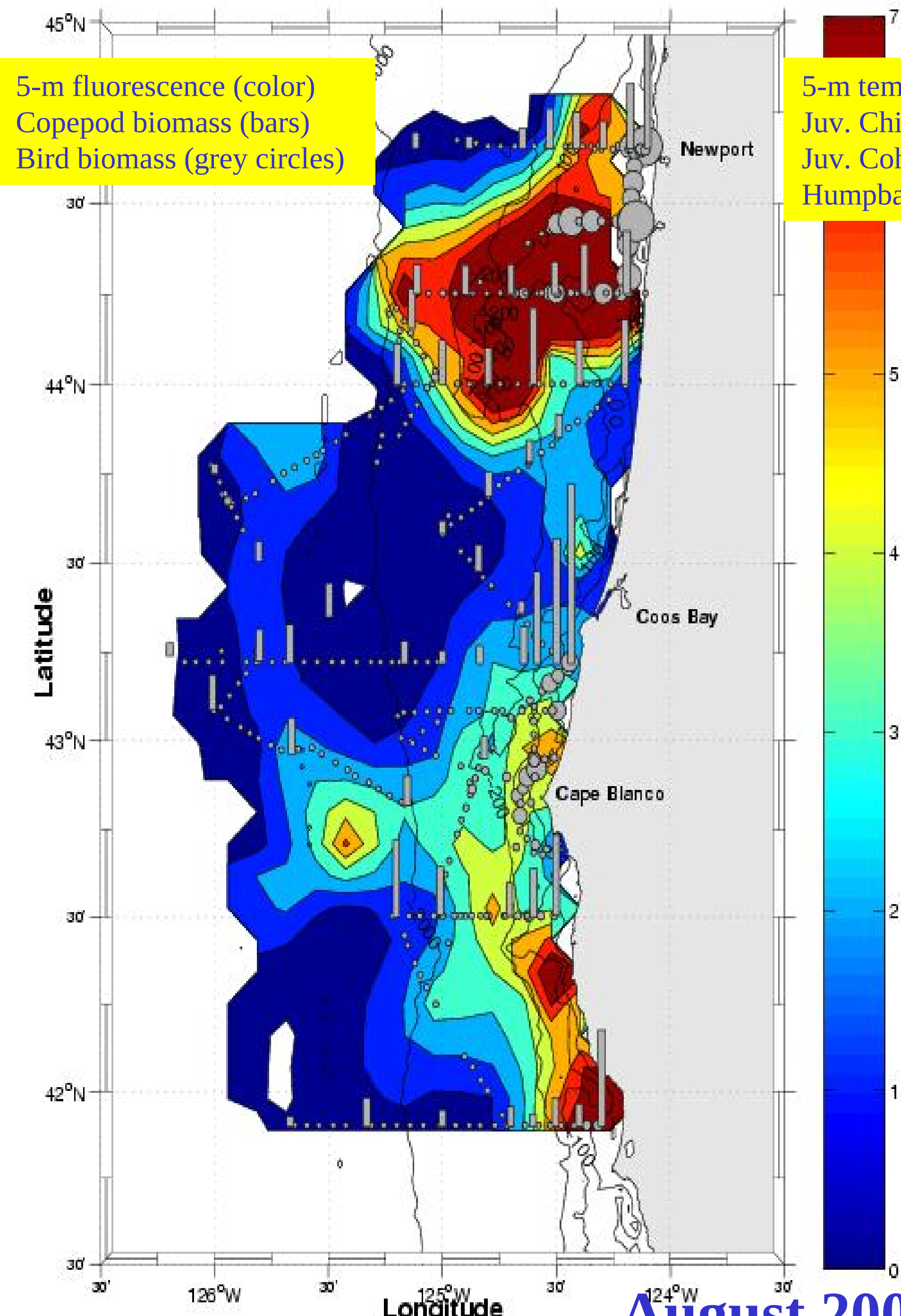
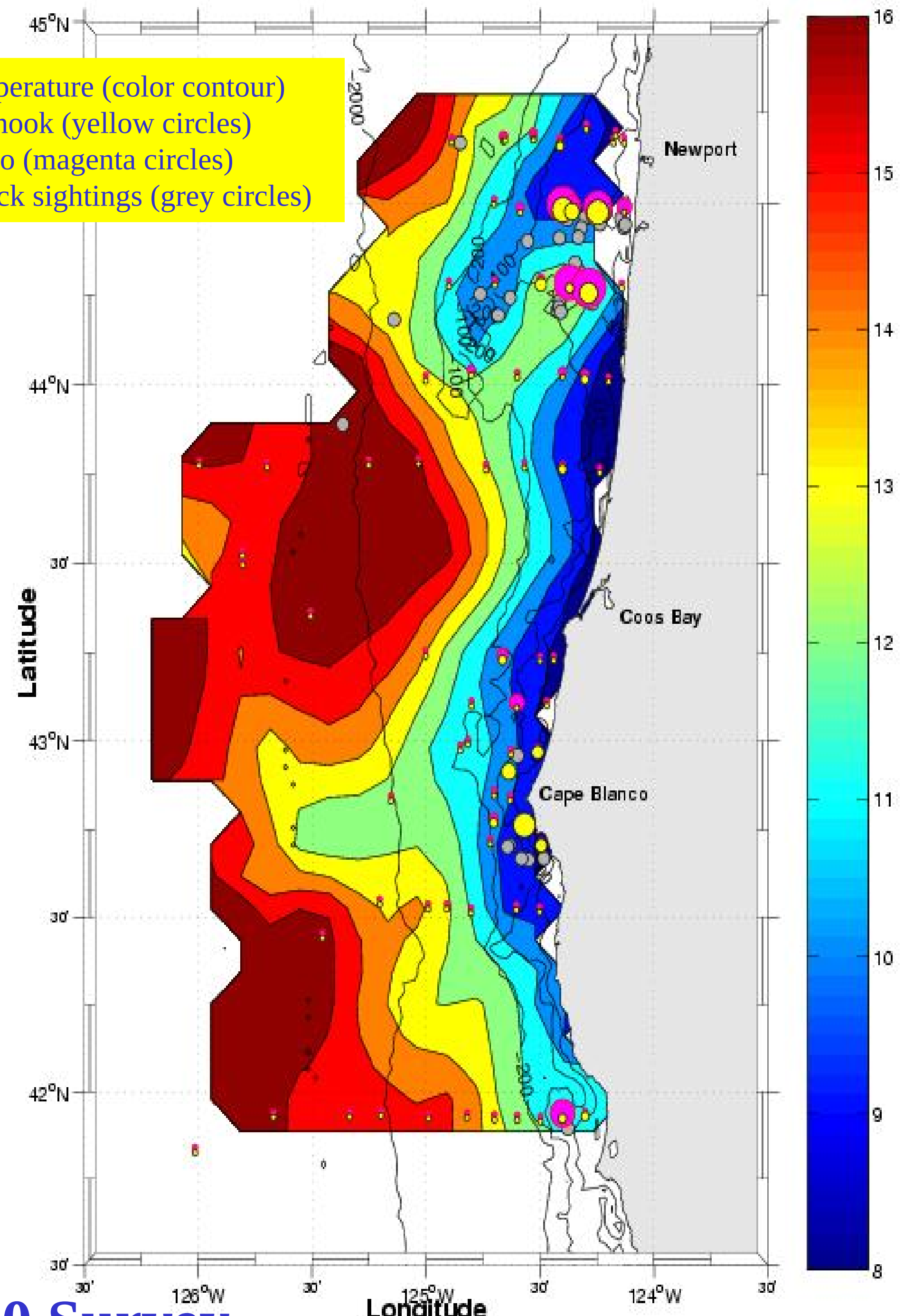
Roadmap

An introduction to what we are doing and why.

Methods

Conclusions/Summary



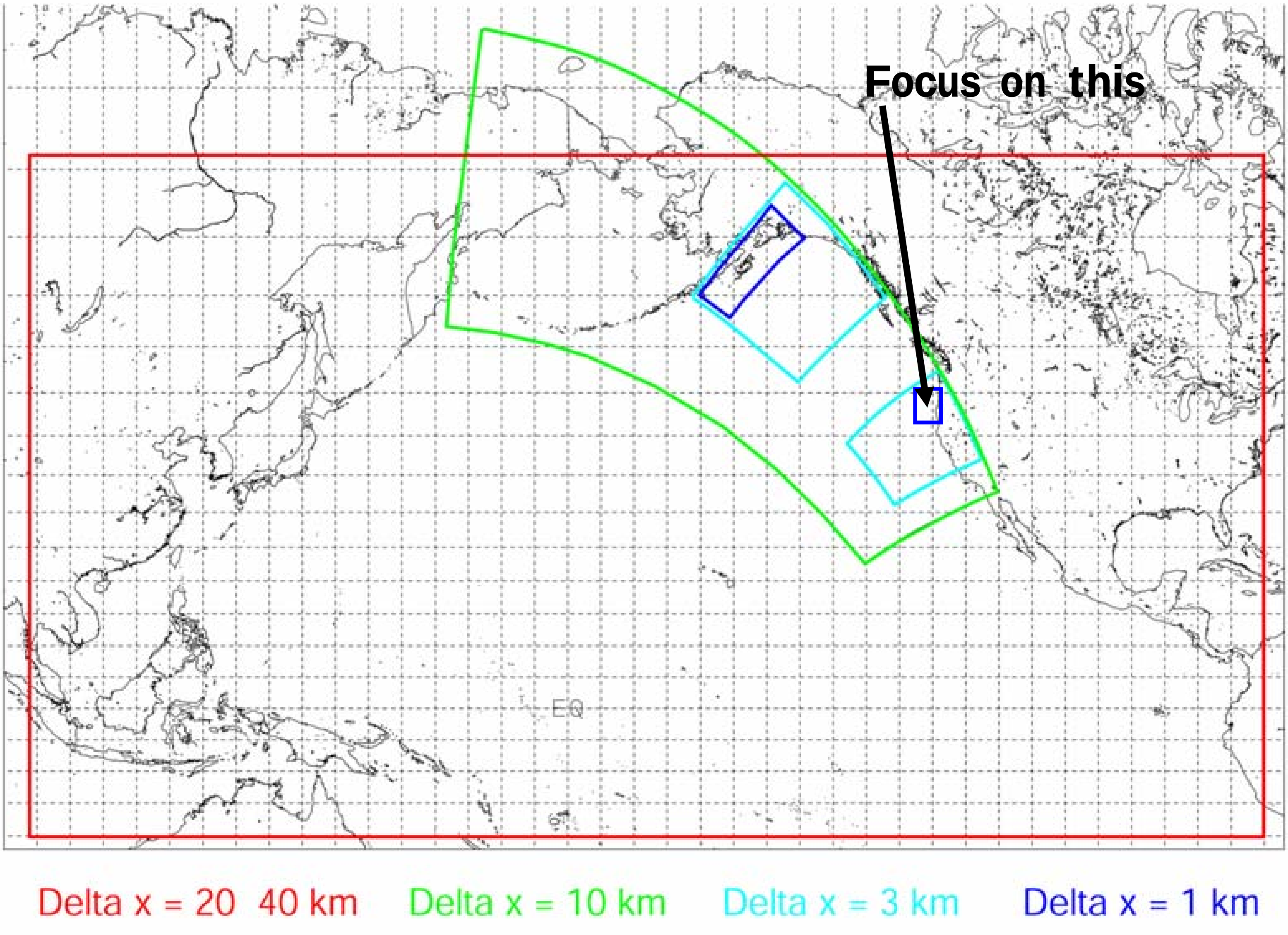


August 2000 Survey

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
EQ
Delta x = 20 40 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.

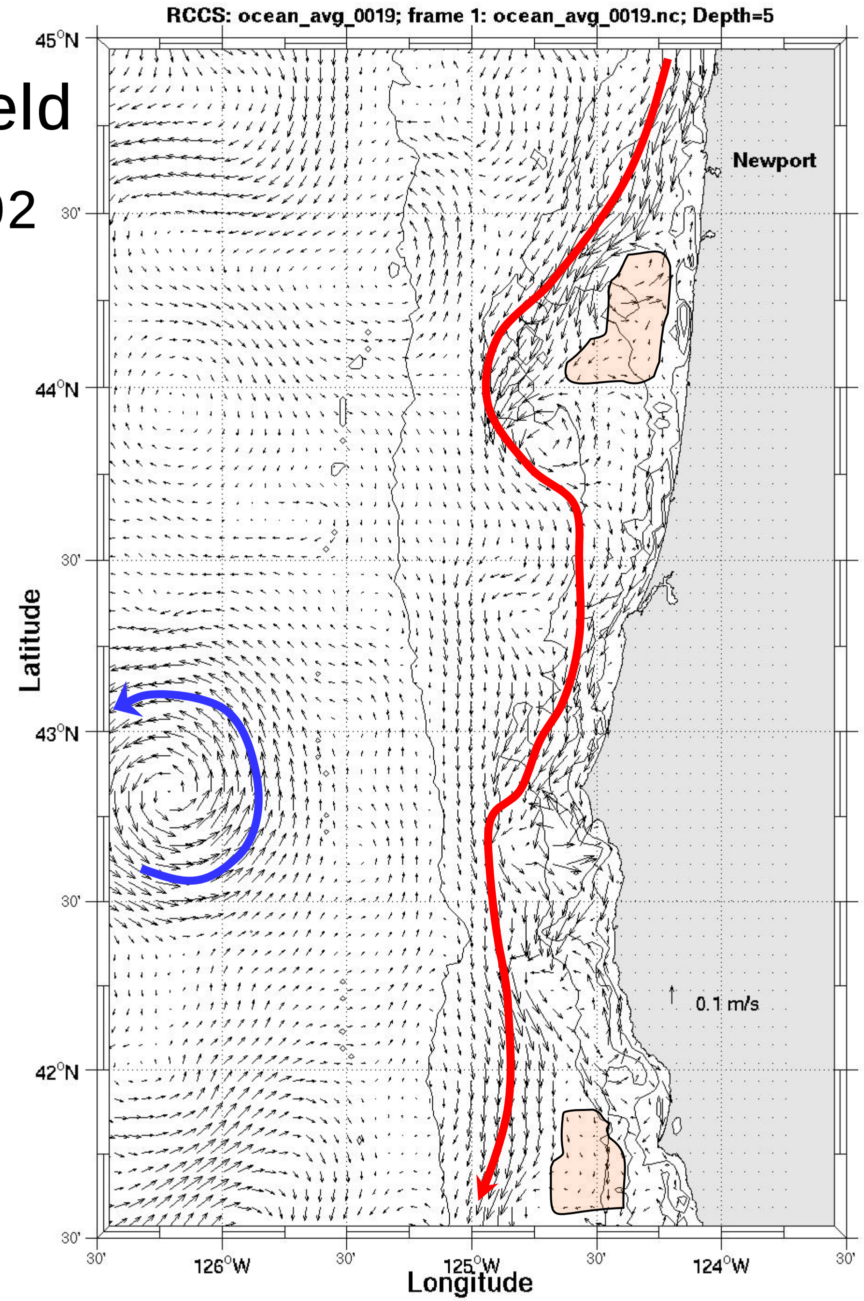
Typical horizontal velocity field

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

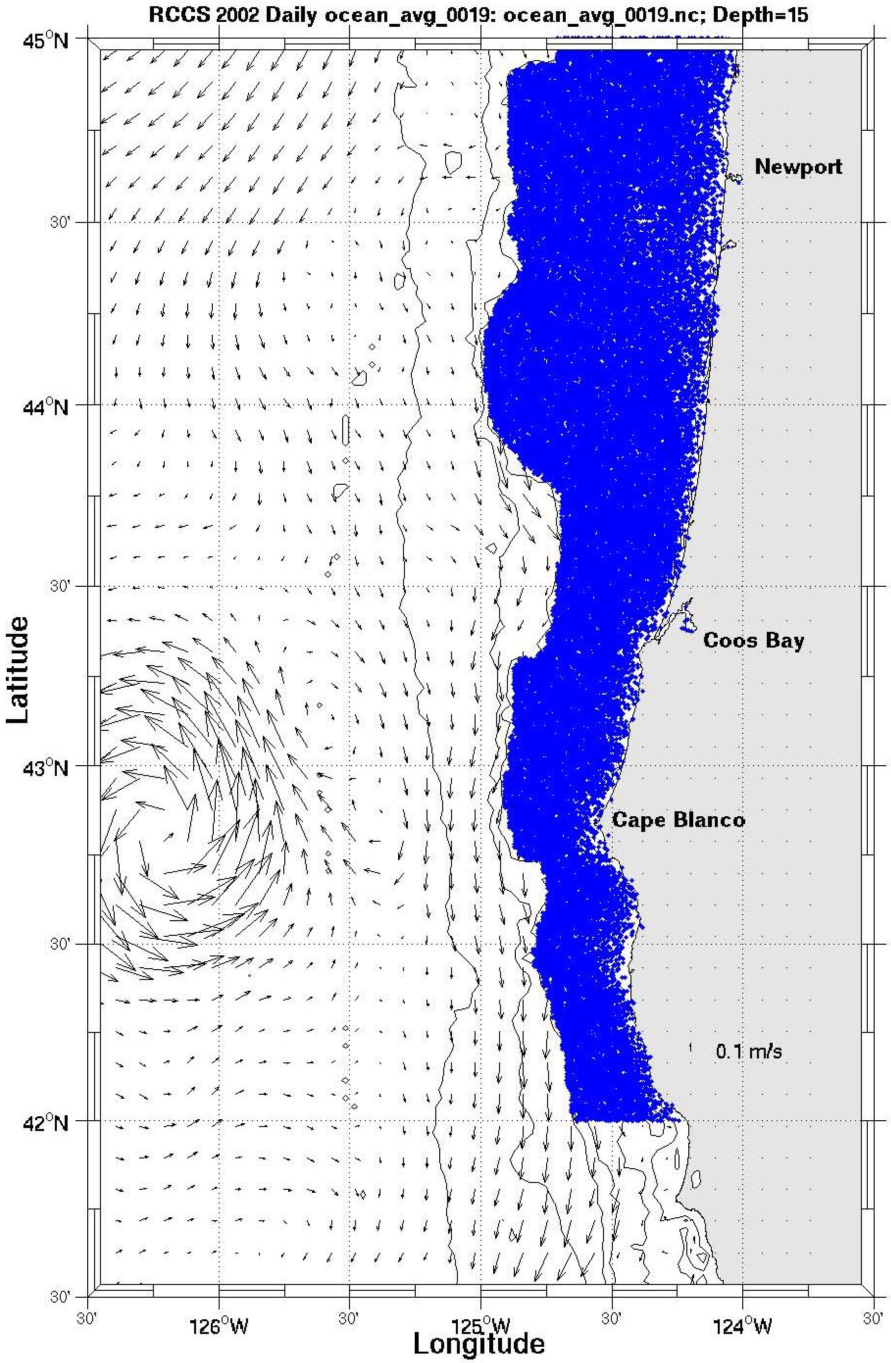
70 <= Bottom depth <= 500 meters

Latitude = 42-45N

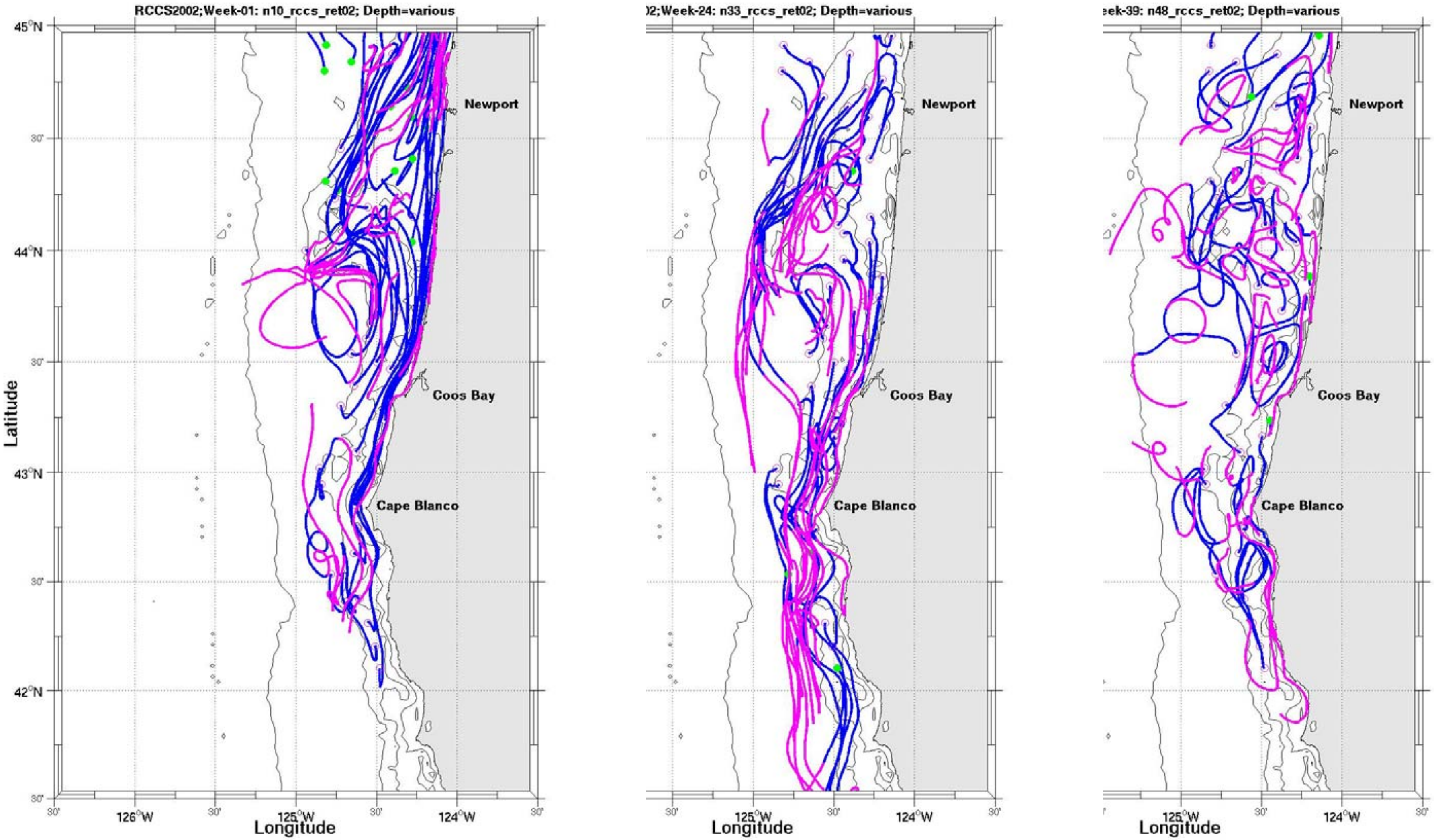
(Averages ~ 1-2 indiv/km^2)

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

Beginning on 2 Jan 2002, each particle was 3D-advected 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)



2 Jan | 12 Jun | 25 Sep



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

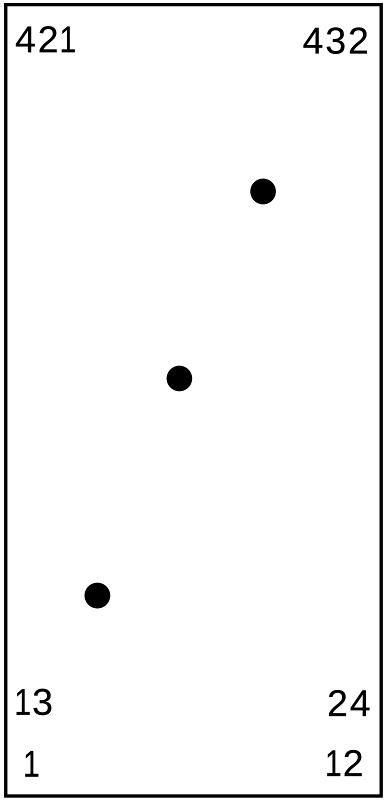
- Displacement distance at some elapsed time
- e-flushing time for a specified control volume (distance)
- retentive vortices (size, location, persistence)

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.

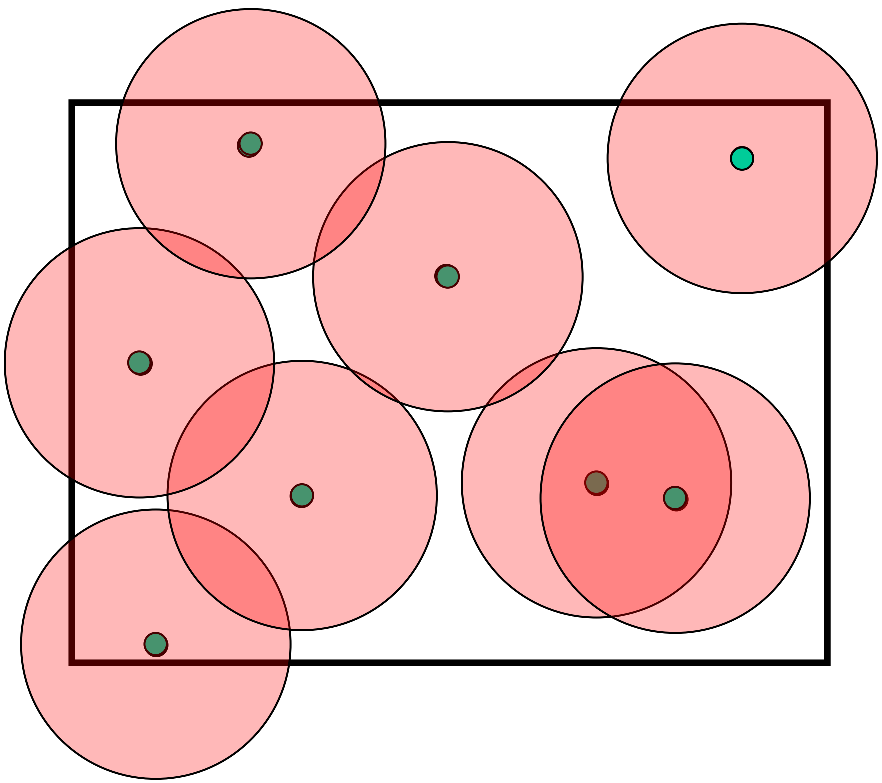
For this domain, the 3° of Latitude and 1° of Longitude were gridded into 5' bins, producing a display grid of 12 x 36. (432 cells total)

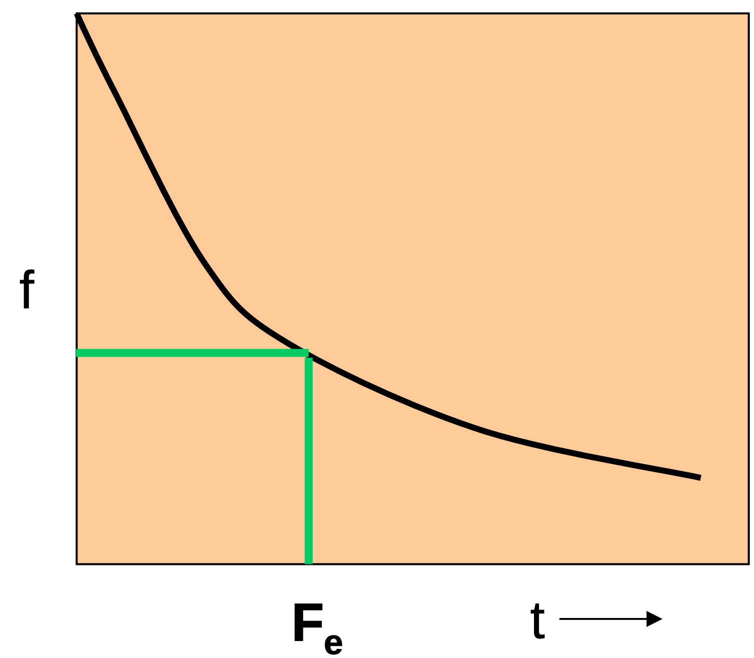
Displacement: Straight-line distance from origin to location at some later fixed Δt; median, mean, std; usually eliminate particles with boundary interactions from statistics (Δt dependent)

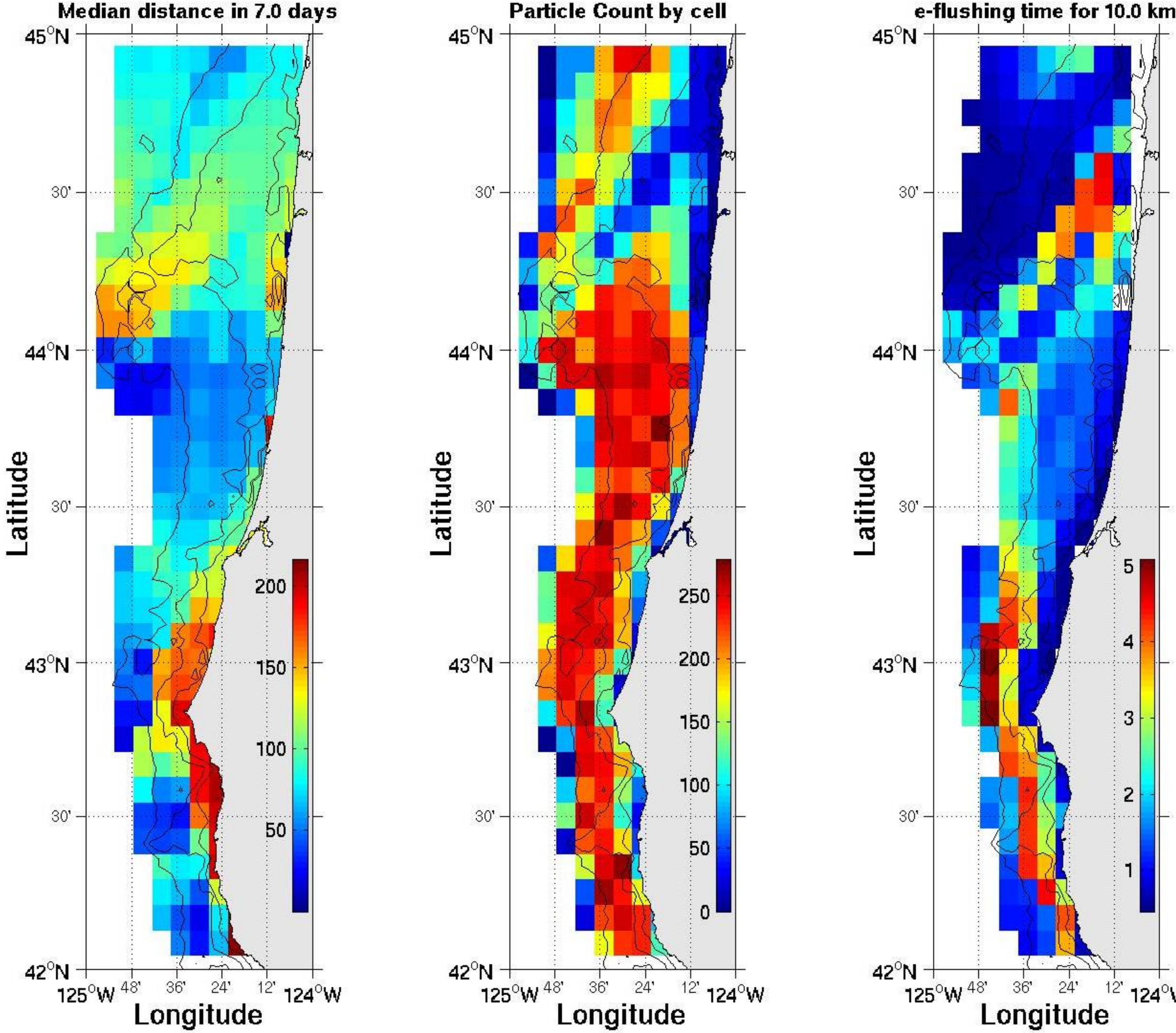
E-flushing time: Time for a fixed fraction of particles within a control volume (or distance) to be lost from the volume (Δd, ΔV dependent)

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)



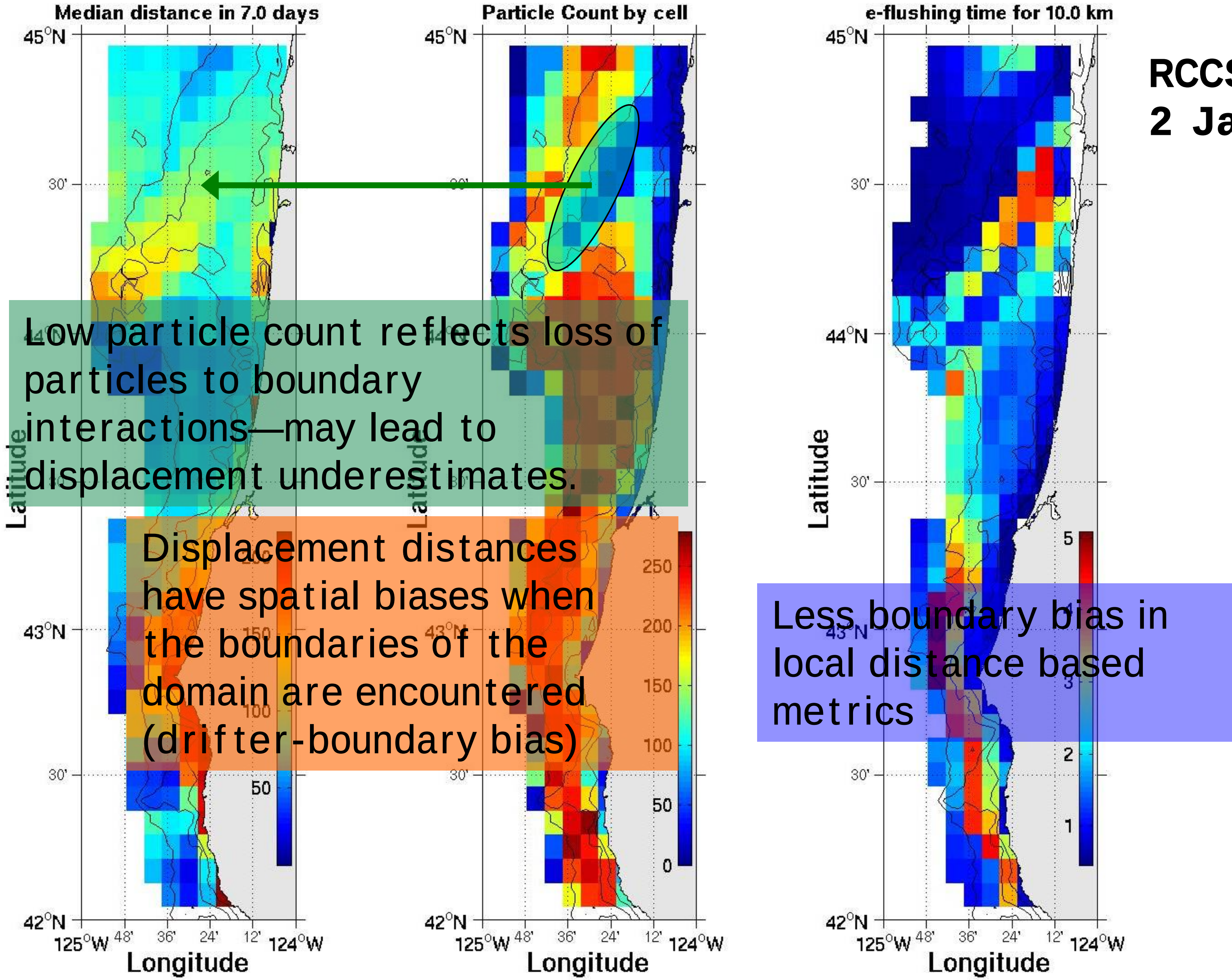




RCCS
2 Jan

Start: 2 Jan 2002; Period of N flow; Particle counts are higher for initloc in south and lower velocity regions

RCCS
2 Jan



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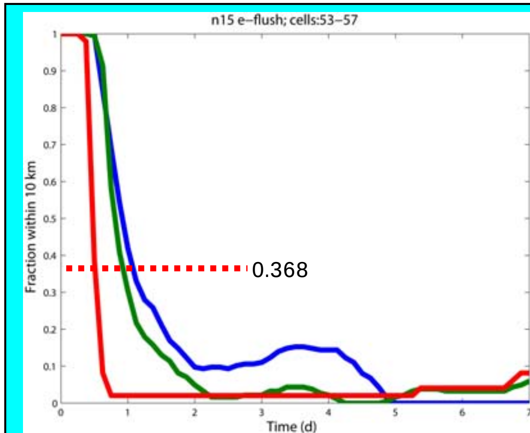
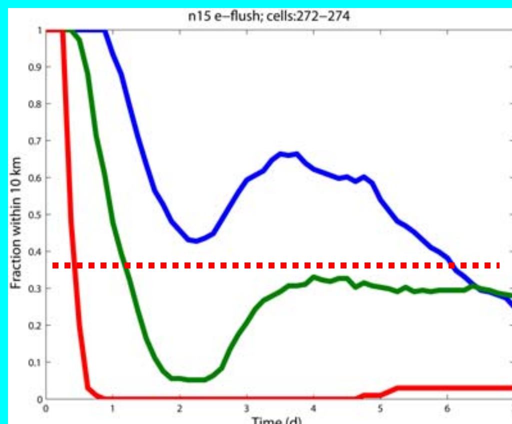
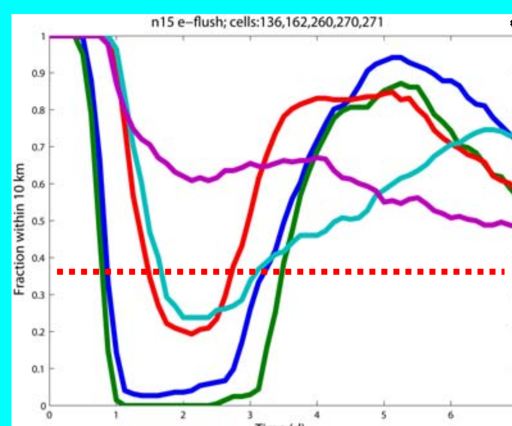
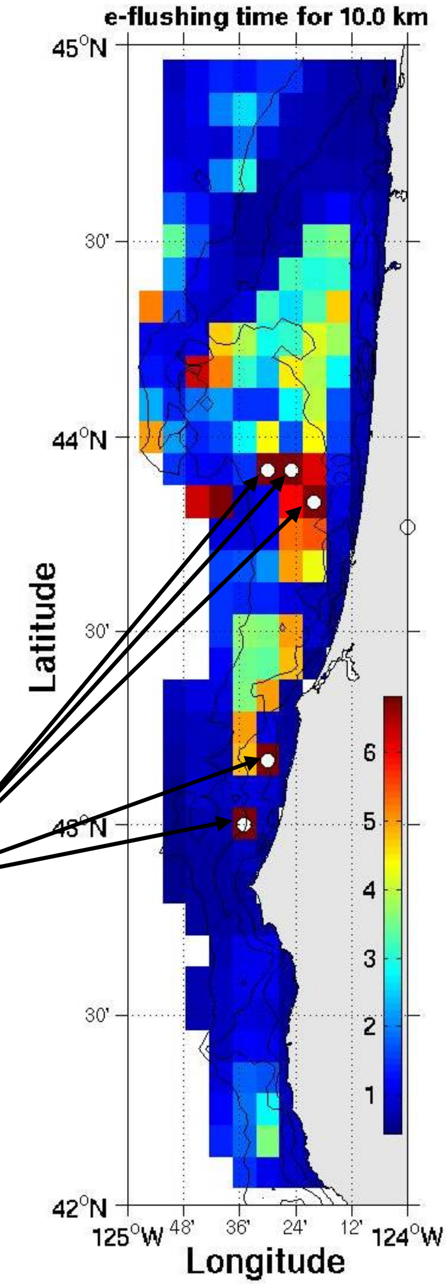


Well behaved "flushing" with single transition through threshold

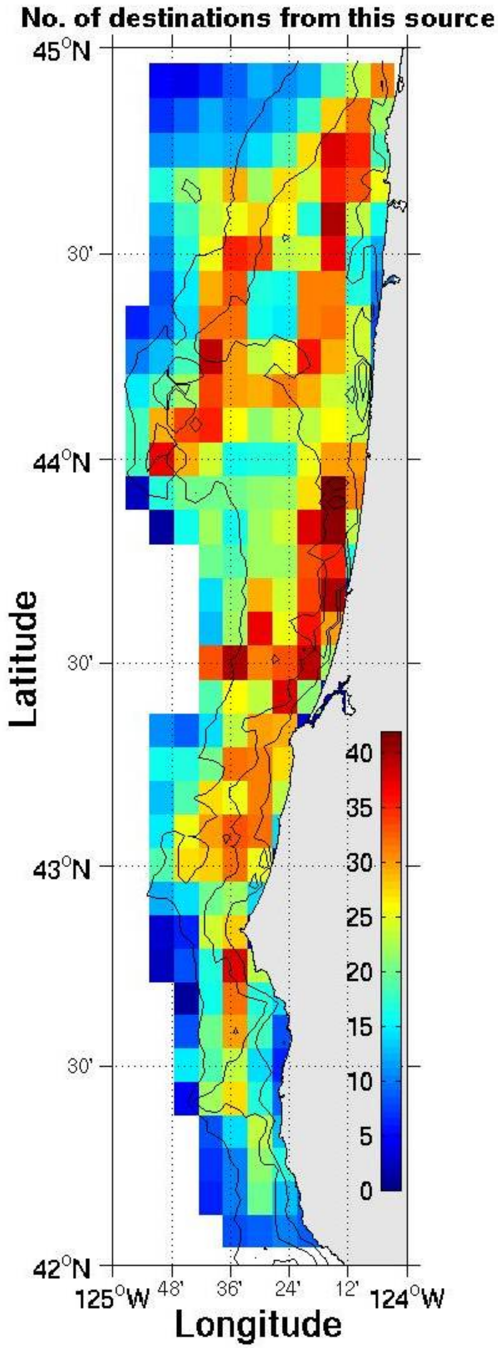


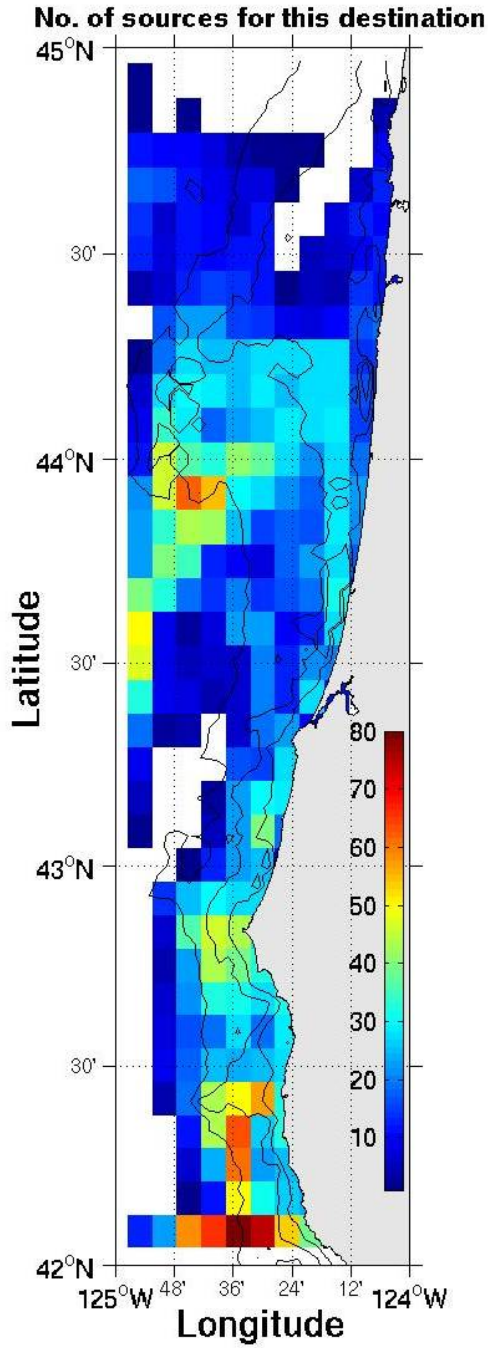
Number of threshold crossings not ONE; rather 0 or >1; zero = slow, but regular flushing; >1 indicates substantial recirculation





RCCS
6 Feb

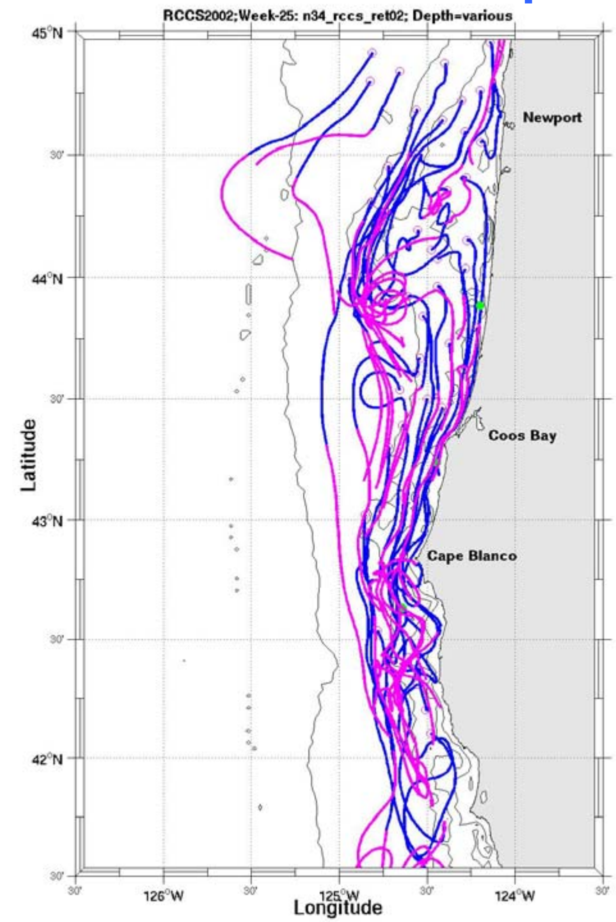




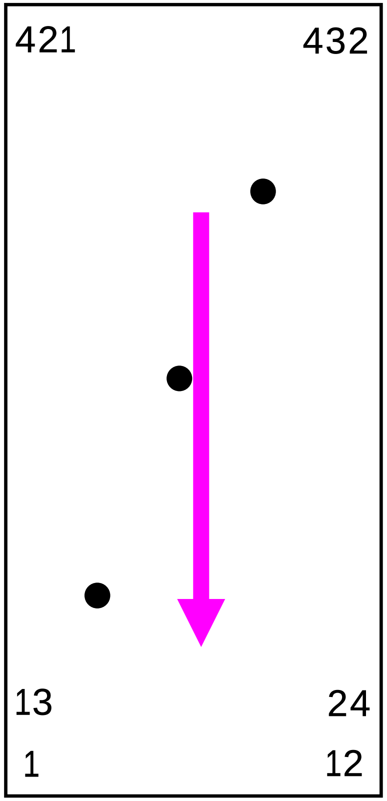
RCCS
19 Jun 2002 start

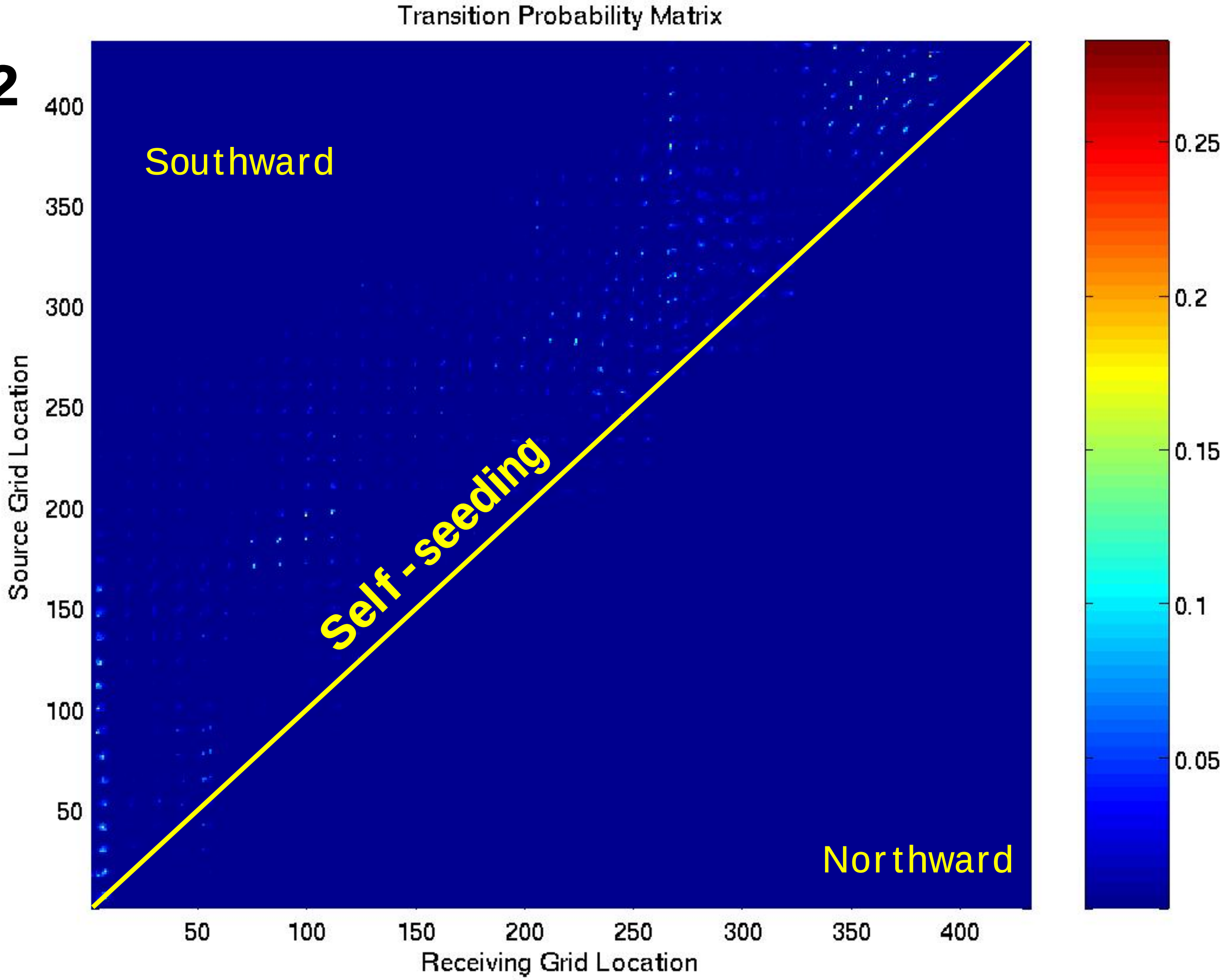
ET = 7 days

Strong Upwelling; southward transport



Connectivity
19 Jun 2002

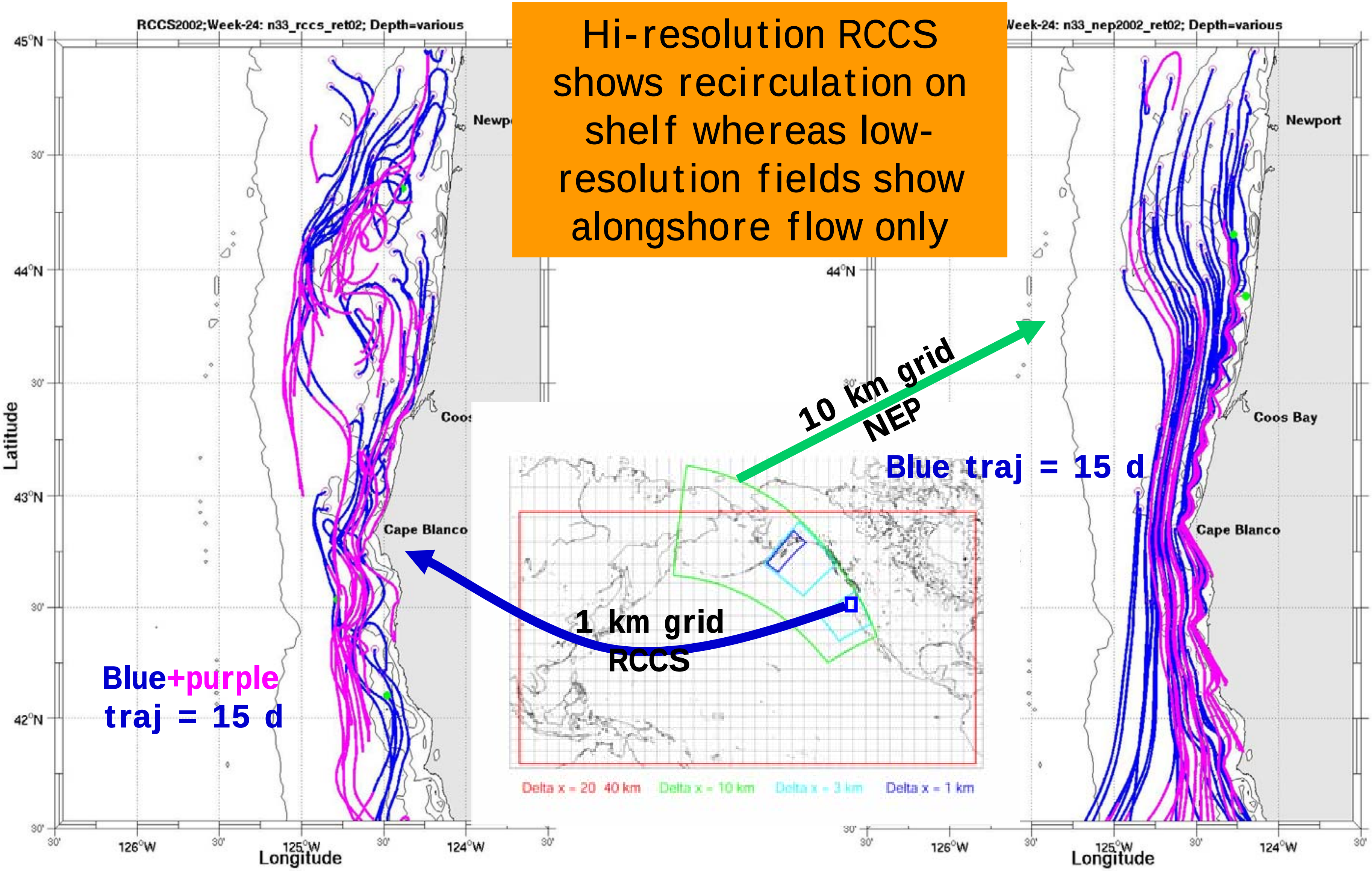




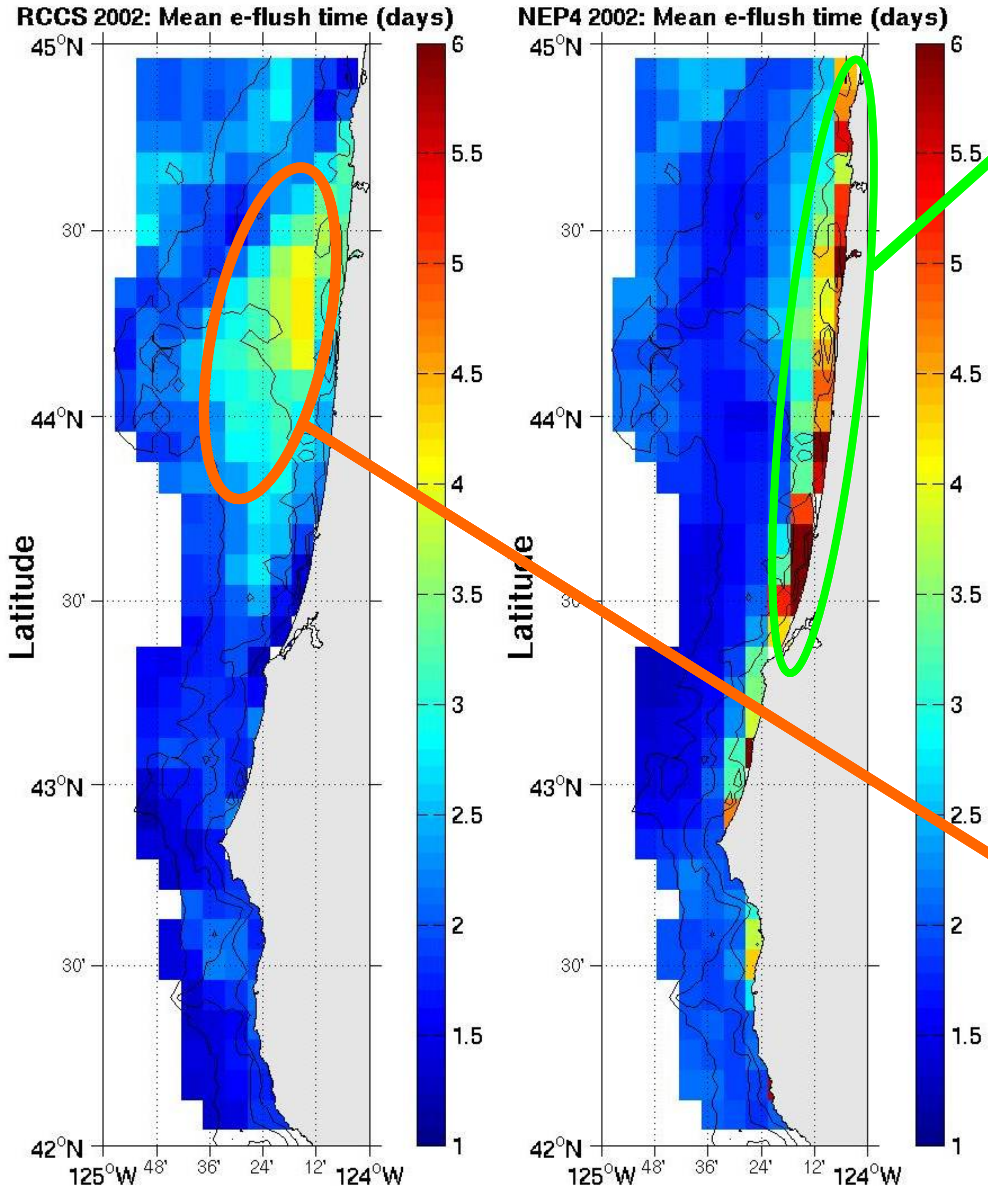
Probability that an indiv starting in grid cell (Y-axis) will be located in grid cell (X-axis) after 7 days. Numbering of grid cells is by row from lower left (SW) of domain to upper-right (NW). This shows southward movement of particles.

Comparison of 1 km and 10 km grids

12 Jun 2002



Comparison of 1 km and 10 km grids



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

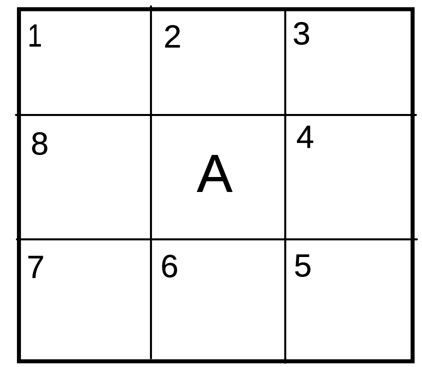
• direction of stream (α); ants are allowed a maximum 45°deviation from stream direction (max of 3 destination cells)

• velocity of the flow in destination cells (μ)

• pheromone concentration (ϕ)in destinations (by population/colony/ant)

• individual ant bias (β)

• 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

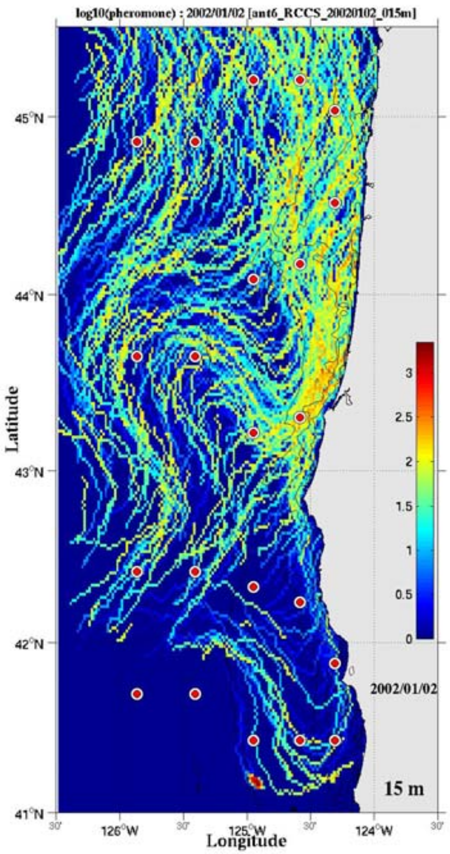
Ant Assessment of “Potentially” Retentive Regions

Depth = 15 m

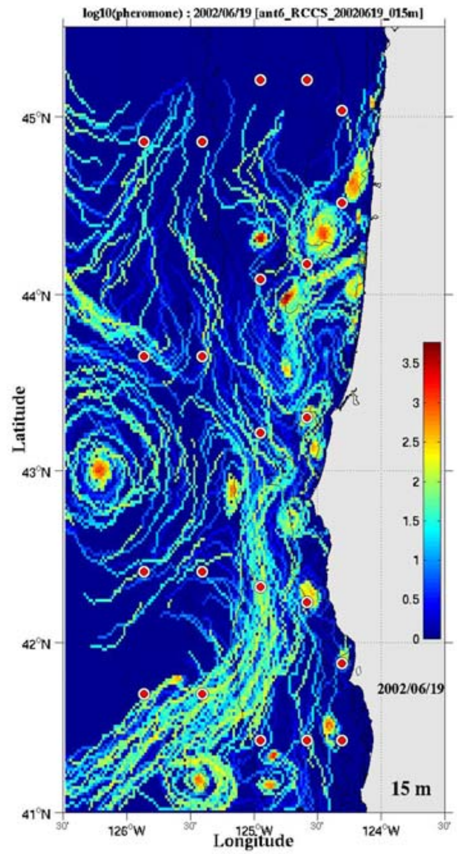
22 Initial Colonies of 16 ants/colony

RCCS

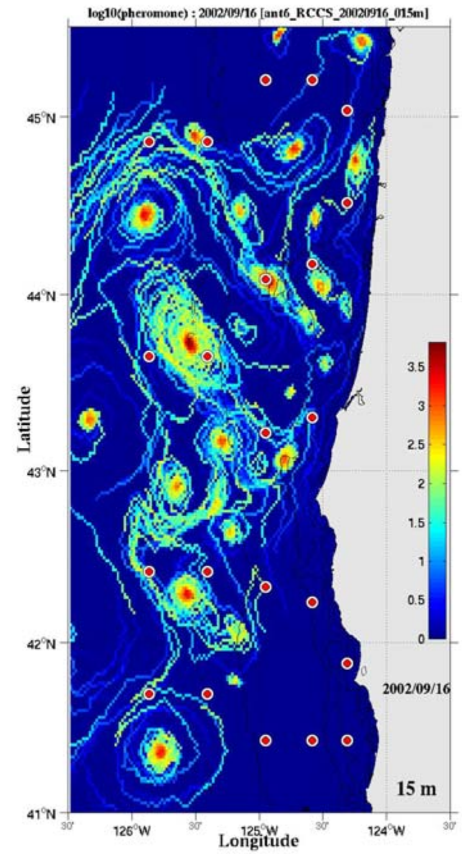
2 Jan



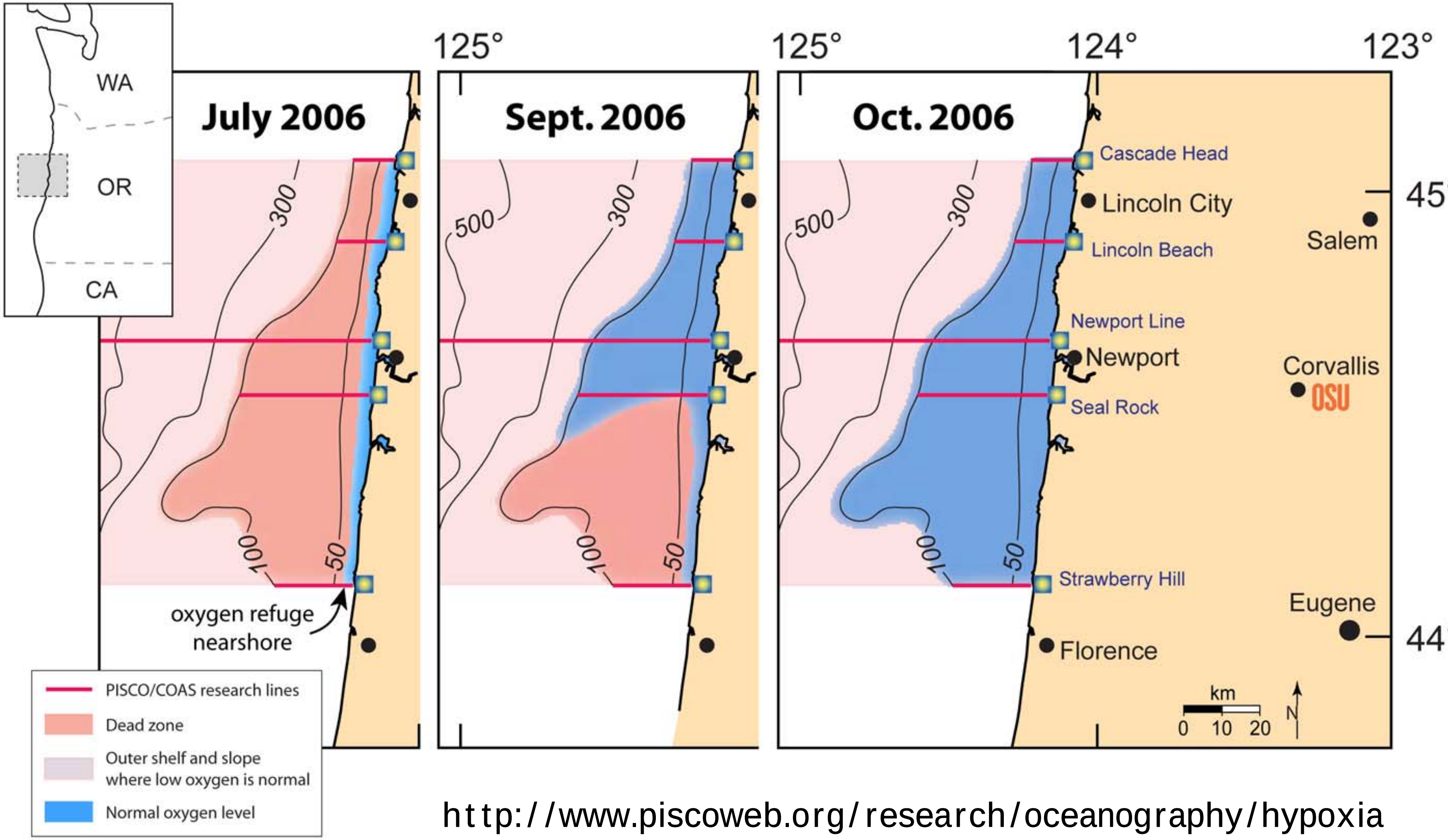
19 Jun



16 Sep



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)

Acknowledgements

- Enrique Curchitser provided the ROMS simulations for which we are very grateful.
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