A Decade in Carmel Bay: Resolving the complex physical structure and flow patterns in a small, ecologically important bay

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Introduction to Carmel Bay

Carmel Bay is an ecologically important region for a variety of pelagic and intertidal species. Recently, 19 Marine Protected Areas (MPAs) were established along the central California coast within the MBNMS. Even though Carmel Bay is only ~1/60th the size of Monterey Bay, 4 of these MPAs are clustered in and around this small embayment. However, currently, very little is known about the circulation patterns and hydrography of Carmel Bay.

Stillwater Cove

Since 2000, the Partnership for Interdisciplinary Studies of Coastal Oceans (PISCO) has maintained an oceanographic mooring in Stillwater Cove, at the northern edge of Carmel Bay (SWC, Fig. 4). This mooring collects continuous measurements of current velocity and temperature throughout the water column.

Temperature Trends

Figure 1. Average monthly temperatures (°C) measured at 13-m (top panel) and 21-m (bottom panel) at the SWC mooring for 2000-2007.

- Months with coolest temps at mid-depths vary from year to year, but generally occur between spring and summer (Apr - Oct).
- Coolest bottom temps are consistently found during spring (Apr - May)
- At certain times, the mean monthly temp at mid-depth may be colder than that at the seafloor

Internal Waves

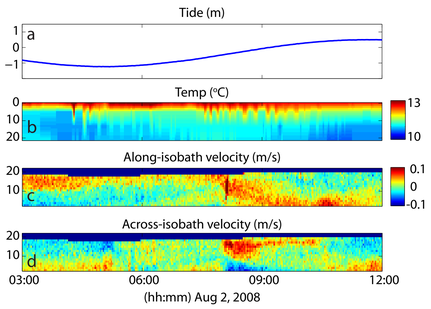

Figure 2. 9-hr time series of tide height (a) and SWC mooring measurements: temperature (b), along- (c) and across-isobath velocity.

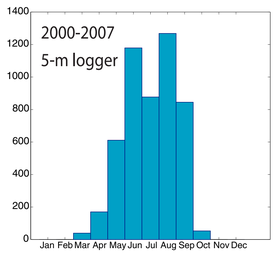

Figure 3. Number of internal wave occurrences observed at 5-m depth of SWC mooring each month for 2000-2007.

- 5044 internal waves detected
- 94.8 % occur between May - Sep
- Average period ~ 20-24 min

Weeklong survey: Aug1-8, 2008

In Aug 2008, we performed a small pilot study to investigate hydrographic conditions in Carmel Bay. In addition to the SWC mooring, from Aug 1-8 we deployed an RDI 600 kHz Workhorse ADCP in the southern region of the bay, near the mouth of the Carmel River (CR, Fig. 4).

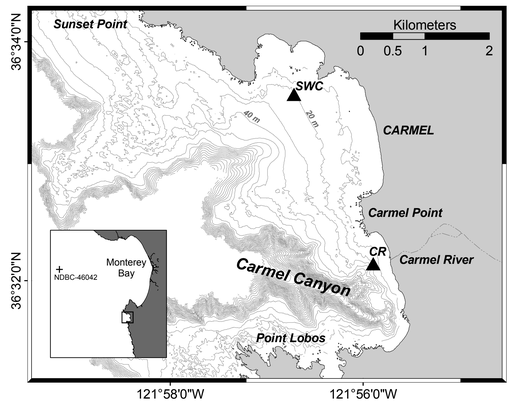

Figure 4. Map of Carmel Bay with 10-m bathymetric contours. Inset shows maps perimeter in relation to Monterey Bay. SWC = permanent Stillwater Cove mooring; CR = Carmel River ADCP deployment site (Aug 1-8, 2008).

Transparency Overlays

Mean daily, depth-averaged currents
Water enters bay from the north and exits from the south; general clockwise circulation

Flood Tide
Northern bay: warming bottom temps; strong westerly flow
Southern bay: cooling bottom temps; weak, non-directional flow

Ebb Tide
Northern bay: cooling bottom temps; currents rotate from west to east
Southern bay: warming bottom temps; strong west-northwesterly current pulse at end of ebb tide

On Aug 1 and 8, we performed across-bay transects using a towed Acrobat profiler (Fig. 5). The Acrobat collected high-resolution measurements of temperature, salinity, density, pressure and chlorophyll-a fluorescence at depths from the surface to < 35 m.

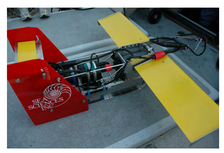

Figure 5. Acrobat profiler on deck.

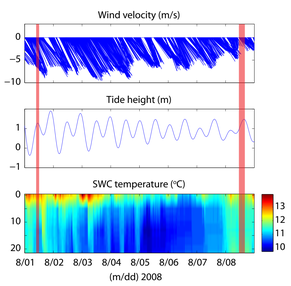

Figure 6. Wind, tide and temperature during the week-long survey. Red bars indicate times of Acrobat surveys.

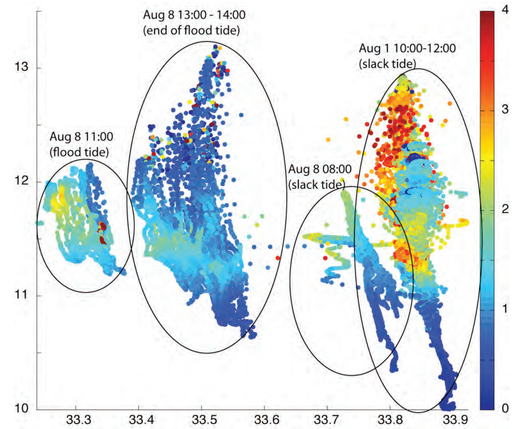

Figure 7. Acrobat data collected on Aug 1 and 8, 2008. X-axis is salnity and y-axis is temperature (°C). Colorbar indicates chlorophyll-a concentration (ug/l)

- Salinity within the bay can change over short time scales
- Highest phytoplankton (chl-a) concentrations associated with highest salinity water

Internal Tide Signature

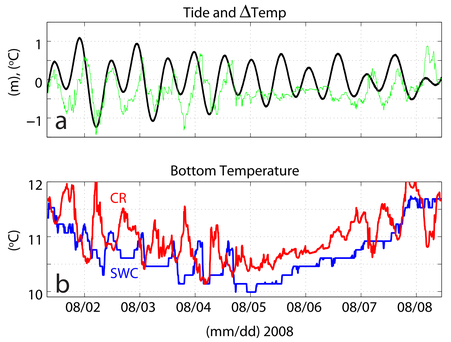

Figure 8. Week-long time series of (a) tide height (black line) and the difference between SWC and CR bottom temperatures (green line); (b) bottom temperature at the CR and SWC sites.

- SWC is generally colder (avg ~ 0.3°C) than CR, except during transition from flood to ebb tide.
- As southern bay temp decreases, northern bay temp increases, and vice versa.
- Greatest temp differences occur during spring tide, at the transition from ebb to flood.

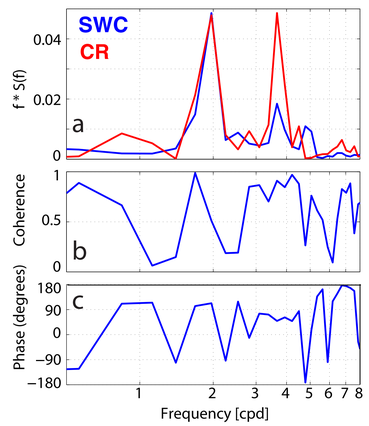

Figure 9. (a) Variance-preserving energy density spectra for SWC and CR bottom temperatures; (b) Coherence spectrum; (c) Phase spectrum. X-axis is log-scale, with labels denoting cycles per day (cpd).

- SWC and CR bottom temperature both exhibit strong peaks at the semi-diurnal (12-hr) frequency
- CR also displays a diurnal (24-hr) peak
- At all freq < 4 cpd, SWC and CR are ~90° out of phase, suggesting a time lag of 3 hr for the semi-diurnal internal tide signal between the two sites