Methods

1. Daily maps

All daily maps contain data in the Santa Barbara Channel and surrounding area (33.5-35°N, 119-121°W) on a 2km grid. Daily maps of HF Radar-derived surface currents are calculated by averaging hourly measurements over each day in the 2012-2019 time period. Hourly data are from the HFRnet Thredds Data Server: https://hfrnet-tds.ucsd.edu/thredds/catalog/HFR/USWC/2km/hourly/RTV/catalog.html. There is a temporal gap in the HFRnet dataset from 4/6/2013-5/19/2013 due to an interruption in the real time data pipeline. This gap was filled using hourly, 2km resolution HFR data (Washburn et al., 2021; https://doi.org/10.21424/R4W61S).

Daily maps of eddy locations are computed using the eddy identification technique described in Graftieux et al. (2001). In this method, the rotational metric Γ_1 is calculated at each point *X* (*X* = (*x,y*)) as:

$$\Gamma_1 = < sin\theta >;\ sin\theta = \frac{R \wedge U}{|R| \cdot |U|} = \frac{v \cdot \delta x - u \cdot \delta y}{(u^2 + v^2)^{1/2}(\delta x^2 + \delta y^2)^{1/2}}$$

where θ is the angle between the velocity vector *U* (*U* = (*u,v*)) at the point X_i and the vector *R* (*R* = $(\delta x, \delta y)$) which points from *X* to X_i, and thus Γ_1 is the spatial average (denoted as $< >$) of all θ within a given area around the point *X*, defined here as 40km (the width of the SBC). This parameter is dimensionless and varies between -1 and 1. The point at the center of a perfectly uniform eddy would exhibit $|\Gamma_1|$ = 1, as each velocity vector around the point would be orthogonal to their respective vector *R*. The metric Γ_2 is similarly calculated as:

$$\Gamma_2 = < sin\theta_m >;\ sin\theta_m = \frac{R \wedge (U - U_m)}{|R| \cdot |U - U_m|} = \frac{(v - v_m) \cdot \delta x - (u - u_m) \cdot \delta y}{((u - u_m)^2 + (v - v_m)^2)^{1/2}(\delta x^2 + \delta y^2)^{1/2}}$$

Mean horizontal velocities (U_m) are removed to correct for horizontal propagation which can decrease Γ_1 (Erickson et al., 2023). We use thresholds to define eddy extents as $|\Gamma_2|$ >2/π and eddy centers as $|\Gamma_1|$ >0.9, with negative (positive) values indicating anticyclonic (cyclonic) rotation.

Lastly, daily maps of retention time are computed using particle simulations driven by hourly HFR surface current measurements. Spatial gaps in the surface currents are first filled using EOF analysis following Emery et al. (2004). Surface current fields are then seeded with particles at every ocean grid point from 34 – 34.5°N and 119.25 – 120.5°W. Particles are simulated forward in time for 30 days using a fourth order Runge-Kutta algorithm (Emery et al., 2019; https://doi.org/10.5281/zenodo.3350830). This is repeated every day in the 8-year time series, resulting in ~$4*10^6$ particles. Retention time (RT) is calculated as the amount of time a particle stays within 20 km of its release location.

2. Monthly time series

All monthly time series are computed as the monthly averages of daily or hourly data. Wind stress (τ) is calculated as ($\tau = \rho_a C_D U_{10}^2$), where ρ_a is the density of air (1.22 kg/m^3), U_{10} is the wind speed 10 meters above the ocean surface, and C_D is the drag coefficient parameterized following the COARE 3.5 algorithm (Edson et al., 2013). Hourly wind velocity measurements are from two National Oceanographic and Atmospheric Association (NOAA) National Data Buoy Center (NDBC) buoys in the region: 46054 (West SBC) and 46053 (East SBC), hereafter referred to as buoys 54 and 53, respectively. Wind data are available in the Environmental Data Initiative database (Kui & Washburn, 2023;

https://doi/org/10.6073/pasta/06cc8320d0e29e7e008dc2c55fcfb789). Gaps in τ at buoy 54 of ~1 – 2 months are filled using linear regression with buoy 53 ($p < 0.01$; $R^2 = 0.73$).

We quantify the alongshore pressure gradient force (PGF) through a combination of sea level data from NOAA tide gauges (https://tidesandcurrents.noaa.gov/stations.html?type=Water+Levels) and atmospheric pressure measurements (http://www.ndbc.noaa.gov). at Santa Monica and Port San Luis. First, the synthetic subsurface pressure (SSP) is calculated as $SSP = \rho_0 g\eta + p_a$ following the methods outlined in Enfield & Allen (1980), Harms & Winant (1994), and Fewings et al. (2015) where ρ_0 is the density of seawater (1025 kg/m^3), g is the acceleration due to gravity, η is the sea level, and p_a is the atmospheric pressure. Next, the difference in SSP (ΔSSP) between the two stations (Port San Luis – Santa Monica) is calculated such that ΔSSP >0 (<0) represents a poleward (equatorward) alongshore PGF. Gaps in sea level at Santa Monica of ~1 month are filled using linear regression from Los Angeles ($p < 0.01$; $R^2 = 0.94$).

We use complex Empirical Orthogonal Function (EOF) analysis to estimate the modes of surface current variability (Kundu & Allen, 1976) using the United States Geological Survey (USGS) *CMGtool* package (https://pubs.usgs.gov/of/2002/0019/CMGToolLibrary.html). The spatial modes and principal components produced are complex, and in the case of the spatial modes, the real and imaginary parts represent the *u* and *v* surface current components, respectively. The real part of the principal component represents the amplitude, which can be interpreted as the surface current magnitude while the imaginary component represents the phase: the angle by which the surface currents are rotated.

Relative vorticity ($\zeta \approx \frac{\Delta v}{\Delta x} - \frac{\Delta u}{\Delta y}$) is calculated using the centered first difference method and is normalized by the planetary vorticity, f. We quantify eddy area as the number of grid points identified using the Graftieux et al. (2001) method multiplied by the grid resolution (2 km^2). Eddy occupancy is quantified as the number of days an eddy is identified in the SBC divided by the total number of days in each month. Lastly, retention times are spatially averaged over the entire SBC (34-34.5°N, 119.25-120.5°W), the cyclonic eddy area (grid cells within the identified cyclonic eddy extent), the eastern SBC (34-34.5°N, 119.25-119.75°W), and the western SBC outside the cyclonic eddy (grid cells 34-34.5°N, 119.75-120.5°W, and not within the identified cyclonic eddy extent).