Local diurnal wind-driven variability and upwelling in a small coastal embayment

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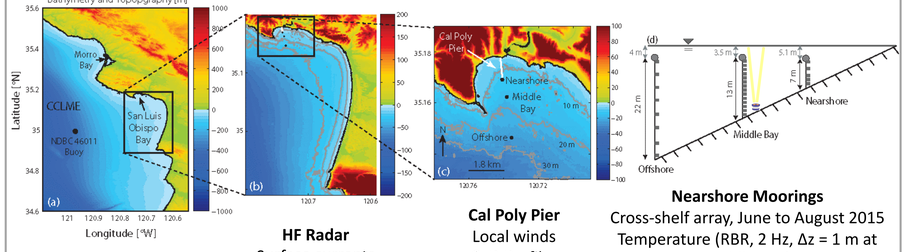
1. Background

- The intense productivity of eastern boundary current upwelling systems, such as the California Current Large Marine Ecosystem (CCLME), is shaped by physical processes on a wide range of spatiotemporal scales, ranging from regional-scale (100s of km) to local-scale (10s of km and smaller) processes.
- On a regional scale, prevailing atmospheric conditions in the CCMLE drive equatorward winds resulting in seasonal coastal upwelling. During the major upwelling season in CA (spring to fall), strong upwelling favorable winds drive intrusions of offshore waters into nearshore regions. This process is interrupted during regional wind relaxation events lasting several days that allow warm offshore waters to move back towards the coast and in some cases poleward. These upwelling/relaxation cycles are often thought of as the dominant feature driving variability and affecting a host of physical and biological processes.
- Local features, however, may play an equally important role in driving ecosystem dynamics in the coastal ocean, particularly with regard to local wind-driven variability, coastline orientation, and topography. Local winds have been shown to influence a range of processes, including upwelling, inertial current oscillations, internal wave development, heat budgets, upwelling fronts, local circulation patterns, and phytoplankton dynamics.
- This study documents the fine-scale (both spatial and temporal) oceanic response of a small (bay length scale of ~ 2 km) coastal embayment that is characteristic of boundary current systems. The effect of local diurnal wind forcing on temperature variability, circulation patterns, and upwelling dynamics is explored.

2. Study Site and Experimental Setup

Small, semi-enclosed embayment located along an understudied stretch of central California south of Monterey Bay and north of Point Conception



NDBC 46011
Regional upwelling winds

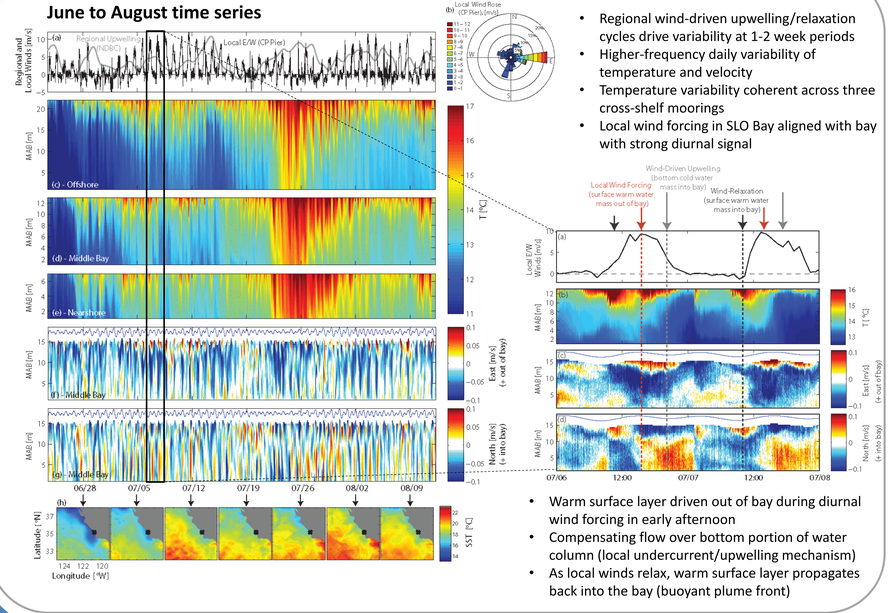
HF Radar
Surface currents

Cal Poly Pier
Local winds
CTD Profiler

Nearshore Moorings
Cross-shelf array, June to August 2015
Temperature (RBR, 2 Hz, Δz = 1 m at Middle Bay)
Velocity (Sentinel V, 2 Hz, 0.4 m bins)

3. General Observations

June to August time series

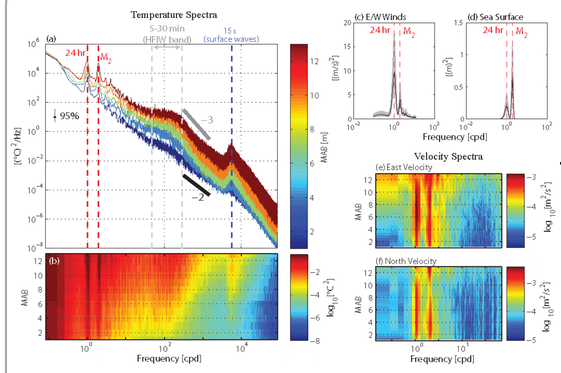


- Regional wind-driven upwelling/relaxation cycles drive variability at 1-2 week periods
- Higher-frequency daily variability of temperature and velocity
- Temperature variability coherent across three cross-shelf moorings
- Local wind forcing in SLO Bay aligned with bay with strong diurnal signal

- Warm surface layer driven out of bay during diurnal wind forcing in early afternoon
- Compensating flow over bottom portion of water column (local undercurrent/upwelling mechanism)
- As local winds relax, warm surface layer propagates back into the bay (buoyant plume front)

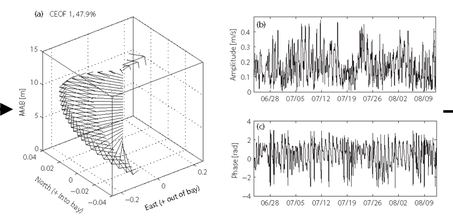
4. Diurnal Variability

(i) Spectral analysis



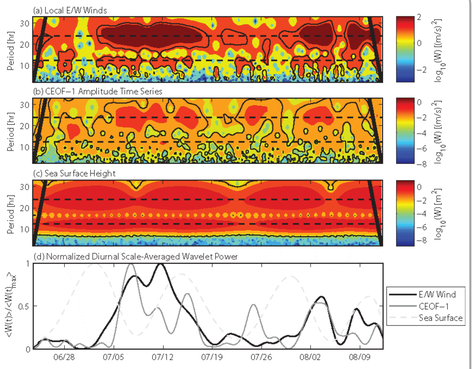
- Temperature displays surface-enhanced peak at diurnal frequency, and enhanced variance in high-frequency internal waveband and sharper spectral falloff near surface
- Velocity spectra shows dominant peak at diurnal frequency, particularly in east component (aligned with direction of wind forcing)
- Local wind variance dominated by diurnal frequency component

(ii) CEOF analysis



- Complex empirical orthogonal function analysis: modal shape dilates/contracts over time based on magnitude of amplitude time series, and modal shape rotates in time based on phase angle
- First modal shape describes 47.9% of velocity variance
- Modal shape profile is sheared with surface 180° out of phase with the rest of the water column

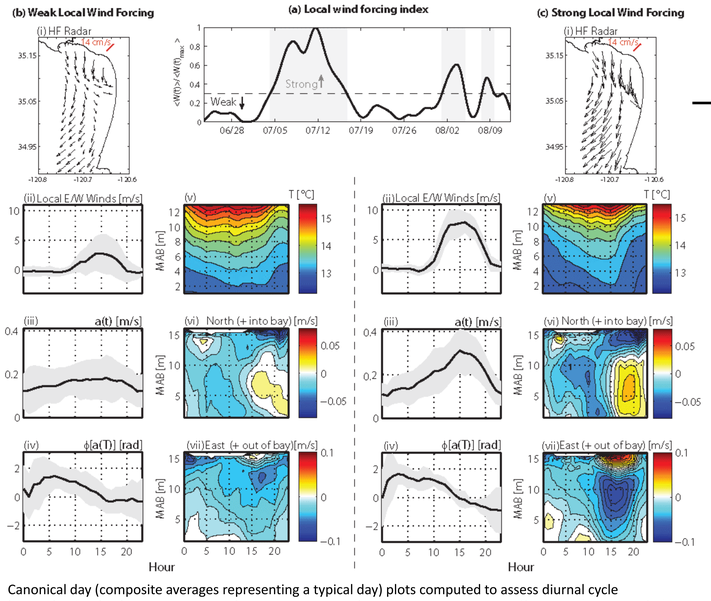
(iii) Wavelet analysis



- Temporal variability in diurnal variance of CEOF amplitude time series aligns with majority of peaks in local wind forcing, but not the local sea surface height
- Local winds and first-mode CEOF amplitude time series significantly coherent at diurnal frequency with almost zero phase lag (not shown)

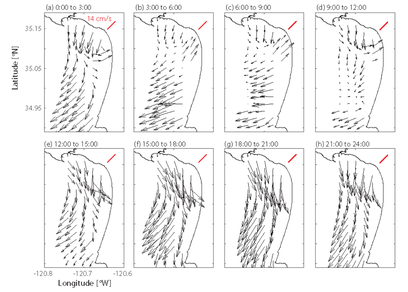
5. Local Diurnal Wind Forcing and Canonical Day

(i) Weak vs. strong local wind forcing



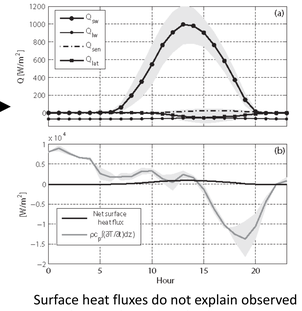
- Canonical day (composite averages representing a typical day) plots computed to assess diurnal cycle
- Local wind forcing index calculated using scale-averaged diurnal wavelet power to define weak/strong periods
- During the morning hours, local winds are absent, near-surface velocities are directed into the bay, and a warm surface layer (buoyant plume front) increases local stratification
- Local winds develop and peak in the late afternoon and a strong near-surface jet oriented out of the bay develops with a compensating flow into the bay over the bottom that brings cold waters into the bay (i.e., undercurrent)
- These cold waters cause isotherms to shoal towards the surface and represent a mechanism for local upwelling distinct from classic coastal upwelling described by Ekman-like dynamics
- Diurnal features enhanced (stronger currents, enhanced upwelling of cold water) during strong wind period

(ii) Surface currents



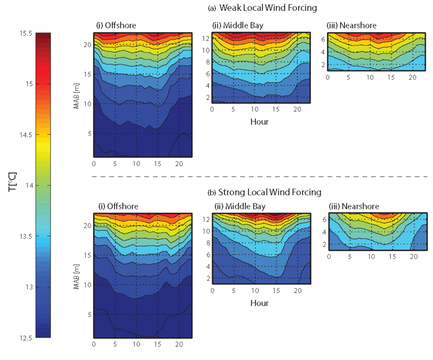
Surface currents directed out of the bay and enhanced during the afternoon (drives undercurrent at depth)

(iii) Heat fluxes

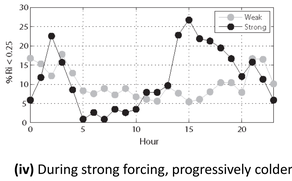


Surface heat fluxes do not explain observed warming/cooling (advective fluxes needed)

(iv) Cross-shore evolution



(v) Local stability



(iv) During strong forcing, progressively colder waters upwell to nearshore, penetrate closer to the surface, and persist along the bottom for greater portions of the day

(v) Water column stability assessed using gradient Richardson number (*Ri*). *Ri* near the surface is below critical value of 0.25 a greater percentage of time during strong wind forcing and subject to shear-driven instabilities.

See Walter et al. (2017), Local diurnal wind-driven variability and upwelling in a small coastal embayment, *J. Geophys. Res. Oceans*, 122 for details

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