

Factors Influencing the Nearshore Sound-Scattering Layer in Hawaiian Waters

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LONG-TERM GOALS

Our long-term goal is to develop the capability to predict the spatial dimensions and temporal occurrence of aggregations of the nearshore sound-scattering layer in the coastal ocean.

OBJECTIVES

Our objectives are (1) to quantify aggregations of the nearshore sound-scattering layer around Hawaii, (2) to identify the physical and optical characteristics associated with these aggregations, and use this information (3) to develop the capability to predict the occurrence of the nearshore scattering layer in Hawaiian waters.

APPROACH

This project takes an interdisciplinary approach in the investigation of the relationships between the nearshore sound-scattering layer, physical processes, the optical properties of the water column, and bathymetry. We combine moored and expeditionary approaches to determine the critical predictors of micronekton distribution.

WORK COMPLETED

We combined moored sensors and expeditionary surveys conducted over two, 5-week periods the first in April/May of 2005 and the second in April/May of 2006 to determine the critical predictors of micronekton distribution at two sites on Oahu's leeward (western) coast (Figures 1,2). We took an interdisciplinary approach, combining work in acoustics, optics, and physical oceanography to look at

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the relationships between the nearshore sound-scattering layer, optical properties of the water column and physical processes in the coastal environment.

We have completed a manuscript entitled “*Behavior Exceeds Physical Forcing in the Diel Horizontal Migration of a Midwater Sound-Scattering Layer in Hawaiian Waters*” (McManus, Benoit-Bird, Woodson) to Marine Ecology Progress Series. This manuscript has received a positive review, and we are currently working on revisions. A second manuscript entitled “*Effects of scattering layer composition, animal size, and numerical density on the frequency response of volume backscatter*” (Benoit-Bird) was submitted to the Journal of Acoustical Society of America and is currently in review. A third manuscript regarding zooplankton as a potential driving force for horizontal migration is currently in preparation (Benoit-Bird and McManus).

RESULTS

Mesoscale and regional scale circulation patterns: In order to understand the local fluctuations in temperature and current velocity we observe at our moorings, it is necessary to understand the mesoscale and regional circulation patterns. The Hawaiian Islands are located within the subtropical gyre, a basin-wide clockwise gyre centered at 28 N, ~8° North of Oahu. The island of Oahu is located in the Hawaiian Island chain between the islands of Molokai and Kauai. At the latitude of Oahu, winds are generally from the northeast and the predominant circulation is roughly from east to west. In the lee of the island of Oahu (on the western side) counter-clockwise (cyclonic) eddies commonly form along the northwestern coast, and weaker, clockwise (anticyclonic) eddies are sometimes observed along the southwestern coast.

Winds: Northeasterly trade winds dominate over the Hawaiian Island chain. Due to orographic steering, trade winds encounter the west Oahu shoreline from the north and northwest and decrease from maximum velocities at the northern end of the study area toward the south. During surveys of the southwestern coast of Oahu (2005) mean wind speeds $\pm$ one standard deviation were 5.8 ± 2.72 m sec⁻¹. During surveys of the northwestern coast of Oahu (2006), mean wind speeds $\pm$ one standard deviation were 6.1 ± 3.17 m sec⁻¹.

Tides: Tides along the west coast of Oahu are generally mixed, semi-diurnal, with two highs and two lows each day of unequal height. The surface tide propagates from north to south at the Hawaiian Islands with little to no observed delay between our northwestern and southwestern sites.

General flow patterns: General flow patterns along the western coast of Oahu are dominated by both surface and internal tidal forcing. Along the southwestern coast in 2005, alongshore (along isobath) current velocities ranged from -57.21 to +65.73 cm/s with an average of $+0.004 \pm 19.32$ cm/s (where negative numbers represent currents moving in a southerly direction, and positive numbers represent currents moving in a northerly direction). Cross shore (cross isobath) current velocities ranged from -33.23 to +29.09 cm/s, with an average of -3.62 ± 6.81 cm/s (where negative numbers represent currents moving in an offshore direction, and positive numbers represent currents moving in an onshore direction). Daily depth averaged currents were oriented parallel to shore (northwest-southeast) 80% of the time. Along the northwestern coast in 2006, alongshore (along isobath) current velocities ranged from -39.03 to +46.84 cm/s, with an average of $+0.012 \pm 14.69$ cm/s. Cross shore (cross isobath) current velocities ranged from -30.58 to +45.58 cm/s, with an average of -2.76 ± 5.89 cm/s. Daily depth averaged currents were oriented parallel to shore (north-south) 75% of the time.

Onshore flows and cold-water intrusions: Distinct pulses of cold-water were observed in the near bottom temperature records at the offshore moorings (25 m or greater in depth) (moorings B, C, D in 2005, moorings C, D in 2006). These ‘cold pulses’ were associated with up to 2°C drops in the local water temperature at the southwestern site. Closer examination of the observed pulses revealed that they were stronger on or near spring tides.

At the southwestern site in 2005, cold pulses were associated with onshore currents occurring at the transition between ebb and flood tides. These onshore current velocities ranged from 0 to 10 cm/s at the 40 m mooring during the spring tide. Examination of the temperature power spectra showed distinct peaks at the semi-diurnal (12 h) and quarter-diurnal (6 h) periods. Cold-water intrusions remained intact for close to 4 hours after each event.

At the northwestern site in 2006, we also observed near-bottom cold pulses at the 25 m and 30 m moorings. The cold pulses were again associated with onshore currents occurring on the ebb tide and the initiation of the transition between ebb and flood tides. These onshore velocities ranged from 0 to 8 cm/s at the 25 m mooring during the spring tide. Power spectra of the near bottom temperature record showed a significant peak at the quarter-diurnal (6 h) period.

Micronekton: The shipboard camera system revealed that all micronekton identified in the nearshore sound scattering layer were myctophid fishes. Densities of micronekton measured with the camera system ranged from 2 to 194 fish m⁻³. Densities estimates from the acoustic measures ranged from 1 to 246 fish m⁻³. Comparing the density estimates from individual camera casts to 10 minutes of acoustic data just before and after the cast showed that there was a nearly one to one relationship with an r^2 of 0.96. This provides validation that the acoustic scattering is being correctly attributed to mesopelagic micronekton. Migration timing was consistent between nights over an individual mooring. In 2005, the layer appeared over the furthest offshore moorings (40 m) between 1815 and 2100 h local time with a mean at 2000 h. The layer disappeared from this site between 0215 and 0430 h with a mean of 0330 h. Further inshore at the 25 m site, the patterns were similar with the arrival of the layer between 15 and 30 minutes later than at the offshore site and the disappearance of the layer occurring between 15 and 30 minutes before the offshore sites. In 2006, the layer appeared over the 40 m mooring between 1800 and 2107 h local time with a mean at 2013 h. The layer disappeared from this site between 0258 and 0418 h with a mean at 0345. The layer appeared an average of 17 minutes later at the 25 m mooring and disappeared an average of 21 minutes earlier.

Coupling Physical and Biological Processes on the mesoscale: We find that the nightly inshore movement of micronekton occurs very predictably each day; onshore migration brings animals nearshore between 2000-2013 h and offshore migration commences between 0330-0345 h. In this area, there are also periodic inshore movements of water associated with the internal tide, which progresses by roughly 42.5 minutes each day. These periodic inshore movements of water are not associated with any specific time of day. Given these offsets in timing, nightly micronekton movement onto the shelf does not appear to be tied to the inshore advection of water. Correlation analyses between cross-shore flow velocity and acoustic backscatter also showed no significant relationship. Further, the micronekton layer’s migration rate is approximately 5-6 times faster than the physical flow field. These results indicate that micronekton are not passively advected into the study region, rather they are actively migrating into coastal waters (Figure 3).

Coupling Physical and Biological Processes on the Regional Scale: We measured the spatial (horizontal and vertical) and temporal scales of the nearshore sound-scattering layer. We found that in the vertical dimension, the scattering layer in these shallow areas ranged from 4-26 m in thickness. Horizontally, the sound-scattering layer could continuously cover several kilometers or it could be distributed in distinct patches with a horizontal extent of as little as 10 meters. Extensive, continuous layers of micronekton (ca 10 km) dominated the site along the northern section of Oahu's leeward coast, while smaller-scale patches (ca 50 m) of micronekton were more common at the southern section of Oahu's leeward coast. These differences in micronekton biomass and distribution were correlated with differences in zooplankton biomass. While our work shows that micronekton were actively swimming into the nearshore environment each evening, and not being advected into the region by physical water flow, it is also clear that horizontal patchiness of these organisms (on spatial scales of km and time scales of days) was strongly correlated with each region's mesoscale physical circulation patterns.

Observations of Thin Biological Layers: The vertical distribution of micronekton was highly correlated with vertical structure chlorophyll a fluorescence and zooplankton distribution. In the last decade, advances in measurement capabilities and deployment techniques have led to the discovery of plankton aggregations over continental shelves with vertical dimensions as 'thin' as of tens of centimeters. These 'thin layers' range in thickness from a few centimeters to a few meters, may extend horizontally for kilometers and may persist for days (Dekshenieks et al. 2001; McManus et al. 2003; McManus et al. 2005; Rines et al. 2002). They are characterized by in-layer planktonic densities that can be orders of magnitude greater than the densities just above or below the structure. Thin layers are a widespread phenomenon, and have been observed in a variety of coastal and offshore environments. These are the first observations of thin layers in the Hawaiian Island Chain. We observed horizontally extensive (>3 km), temporally persistent (>24 days), layers of phytoplankton at the base of the pycnocline. We also observed thin layers of zooplankton that ranged in thickness from 0.7 to 3.5 m in vertical dimension. These layers typically had a biovolume of zooplankton 2 orders of magnitude higher than the rest of the water column. The species composition of zooplankton was significantly different when animals were aggregated into thin layers than when no such structures were observed. Zooplankton thin layers were strongly associated with phytoplankton thin layers and were most often found just below phytoplankton layers. We also observed that the deep-scattering layer, primarily micronektonic myctophid fishes, was affected by the presence of thin layers. There was strong aggregation of these micronekton at the depth of zooplankton thin layers. Thin layer presence was correlated with a reduction in vertical migration of myctophids by about 5 m, or one-quarter of the water column in our study site. Our results suggest that thin layers affect the distribution of adjacent trophic levels; energy is transferred from phytoplankton through zooplankton to micronekton. These layers, both thin layers and the deep-scattering layer, affect acoustic backscatter through the aggregation of zooplankton scatterers near phytoplankton thin layers and by the aggregation of strongly scattering micronekton just below zooplankton thin layers.

IMPACT/APPLICATIONS

While our work shows that micronekton were actively swimming into the nearshore environment each evening, and not being advected into the region by physical water flow, it is also clear that horizontal patchiness of these organisms (on spatial scales of km and time scales of days) was strongly correlated with each region's mesoscale physical circulation patterns. In addition, it should be noted that the purpose of our field efforts in 2005 and 2006 was to detect the nearshore sound scattering layer. Our observations of thin layers were fortuitous and, as previously mentioned, the first observations of thin

layers in the Hawaiian Island Chain. It is now immediately clear that thin layers are (1) persistent, real features that are common in nearshore Hawaiian waters, (2) important in structuring trophic interactions in Hawaii's nearshore ecosystem, and (3) have significant impacts on both optical and acoustical measurements in the nearshore environment.

This project was involved in the training of a summer "Research Experience for Undergraduates" fellow at Oregon State University and a post-doctoral fellow at the University of Hawaii.

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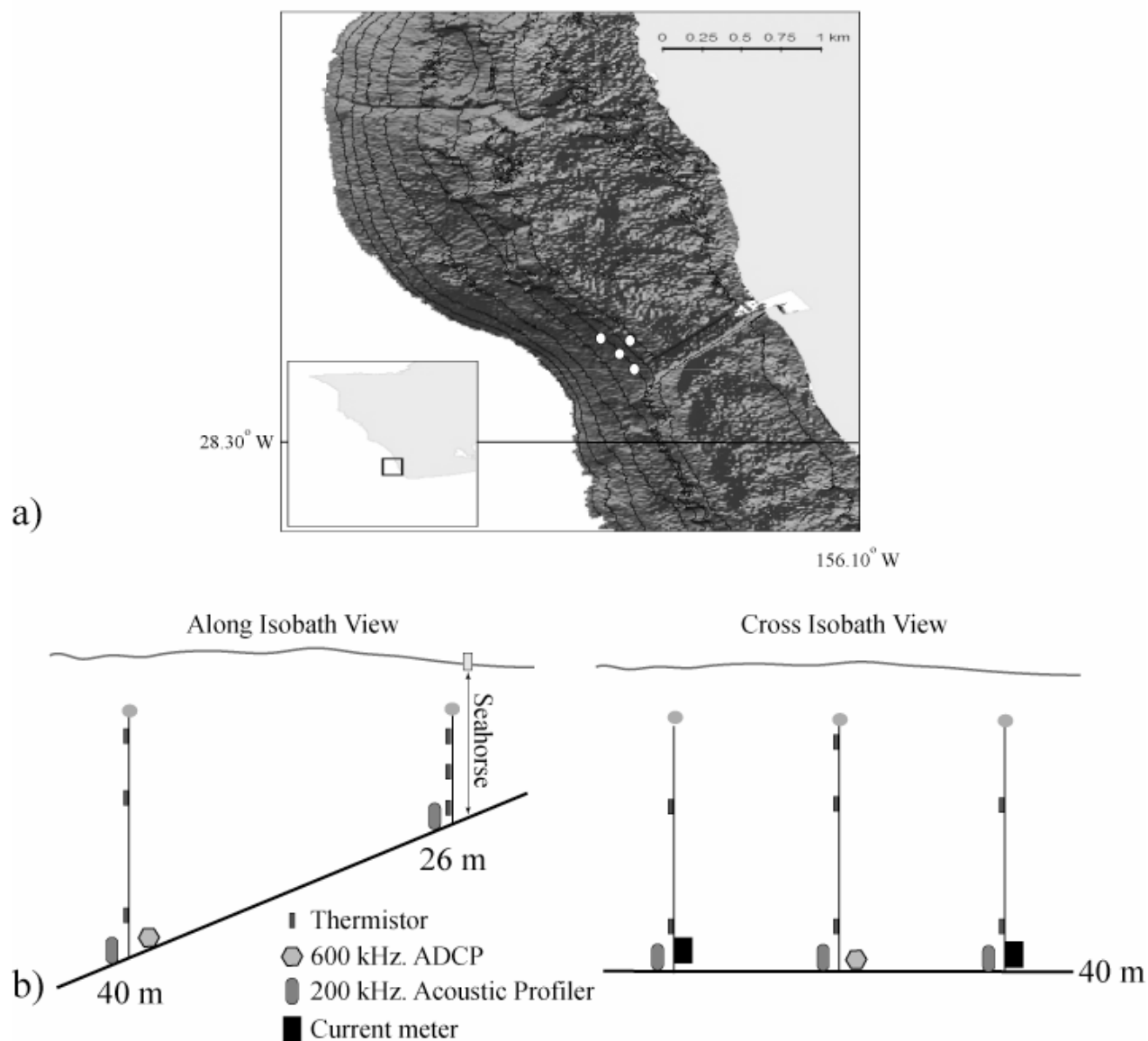


Figure 1. Study area and instrument deployment locations for 2005 study.
(a) Study area showing mooring array configuration (white dots). (b) Along isobath view of array showing location of mooring C (40 m) and mooring A (26 m) as well as instrument locations and depths. Across isobath view of array showing location of moorings B, C and D (from left to right) as well as instrument locations and depths.

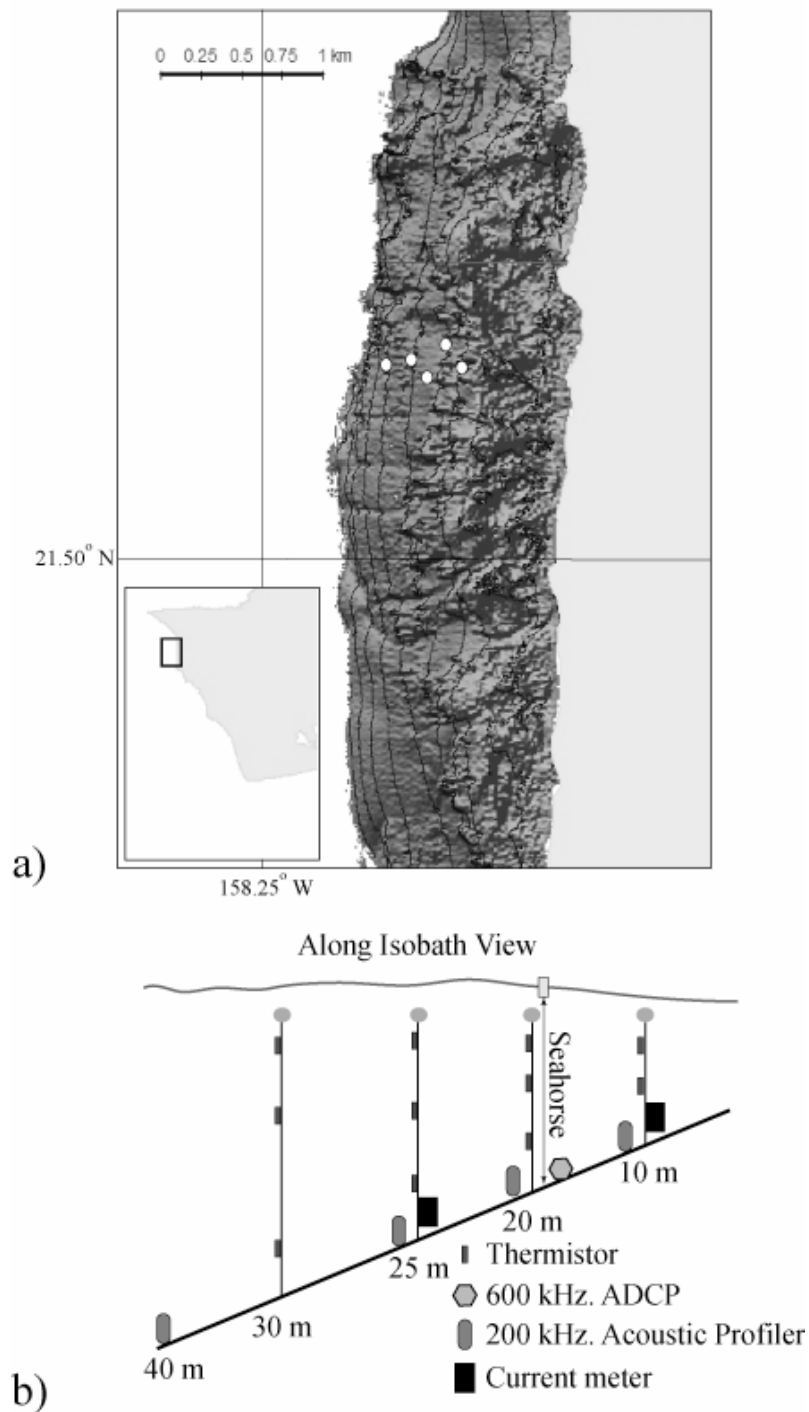


Figure 2. Study area and instrument deployment locations for 2006 study. (a) Study area showing mooring array configuration (white dots). (b) Along isobath view of array showing location of moorings E (40 m), D (30 m), C (25 m), B (20 m) and A (10 m) (from left to right) as well as instrument locations and depths.

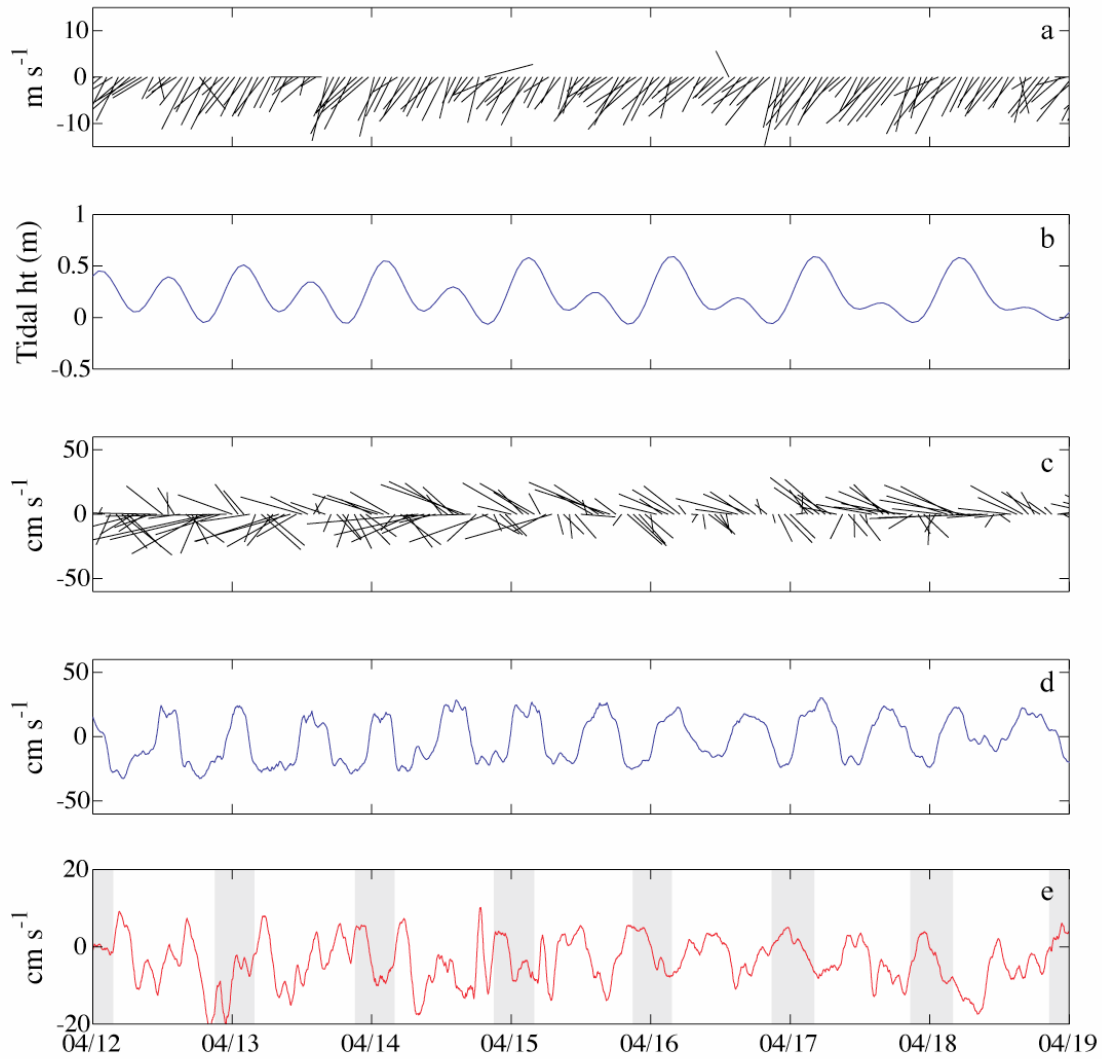


Figure 3. 7-day time records from 2006 (25 m mooring) showing (a) Hourly wind velocity, (b) Hourly tidal height, (c) Hourly 1 m.a.b. current velocity vectors oriented alongshore (positive-y is north), (d) Along shore (along isobath) current magnitude, (e) Across-shore (across isobath) current magnitude (+onshore/-offshore), grey shaded regions show period when micronekton are onshore (over array).