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Methods

(1 & 2) *In situ* nitrate concentrations and collocated remote sensing/reanalysis predictors

In situ nitrate concentrations at the surface (0-1m) and mixed layer depth (MLD) are extracted from cruise data and collocated with remotely sensed and reanalysis predictor variables to generate generalized additive models (GAMs) for the prediction of nitrate. First, vertical profiles of nitrate and density are acquired from cruise programs spanning 2000-2020: California Cooperative Oceanic Fisheries Investigations (CalCOFI; https://calcofi.org/data/oceanographic-data/bottle-database/), NASA Plumes & Blooms (PnB; https://seabass.gsfc.nasa.gov/archive/UCSB/CRSEO/PnB/pb/archive), and Santa Barbara Coastal Long Term Ecological Research grid surveys (LTER; https://sbclter.msi.ucsb.edu/data/catalog/package/?package=knb-lter-sbc.1220). The MLD is calculated from each density profile as the depth of a density change associated with a 0.8 °C temperature change (Kara et al., 2000). Nitrate values are then extracted at the profile-specific MLD and at the surface. If multiple surface values are reported (i.e. both 0m and 1m) for one profile, they are averaged. Then, values for seven predictor variables are extracted at the same points in time and space as each *in situ* nitrate measurement. The seven predictor variables are: sea surface temperature (SST; Kahru et al., 2012; https://spg-satdata.ucsd.edu/), 15-day cumulative wind stress ($\tau_{15\text{-lead}}$; Jones et al., 2021; https://clivac.eri.ucsb.edu/clivac/SBCWRFD/index.html), sea surface chlorophyll lagging nitrate by 5 days (SSChl; Kahru et al., 2012; https://spg-satdata.ucsd.edu/), a proxy for the offshore position of the California Current (X_{off}), defined using satellite sea surface height-derived geostrophic surface current velocities (Copernicus Climate Change Service, 2018; https://cds.climate.copernicus.eu/datasets/satellite-sea-level-global?tab=overview), as the transition between poleward (inshore countercurrent) and equatorward (California Current) flow, along-channel distance (ΔX), across-channel distance (ΔY), calculated as the difference in longitude and latitude from [120°W, 34.25°N] (the approximate center of the channel), and an index for day of year (DOY), calculated as $DOY = \sin\left(2\pi\left(\frac{day\ of\ year}{366}\right)\right)$. All values of *in situ* nitrate and collocated predictor variables are organized in the accompanying NetCDF file with corresponding space (latitude and longitude) and time (date) data.

(3) R script for generating generalized additive models

Two generalized additive models (GAMs), one at the surface (0-1m) and another at the mixed layer depth (MLD), are developed using the *in situ* nitrate concentrations as response variables and the seven collocated predictor variables previously described. GAMs are constructed with the R package *mgcv* (Wood, 2006; https://cran.r-project.org/web/packages/mgcv/index.html), using the Akaike criterion (Akaike, 1973) and k-fold cross-validation to optimize model performance while avoiding overfitting.

(4) Daily maps

All daily maps contain data in the Santa Barbara Channel and surrounding area (approximately 33.5-35°N, 119-121°W) on two different grids (grid spacings of 1km and 2km). Daily maps of satellite sea surface chlorophyll (SSChl) are from a daily, 1km merged dataset which combines all available satellites (MODIS-Terra, MODIS-Aqua, VIIRS) over the 2012-2019 time period studied here (Kahru et al., 2012; https://spg-satdata.ucsd.edu/). Daily, 2km maps of HF Radar-derived surface currents are calculated by averaging hourly measurements over each day in the 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. As of June 30, 2025, this server is unavailable and the Integrated Ocean Observing System (IOOS) recommends that users instead access data through the National Data Buoy Center THREDDS server (https://dods.ndbc.noaa.gov/thredds/catalog/hfradar.html?dataset=hfradar_uswc_2km). 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, which is filled using hourly, 2km resolution HFR data from Washburn et al. (2021; https://doi.org/10.21424/R4W61S). Vertical velocities at the base of the mixed layer are estimated from 1.5km modeled wind fields from a local weather research and forecasting (WRF) model (Jones et al., 2021; https://clivac.eri.ucsb.edu/clivac/SBCWRFD/index.html). Two components of wind-driven vertical velocity, one due to wind stress curl (w_{curl}) and another due to coastal divergence (w_{coast}) are computed from spatial fields of wind vectors. w_{curl} is computed at every ocean grid point in the SBC as

$$w_{curl} = \frac{1}{\rho_w f}\left(\frac{\partial \tau_y}{\partial x} - \frac{\partial \tau_x}{\partial y}\right)$$

where f is the Coriolis parameter, ρ_w is seawater density (1025kg/m^3), and $\frac{\partial \tau_y}{\partial x} - \frac{\partial \tau_x}{\partial y}$ is the curl of the wind stress field, estimated using the centered first-difference method. At every grid point within 10km of the coastline, w_{coast} is calculated as

$$w_{coast} = \frac{1}{R_d}\frac{\tau_a}{\rho_w f}$$

where τ_a is the wind stress in the alongshore direction, with positive (negative) values defined as having the coastline to their left (right), and R_d is the local Rossby radius of deformation (10km). Maps of predicted nitrate at the surface and mixed layer depth (MLD) are generated by applying the GAMs described in section 3 to daily maps of observed predictor values. Maps of advective nitrate fluxes are available in the horizontal and vertical directions. First, all daily maps of velocity and nitrate concentrations are interpolated to the same 2km grid. Total HFR surface currents ([u,v]) are multiplied by predicted surface nitrate concentrations to produce horizontal advective fluxes (FX = [F_x,F_y]). The two vertical velocities (w_{curl} and w_{coast}) are multiplied by predicted MLD nitrate concentrations to produce two vertical advective fluxes (FZ_{curl} & FZ_{coast}).

(5) Daily time series

Daily time series of channel-wide sea surface chlorophyll are generated by taking the spatial average of daily maps of SSChl within the SBC (approximately [34-34.5°N, 119.25-120.5°W]). Daily time series of the principal component corresponding to the first mode of surface current variability (U_{EOF}) are from complex empirical orthogonal function (EOF) analysis on HFR surface currents. Complex EOF is performed using the United States Geological Survey (USGS) *CMGtool* package (https://pubs.usgs.gov/of/2002/0019/CMGToolLibrary.html). The alongshore pressure gradient is quantified as the difference in synthetic subsurface pressure (ΔSSP) between tide gauges at Santa Monica (SM) and Port San Luis (PSL) such that positive (negative) values indicate poleward (equatorward) alongshore PGF. SSP at each location is calculated as

$$\mathrm{SSP} = \rho_w g \eta + p_a$$

where ρ_w is seawater density (1025kg/m^3), g is the acceleration due to gravity, η is the sea level (Caldwell et al., 2015; https://uhslc.soest.hawaii.edu/data/?rq), and p_a is the atmospheric pressure (Enfield & Allen, 1980). Upwelling strength is estimated using wind stress at NOAA National Data Buoy Center (NDBC) buoy 46054 (τ_{54}). Wind stress is calculated as

$$\tau = \rho_a C_D U_{10}|U_{10}|$$

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where ρ_a is air density (1.22kg/m^3), C_D is the drag coefficient (Edson et al., 2013) and U_{10} is wind vector at 10m (SBC LTER et al., 2023; https://doi.org/10.6073/pasta/06cc8320d0e29e7e008dc2c55fcfb789). Hourly values of both ΔSSP and τ_{54} are averaged daily.

To quantify fluxes into and out of the channel, two horizontal boundaries are defined: the western channel between San Miguel Island and Point Conception, and the eastern channel between Anacapa Island and Port Hueneme. Cross-boundary horizontal velocities are computed as the dot product of the total surface current vectors at each boundary point and a unit normal vector pointing into the channel. This produces a scalar quantity for which positive (negative) values indicate flow into (out of) the channel. These values are spatially averaged to produce time series of mean horizontal flow at each boundary. Vertical velocities are also spatially averaged over every point within these boundaries to produce time series of mean vertical velocities. Daily time series of mean predicted surface nitrate at these channel boundaries are quantified, as well as channel-wide spatial mean surface nitrate and MLD nitrate at points within these boundaries. Finally, mean horizontal and vertical advective nitrate fluxes are quantified in an identical manner to produce daily time series of these values.

(6) MATLAB script for plotting daily maps and time series

This script includes example code for plotting examples of the daily maps discussed in section 4 and the daily time series discussed in section 5.

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