Connectivity study using surface current observations

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Data-driven model for the surface transport estimates of larvae and pollutants

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Outline

• Motivation
  • Connectivity studies
  • Marine Protected Areas (MPAs)
  • Areas of Biological Significance (ASBS)

• Background of surface current measurements using high-frequency radar

• Data-driven surface transport model
  • Examples and applications

• Summary
Fig. 1. Coral reef fish settlement habitat in the Caribbean region buffered by a 9-km larval sensory zone. The coral reef mosaic is largely fragmented and restricted to shallow water near continental coastlines or around islands and isolated seamounts, and it represents a small fraction of the entire oceanic and coastal areas. Subregions within the wider Caribbean region are color coded and segmented into a total of 260 polygons (9 km by 50 km) or nodes (Nj).

Scaling of Connectivity in Marine Populations

R. K. Cowen,1* C. B. Paris,1 A. Srinivasan2

Larval Dispersal and Marine Population Connectivity

Robert K. Cowen and Su Sponaugle

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(Science, 2006) (ARMS, 2009)
The stochastic nature of larval connectivity among nearshore marine populations


(PNAS 2006)
The state of California designates thirty-four coastal regions in the California Ocean Plan as Areas of Special Biological Significance in an effort to preserve these unique and sensitive marine ecosystems for future generations. To assist in ensuring compliance with the ocean plan, CORDC is conducting a joint pilot program between the City of San Diego and Scripps Institution of Oceanography, with assistance from San Diego Coastkeeper, to monitor impacts on ASBS locations in the San Diego metropolitan region.

To discover more about an ASBS region, click on the markers below, or visit the State Water Resources Control Board ASBS page for full details. You can also view a comprehensive interactive map showing all critical coastal areas in the state, including ASBS regions, on the California's Critical Coastal Areas website. The regions below are derived from third-party sources, and are intended to provide an approximate sense of ASBS extents only.

To view sampling locations in the San Diego area, continue on to our sampling locations page.
Radio signals used in high-frequency radar

3-30 MHz (between AM radio and TV)
Wavelength \( (\lambda_r) \) : 10 ~ 100 (m)

Bragg backscattering
When the radar signals are backscattered in phase,
\[ \lambda_w = \frac{\lambda_r}{2} \]
Surface radial current map

- **Range**
  - Operating and sweeping frequency

- **Angle**
  - Direction finding v.s. MUSIC

- **Radial velocity**
  - Doppler shift
  - Projected current component

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- 30 cm/s, \( \Delta r = 1.5 \) km, \( \Delta \theta = 5 \) degrees

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true current

- R1
- R2
- R3
Surface radial current map

- Range
  - Operating and sweeping frequency
- Angle
  - Direction finding v.s. MUSIC
- Radial velocity
  - Doppler shift
  - Projected current component

Latitude (N) vs. Longitude (W)

- $30 \text{ cm/s}$
- $\Delta r = 1.5 \text{ km}, \Delta \theta = 5 \text{ degrees}$

Points R1, R2, R3 with true current vectors.
Multiple surface radial current maps

- Vector current map estimates
  - Un-weighted least squares fit (UWLS)
  - Optimal interpolation (OI)

(Kim et al, JGR 2008; Kim, CSR 2010)
Combined vector currents & type of HFRs

University of Hamburg, Germany
A network of high-frequency radars (HFRs) along the coast over 2500 km of US West Coast provides km resolution and near-real time hourly surface current maps (0.5, 1, 2, and 6 km resolutions) which cover about 150 km offshore from shoreline.

Upper 1 m depth-averaged currents

(Kim et al, JGR 2011)
HFR-derived surface currents off the U.S. West Coast
Energy spectrum of hourly surface currents for two-years off southern San Diego: peaks at tidal frequencies, wind, and variance in three frequency bands.
Data-derived surface transport model

\[ x(t) = \int_{t_0}^{t} (u(t') + \varepsilon^u)\,dt' + x(t_0) \approx \sum_k (u(t_k) + \varepsilon^u_k)\Delta t + x(t_0) \]

\[ y(t) = \int_{t_0}^{t} (v(t') + \varepsilon^v)\,dt' + y(t_0) \approx \sum_k (v(t_k) + \varepsilon^v_k)\Delta t + y(t_0) \]

where \( \mathbf{x}(t) = [x(t)\,y(t)]^\dagger \) and \( \mathbf{u}(t) = [u(t)\,v(t)]^\dagger \) denote the location of the particle and the surface currents at the particle location at a given time \( t \), respectively \( (t_0 \) is the initial time of the simulation and \( \dagger \) denotes the matrix transpose). \( \varepsilon^u \) and \( \varepsilon^v \) are the random variables with zero mean and rms of \( \varepsilon \).

Random walk vs random flight?
>> passive vs. active tracer
San Diego shoreline
water quality sampling

Water quality

Rainfall

River flux
Lagrangian particle track model

- Objectively mapped surface currents
- Forward time integration
- Particle concentrations vs. water quality samplings
- ROC (Receiver Operating Characteristics) analysis

AOC = 0.72

(Kim et al, ES&T 2009)
### Exposure map (2D PDF)

Exposure map normalized by # of particles at the source location.
(when each source is active)  
(Kim et al, ES&T 2009)

<table>
<thead>
<tr>
<th>Sources</th>
<th>Location</th>
<th>Discharge type</th>
<th>Flow rate (m$^3$s$^{-1}$ (MGD))</th>
</tr>
</thead>
<tbody>
<tr>
<td>TJR</td>
<td>Longitude (W): 32.5556</td>
<td>Latitude (N): 117.1369</td>
<td>Wet season</td>
</tr>
<tr>
<td>SBO</td>
<td>Longitude (W): 32.5373</td>
<td>Latitude (N): 117.1835</td>
<td>Plume surfacing</td>
</tr>
<tr>
<td>PBD</td>
<td>Longitude (W): 32.4336</td>
<td>Latitude (N): 117.1100</td>
<td>Continuous</td>
</tr>
</tbody>
</table>
Figure 1. Coastal exposure kernels are computed using a random walk model for two years (March 2008 – February 2010). Particles are released at every hour and tracked for three days. (a) No constraints. (b) When there is rainfall at San Diego Lindbergh Airport. Particles are counted for three days after every hourly rain event with a square bin of 100 x 100 m$^2$. We had rain events for two years for 236 hours (hourly count) or 62 days (daily count).
Oil spill experiment with surface drifters
Oil spill experiment

CA OSPR NOW CAN ACCESS DATA FOR SPILL RESPONSE
San Francisco oil spill

The intermediate fuel oil (8,000 gallons) on November 7, 0830 (PST) 2007 was spilled near Oakland Bay Bridge in the San Francisco Bay. Owing to the limited spatial coverage of HF radars, the Lagrangian surface transports were simulated at two locations: Oakland Bay Bridge and San Francisco Bay mouth (Figures 1B-a and 1B-b). The particles released during the first 12 hours were tracked for seven days, and a series of the snapshots of the tracked particles are shown in Figure 4. The trajectory simulation results are compared with the records of eye witnesses and reports on the spreading of oil slicks.
Summary

• Surface current measurement using HF radars
  • Hourly, 1-6 km resolution surface current maps
  • Spatial coverage of 50-150 km offshore from coast (except for surfzone)
• Applications using a data-derived model
  • Larvae spreading (ASBS) and MPA studies
  • Water quality, oil spill events, and search and rescue missions
  • Hindcast and real-time mode simulations
  • Decision and policy maker in coastal environment