Spatial and Temporal Variability of Zooplankton Thin Layers: The Effects of Composition and Orientation on Acoustic Detection of Layers

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LONG-TERM GOALS

Our primary long-term objective is to better understand the physical and biological mechanisms of formation and maintenance of thin layers of zooplankton. Because zooplankton can be strong sound scatterers, acoustic instruments are effective at detecting and describing zooplankton thin layers. Using a combination of instruments (acoustics, image-forming optics, ADCP's, CTD's, and bio-optical sensors) and sampling platforms (a fleet of gliders and a profiling package), we plan to determine the temporal and spatial scales of acoustic backscatter from zooplankton aggregations, the taxonomic and size composition of the zooplankton in such layers, and the associations of zooplankton thin layers with physical parameters. To do this, it is imperative that we understand the factors influencing the frequency dependent backscatter from the organisms. In particular, the orientations of the plankton relative to the acoustic source can have significant effects on the resultant backscatter. Hence, a

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secondary objective is to improve our understanding of *in-situ* acoustic backscatter from zooplankton so that moving platforms that change orientation, such as gliders, can provide accurate acoustic survey data on the distribution and composition of scattering features.

Questions to be addressed by the proposed research:

1. What is the temporal and horizontal spatial variability of zooplankton scattering layers and the spatially coincident physical and biological parameters associated with these layers?

2. What is the time-scale of zooplankton layer generation (aggregation) and destruction (dispersal) and how do these correlate with physical characteristics and phytoplankton thin layer formation?

3. What are the composition of zooplankton scattering layers and the *in-situ* orientation of the organisms and how does this affect the spectrum and magnitude of measured backscatter?

4. How do physical and biological mechanisms together form and maintain scattering layers?

APPROACH

To address the first two question listed above, we used acoustic backscatter and physical data collected in the summer of 2005 and 2006 from a fleet of gliders in Monterey Bay (part of the LOCO program). This data will be analyzed to describe the temporal and spatial variability of zooplankton scattering layers and the associated physical and biological parameters and the time-scales of zooplankton layer formation and destruction.

We are using data collected in July 2006 to address zooplankton composition and orientation in the thin layers. These data will allow us to determine some of the taxa specific and behavioral responses that are important to zooplankton thin layer formation and persistence and to address the question of how orientation of the scatterers affects the backscatter intensity. In addition to the glider surveys, we conducted field work consisting of a detailed investigation of the taxonomic composition of the scattering layers at different depths using a shipboard CTD profiling package equipped with a 6-frequency TAPS (Tracor Acoustic Profiling System) and the ZOOVIS-SC (the self-contained Zooplantkon visualization System) imaging system in conjunction with a vertical net samples and discrete pump samples (Figure 1). These instruments provided data on the taxonomic composition of the scattering layers and the *in-situ* orientation of the zooplankton, and allow us to resolve the spectral character and magnitude of the acoustic backscatter.

Figure 1. ZOOIS-SC, the TAPS, and the pump sampler intake mounted on the R/V Thompson's CTD frame.

WORK COMPLETED

Field Work

The July 2006 field work has been completed. There were 15 ZOOVIS/CTD/TAPS casts completed with complementary net and pump sampling. Six of these casts were day/night pairs and two of these pairs were part of 24 hour sampling regimes as part of the LOCO program. Over 150,000 images were collected with ZOOVIS-SC.

The glider operations were successful and are described in more detail by D. Fratantoni (WHOI) in his annual report. One glider successfully operated continuously for 10 days, completing approximately 2400 vertical profiles and covering 210 km. The glider occupied a section line with one end point near the mooring array (near the 20 m isobath) and extending to the Southwest across the 75 m isobath. Profiling operations were conducted near the glider on several occasions to allow for comparison of the instrument data on both platforms.

Analysis of Glider ADCP data

The ADCP backscatter data from the gliders deployed in 2005 and 2006 has been corrected for transmission loss and converted into volume backscatter (S_V). The corrected data were then interpolated over space and time using the geostatistical interpolation method of kriging.

A calibration of the ADCP used to collect data in 2005 and 2006 was conducted by A. Lavery and M. Sutor using a standard target in a tank facility at WHOI. The results of that calibration are still being analyzed in consultation with the ADCP manufacturer, Nortek. This is the first known attempt to calibrate an ADCP using a standard target and the results of this calibration may prove useful for other ADCP users who would like to convert backscatter data from relative magnitudes into absolute magnitudes.

Analysis of ZOOVIS data

The image data from ZOOVIS have been merged with the data from the roll and pitch sensor and the CTD so that there is a corresponding value of roll, pitch, pressure, temperature, salinity, and fluorescence to accompany each image from the camera system. Qualitative analysis of all of the ZOOVIS casts has been completed and detailed manual sorting of the images is ongoing. Automated image extraction and recognition software is being developed for use on this image data and this software will be available by the end of October 2007. At that time, manual sorting of the ZOOVIS data will be compared with the automated techniques to determine extraction efficiency of images of interest and validation of the automated classification techniques. If the automated techniques prove accurate, the rest of the ZOOVIS data will be analyzed using these automated techniques.

Analysis of Pump and Net Samples

An undergraduate student who participated in the cruise and is completing a UROP (Undergraduate Research Opportunities) project on this data, has been conducting silhouette analysis of the net and pump samples. This work is ongoing.

RESULTS

ADCP Backscatter Data

The backscatter data from the ADCP mounted on a glider shows that there was a diel signal in the backscatter data with a layer of increased backscatter forming in the upper water column at night, but disappearing during the day (Figure 2). This pattern was seen both in 2005 and 2006. The increase in backscatter intensity in the upper water column at night is not a function of location as it was observed in both the offshore (Figure 4) and inshore (Figure 3) portions of the glider track. What may be an aggregation of zooplankton moving up in the water column at night to form the layer and descending at dawn as the layer dispersed was also observed. The layer was located above 3 m, was 1-3 m thick and had a spatial gradient of 5 dB (more than a two-fold increase on a linear scale) calculated over 1 m vertical bins. The layer appeared to form rapidly (in less than 1 hour), though this cannot be definitively quantified as the glider data is spatially aliased. These data demonstrate the ability of glider mounted acoustic systems to resolve sharp spatial and temporal gradients in backscatter and to provide a long-term, continuous data set of acoustic backscatter measurements.

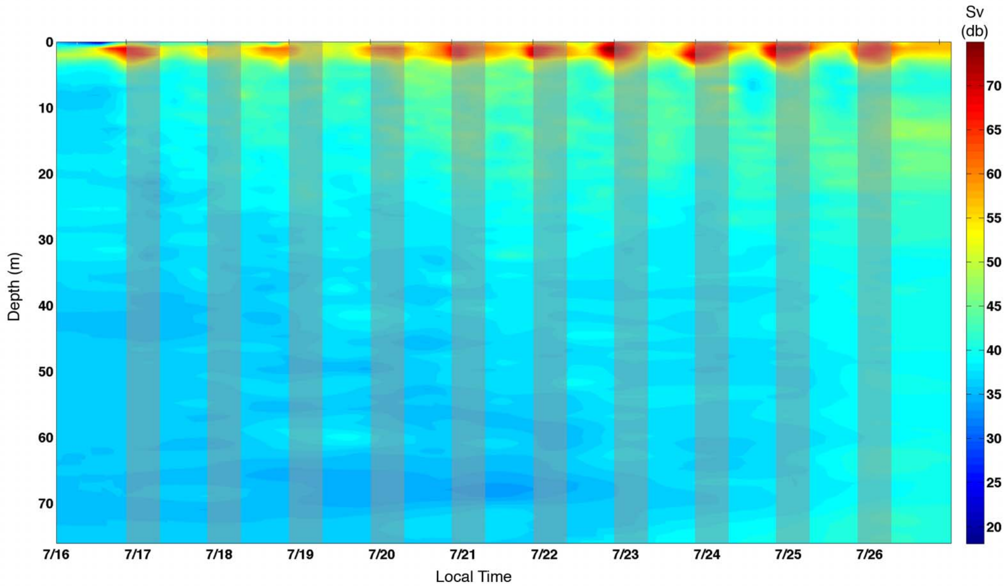

Figure 2. Interpolated backscatter data from the glider mounted ADCP in Monterey Bay in July 2006. The shaded regions mark the time period between sunset and sunrise.

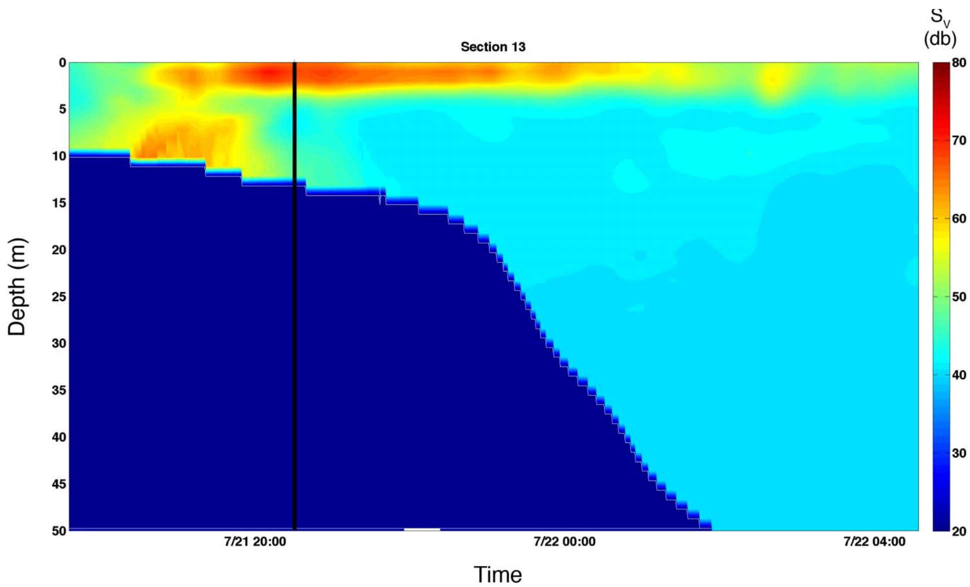

Figure 3. One inshore-offshore section (13) of interpolated backscatter data from the glider mounted ADCP in Monterey Bay in July 2006. The black line marks sunset.

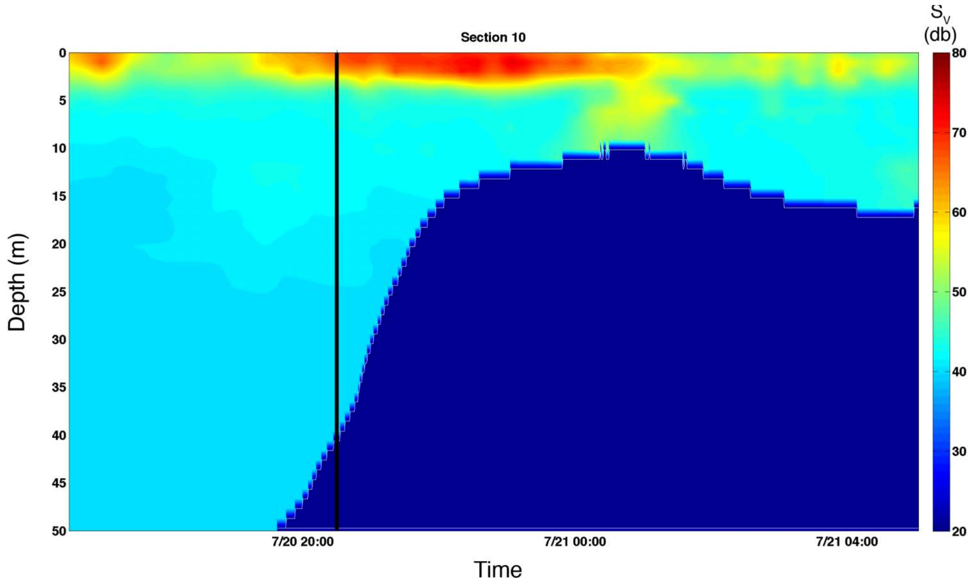

Figure 4. One offshore-inshore section (10) of interpolated backscatter data from the glider mounted ADCP in Monterey Bay in July 2006. The black line marks sunset.

ZOOVIS Data

Our initial analysis of the image data shows that ZOOVIS-SC collected numerous, clear, images of zooplankton. We saw many images that contained multiple copepods and delicate gelatinous taxa such as larvaceans and medusae (Figures 5 and 6). Images of small targets including ciliates (Figure 7, panel A), dinoflagellates (Figure 7, panel B), radiolarians (Figure 7, panel C), and diatom chains (Figure 8) were also collected. The system clearly resolved small individuals (copepods less than 1 mm in length) and provided striking images of marine snow and other particles in the water column. Combined with the CTD data and information from the camera's roll and pitch sensor, we will be able to resolve the vertical distribution of zooplankton, their *in-situ* orientation, and in many cases nearest neighbor distances. Qualitative analysis of the data has shown that copepods are oriented predominantly head-up or head-down, and are rarely horizontal in the water column. Additionally, orientation does not appear to be random as images with multiple copepods show that all of the individuals are oriented in the same direction (Figure 5).

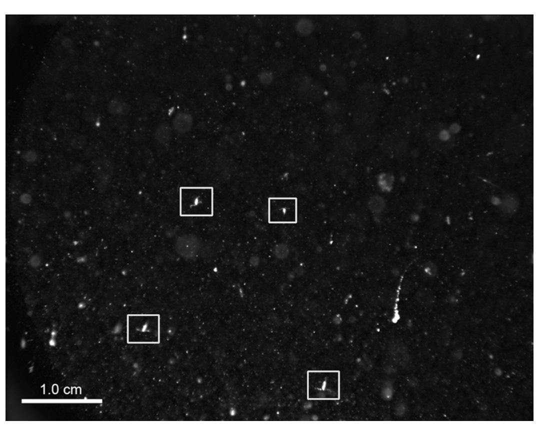

Figure 5. Image of multiple copepods taken with ZOOVIS-SC in Monterey Bay in July 2006.

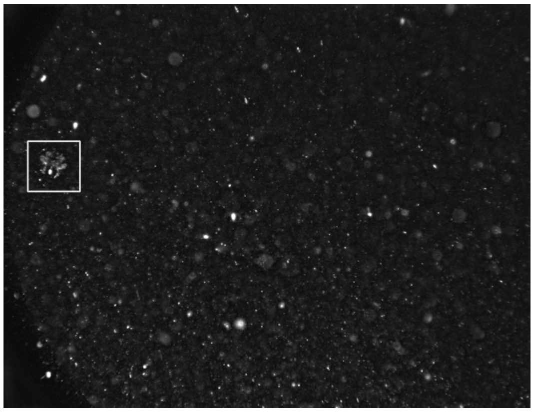

Figure 6. Image of larvacean with intact mucous house taken with ZOOVIS-SC in Montery Bay, July 2006.

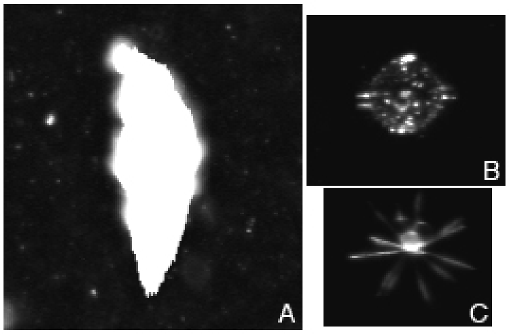

Figure 7. Image of a ciliate (Laboea, panel A), dinoflagellate (Protoperidinium, panel B), and radiolarian taken with ZOOVIS-SC in Monterey Bay in July 2006.

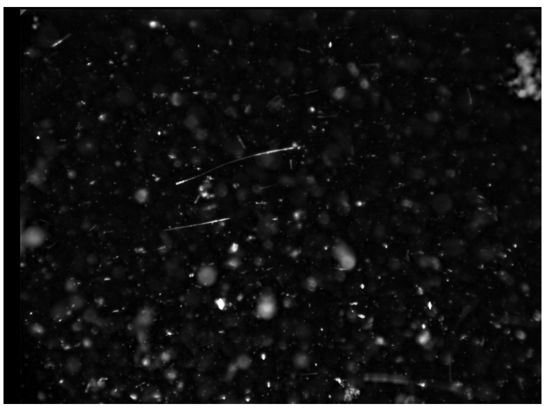

Figure 8. Image of multiple diatom chains taken with ZOOVIS-SC in Monterey Bay in July 2006.

Net and Pump Data

Silhouette analysis of the net and pump samples is ongoing. Priority has been given to samples that can be used to groundtruth the acoustic data from the gliders and the ZOOVIS image data. An example of the type of data that results from silhouette analysis is shown in Figure 9. These plots show the abundance of different zooplankton taxa and the mean length of individuals in each taxonomic group for seven integrated water column pump samples. Small copepods (less than 1 mm) numerically dominate the zooplankton community in each sample, but the overall abundances, sizes, and proportion of less abundant taxa varies a great deal between samples.

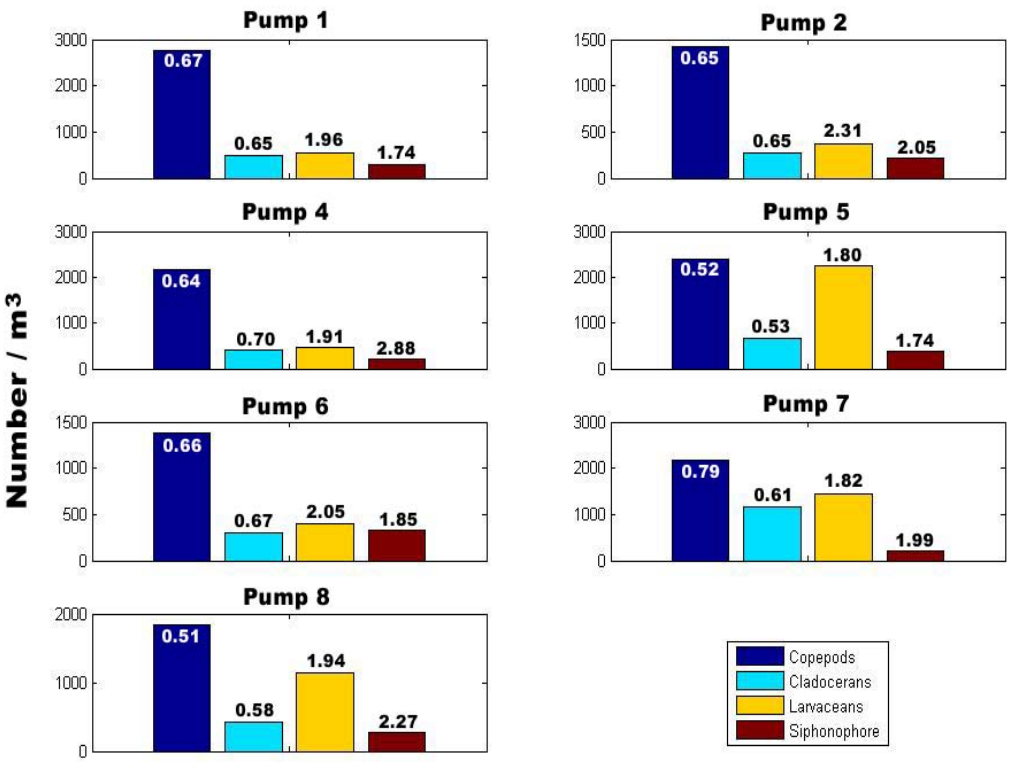

Figure 9. Abundance estimates derived from the silhouette analysis of the pump samples. The average length for each taxa is noted at the top of each bar. Lengths are in millimeters. Data from Pump 3 are not presented as the analysis if this pump sample is not yet complete.

IMPACT/APPLICATIONS

The image data from ZOOVIS-SC can be used to determine the composition of observed scattering layers, improve upon scattering models used to interpret acoustic signal, and help us to make some inferences about behavioral mechanisms of zooplankton aggregation. Utilizing a suite of sensors (acoustics, image-forming optics, CTD, nets and pumps) and two different platforms (ship-board profiler and gliders) will greatly expand out understanding of the dynamics of zooplankton layers and how we interpret acoustic backscatter signal from layers.

RELATED PROJECTS

This work is directly related to several past and current ONR projects. Project N00014-98-1-0563 "Development of a Vertically Profiling, High-Resolution, Digital Still Camera System" awarded to Mark Benfield (LSU) provided the initial funding for the development of the ZOOVIS imaging system that was used in this work. The current project is also tightly linked to all of the funded LOCO projects and is most closely linked to "The physical context for thin layers in the coastal ocean" (N00014-04-1-0250), awarded to Dave Fratantoni (WHOI) and "Finescale planktonic vertical structure: horizontal extent and the controlling physical processes" (N00014-04-10277), awarded to Tim Cowles (COAS-OSU).

This work is also related to ongoing research on the interpretation of acoustic scattering in the coastal ocean by A. Lavery (WHOI) in the current ONR project "High-frequency broadband acoustic scattering from temperature and salinity microstructure: From non-linear waves to estuarine plumes" (N00014-02-0359).