High-Frequency Broadband Acoustic Scattering from Temperature and Salinity Microstructure: From Non-Linear Internal Waves to Estuarine Plumes

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LONG-TERM GOALS

To understand high-frequency broadband acoustic backscattering from small-scale physical processes, such as internal waves, turbulence, and microstructure, in shallow, stratified coastal waters.

OBJECTIVES

The primary objective of the proposed research was to measure high-frequency broadband acoustic backscattering in highly stratified, energetic environments and to determine the contribution to scattering from temperature and salinity microstructure. Testing the validity of existing scattering models and the initial development of new, and/or extension of existing, simple physics-based scattering models was a secondary objective of this work.

To accomplish the stated objectives, high-frequency broadband (150-600 kHz) acoustic backscattering measurements were performed during the generation, propagation, and dissipation of non-linear internal waves in August 2006 as a part of the SW06/NLIWI experiment. Almost coincident microstructure measurements were collected by Jim Moum with a profiling microstructure instrument, Chameleon. The contribution to scattering from biological organisms was quantified using a multiple-opening and closing net and environmental sensing system (MOCNESS), from which the zooplankton taxa, size, and depth (in relatively coarse vertical bins) can be determined.

APPROACH

The approach taken here to understanding acoustic scattering from oceanic microstructure involves the combination of field measurements in which as many sources of scattering as possible are characterized, and interpretation of the data within the framework of existing physics-based acoustic scattering models, and refining existing scattering models or guiding the initial development of new scattering models.

First, measurements of high-frequency broadband acoustic backscattering were performed in an energetic shallow-water coastal region in which there are strong temperature gradients. The contribution to scattering from temperature microstructure should be maximized in these environments, increasing the likelihood of observing scattering from microstructure over other scatterers. Scattering from marine organisms, predominantly small fish and zooplankton, which can

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14. ABSTRACT
The primary objective of the proposed research was to measure high-frequency broadband acoustic backscattering in highly stratified, energetic environments and to determine the contribution to scattering from temperature and salinity microstructure. Testing the validity of existing scattering models and the initial development of new, and/or extension of existing, simple physics-based scattering models was a secondary objective of this work.

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act as passive tracers of physical processes such as internal waves and turbulence, are a significant confounding factor during the interpretation of high-frequency acoustic volume backscattering.

The data analysis involves capitalizing on the broadband nature of the transmitted signals and using pulse compression techniques (Chu and Stanton, 1998) to both increase the signal to noise ratio and the spatial resolution of the measurements. It has been possible to obtain almost cm scale resolution in the direction of acoustic propagation using these techniques, a significant improvement over traditional single-frequency echosounder observations of water-column scattering. Additional information is obtained by further capitalizing on the broadband nature of the acoustic signals by using the spectral content of the scattering to determine if the scattering is consistent with scattering from small-scale physical processes or biology. In regions in which the scattering is determined to be dominated by turbulent microstructure, it may be possible to extract parameters such as the dissipation rate of turbulent kinetic energy. Direct measurements of microstructure and biology are important for allowing comparisons of acoustic measurements to physics-based model simulations.

WORK COMPLETED

Instrument development: A 4-channel high-frequency broadband acoustic backscattering system has been developed spanning the frequency range, in four almost overlapping bins, from 150 kHz to 590 kHz: the low-frequency channel spanning 150-270 kHz, the mid-frequency channel spanning 220-330 kHz, the high-low frequency channel spanning 330-470 kHz, and the high-high frequency channel spanning 450-590 kHz. The four Airmar transducers (full beamwidths between 8 and 12 degrees depending on the frequency) are mounted on a rotatable frame that allows the transducers to be orientated in either a down-looking or side-looking mode. The system is designed to either profile vertically with the transducers in a side-looking mode or to be suspended at a particular depth with the transducers in a down-looking mode (resembling a more traditional echosounder). A SeaBird SBE 49 FastCAT CTD (16 Hz sampling rate) is mounted on the system to measure fine-scale temperature and salinity gradients while in profiling mode. Pitch, roll, and heading are also measured. GPS data are recorded to allow accurate synchronization with other instruments.

Field measurements: This system has been deployed during the SW06/NLIWI experiment during a month long cruise (July 30- August28, 2006) on the RV Oceanus. Direct microstructure measurements were performed by Jim Moum using the turbulence profiler Chameleon (Moum et al., 2003). The broadband acoustic system was fully operational throughout the experiment and high-frequency broadband acoustic backscattering has been measured for 28 internal solitary wave trains, in some cases chased over many kilometers from generation to dissipation stages. The acoustic system was deployed in both down-looking and side-looking mode, allowing scattering anisotropy during the passage of internal solitary waves to be investigated. In addition, 5 depth-resolved net tows (MOCNESS) were performed during this experiment in order to quantify biological scatterers.

Instrument calibration: The system has been calibrated in sea-water tanks at WHOI and at SMAST (on multiple occasions), in the WHOI sea well (also on multiple occasions), and in-situ using 20 mm and 38.01 mm diameter Tungsten Carbide standard targets. The beam width of each transducer has been measured, and scattering from a flat air-water interface in the sea-water tank has been measured in order to determine the frequency range over which each transducer has a flat frequency response. Standard target calibrations as a function of depth have also been performed in order to quantify the effects of changing pressure on the performance of the transducers.

Analysis of microstructure and biological measurements: Jim Moum is primarily responsible for the analysis of the microstructure measurements, and much of the data collected during the field experiment has been analyzed. In addition, two out of the five MOCNESS tows have been analyzed for composition, size, and abundance of zooplankton. Predictions based on scattering models (Lavery et al., 2003, 2007) that incorporate these data have been performed at select locations (the "forward problem") to determine the contribution to scattering from biology and turbulent microstructure.

RESULTS

The primary effort to date has been in the data collection and in the accurate calibration of the broadband acoustic scattering system. It became apparent during the early stages of the data analysis that though great care had been taken in carefully calibrating the system, an unforeseen calibration problem was resulting unexpectedly high scattering levels. The scattering spectra across all frequency bands were continuous, and showed structure expected based on model predictions, however, there was a uniform offset that resulted in scattering levels many dB larger than predicted based on zooplankton and microstructure scattering models across the entire frequency band of interest. Great effort has been dedicated to solving this problem. Repeated multiple-standard-target calibrations have been performed, and the measured system response based on one standard target used to calibrate the scattering from a second standard target, accurately reproducing theoretical spectra based on exact modal series solutions. All calibrations performed, before and after the experiment, were highly consistent. It was finally discovered that an undocumented analog gain had been applied to the data, in addition to the standard TVG that is normally applied to account for spherical spreading. This strongly range-dependent analog gain was not recognized during the standard target calibrations as these were performed at short ranges (2-5 meters). This calibration problem has been satisfactorily resolved and data analysis has resumed. However, as a result of this set back, detailed data analysis from the SW06/NLIWI experiments is still in its early stages. The results of the analyses performed to date are summarized below:

Analysis of biological samples and the forward problem based on these data: Two of the five MOCENSS tows performed during the SW06 experiment have been analyzed. The results show that biomass and numerical abundance of zooplankton are dominated by copepods, with larger copepods located in a deep scattering layer and the shallower waters being populated by smaller copepods (Fig. 1). Both these MOCNESS tows were performed during day light hours. Scattering predictions based on these data and available zooplankton models (Lavery et al., 2007) have shown that the predicted scattering from zooplankton is also dominated by copepods (Fig. 2). The scattering predictions are in good agreement with the measured broadband spectra (Fig. 2).

Forward problem based on microstructure data: Scattering predictions have also been made based on the microstructure data and turbulent microstructure scattering models, at select locations. These predictions suggest that the scattering from microstructure is dominated by temperature and not salinity microstructure (Fig. 3). However, none of the broadband acoustic data spectra analyzed to date are consistent with scattering dominated by temperature microstructure alone (Fig. 3).

Scattering due to small-scale physical processes versus biology: Though the frequency response of the scattering was often consistent with scattering from biology (scattering increasing with increasing frequency), many regions have been found in which the scattered frequency spectra are indicative of scattering from physical processes (Fig. 3). To date, it has been found that a strong scattering layer is associated with regions of high temperature and salinity gradients (Fig. 3), at depths close to the base of the seasonal thermocline, and not necessarily regions with high dissipation rates.

Scattering anisotropy: Doris Leong, a graduate student at Dalhousie University, is investigating the scattering anisotropy observed during SW06. Thin horizontal scattering layers were consistently observed with the high-frequency broadband acoustic scattering system in down-looking mode. However, significantly less structure was observed with the acoustic system in side-looking mode.

IMPACT/APPLICATIONS

It is important to understand the circumstance under which different processes and/or targets contribute to high-frequency acoustic scattering. For example, a common misconception is that high-frequency acoustic scattering in the water-column is dominated by biological organisms. Only recently has it become more accepted that microstructure can also contribute to scattering, under certain circumstances. The results of the measurements performed here provide additional evidence that small-scale physical process can be significant contributors to volume scattering in regions of internal solitary waves. This project has also developed high-frequency broadband acoustic scattering techniques that 1) increase the circumstances under which scattering from microstructure and biology can be distinguished, and 2) increase the spatial resolution with which physical and biological processes are imaged, which is especially relevant as it has become increasingly evident that thin biological and physical layers are prevalent in coastal regions. Finally, these measurements may provide valuable environmental data to the SW06 community, in addition to potentially allowing high-frequency acoustic scattering techniques to become a quantitative remote sensing tool for physical oceanographers.

RELATED PROJECTS

A collaboration with Jim Moum (OSU), a lead PI in the SW06/NLIWI experiment, is underway on the analysis of coincident microstructure and broadband acoustic scattering data.

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STUDENTS ASSOCIATED TO THIS PROJECT

Doris Leong, Graduate Student, Dalhousie University, Canada. July 2006- present.
Paul Heslinga, WHOI Guest Summer Student, Cruise Participation. July-August 2006.

HONORS/AWARDS/PRIZES

Andone C. Lavery has been awarded a WHOI Coastal Ocean Institute Fellowship.

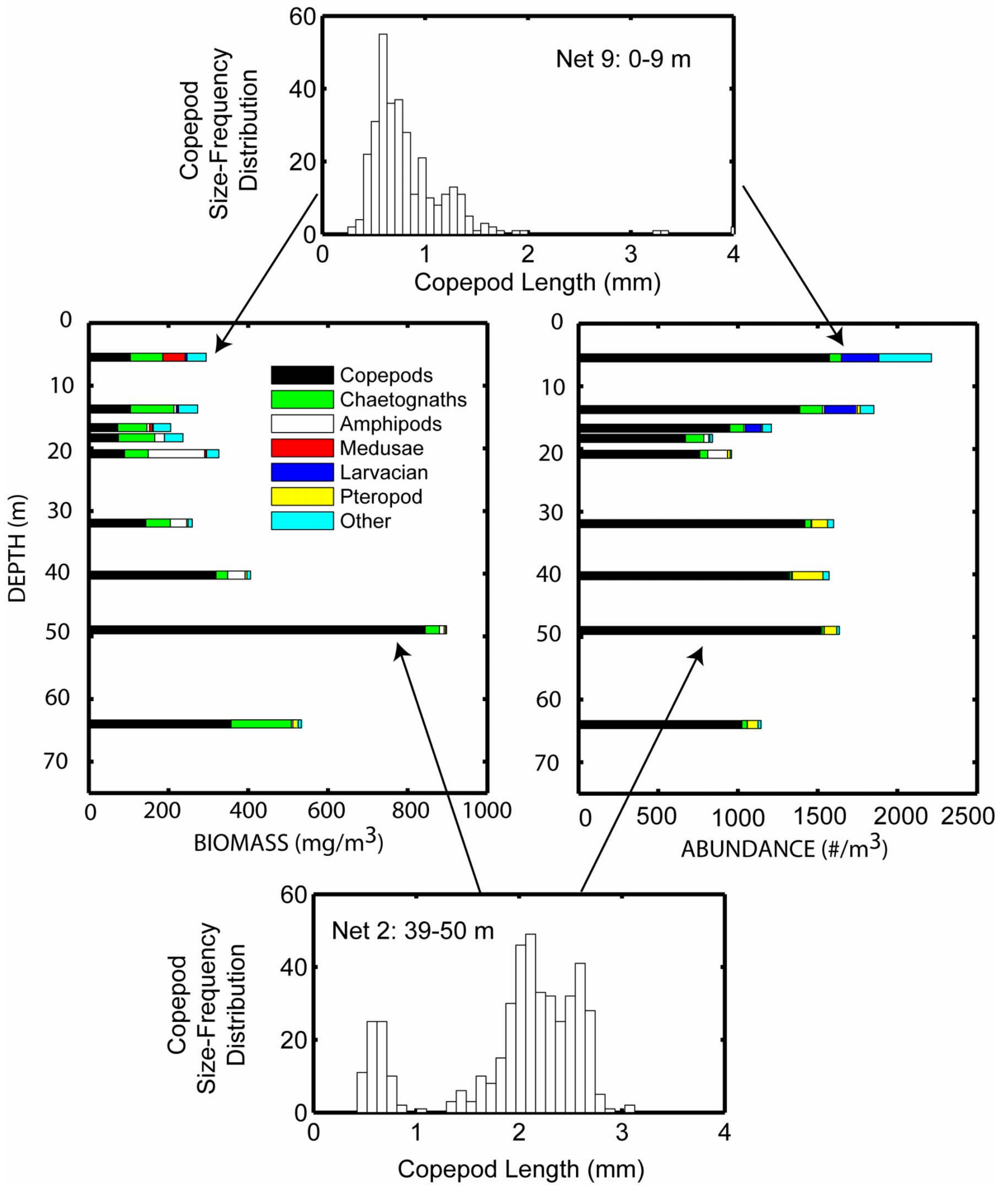

Figure 1: Biomass (mg/m^3) and abundance (#/m^3) of zooplankton as a function of depth as determined from MOCNESS tow 5 performed on 26 August 2006. The biomass and numerical abundance of zooplankton are dominated by copepods. Small copepods (mean length approximately .75 mm) dominated the near-surface nets while larger copepods (mean length 2 mm) dominated the deeper nets.

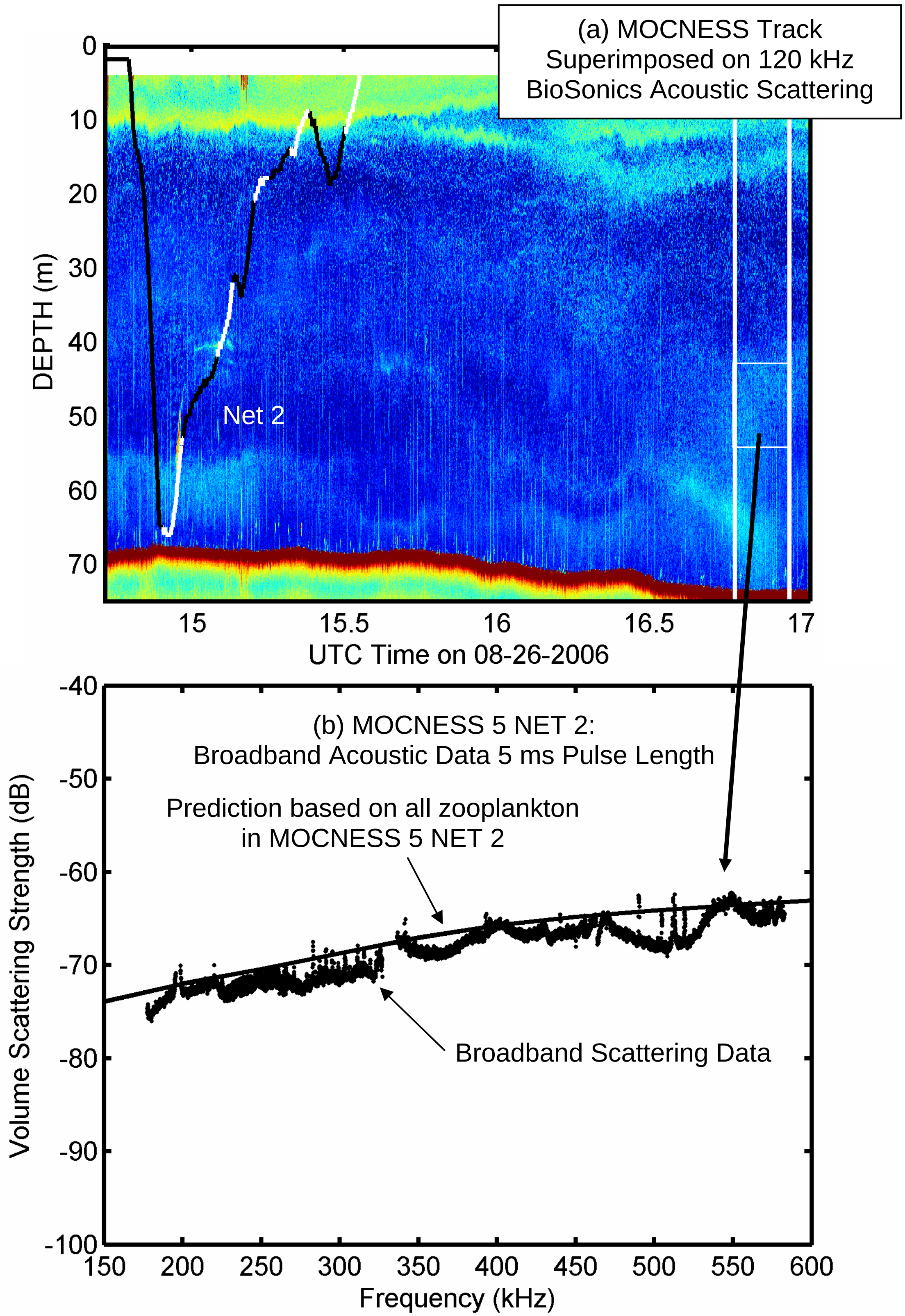

Figure 2: (a) MOCNESS 5 (26 August 2006) trajectory superimposed on the uncalibrated 120 kHz Biosonics acoustic backscattering record. The broadband system could not be deployed to collect data while the MOCNESS was in the water. (b) Comparison of broadband scattering spectra and model predictions based on almost coincident biological data from MOCNESS 5 Net 2 (depths 42-53 m). The acoustic data have been filtered for noise spikes.

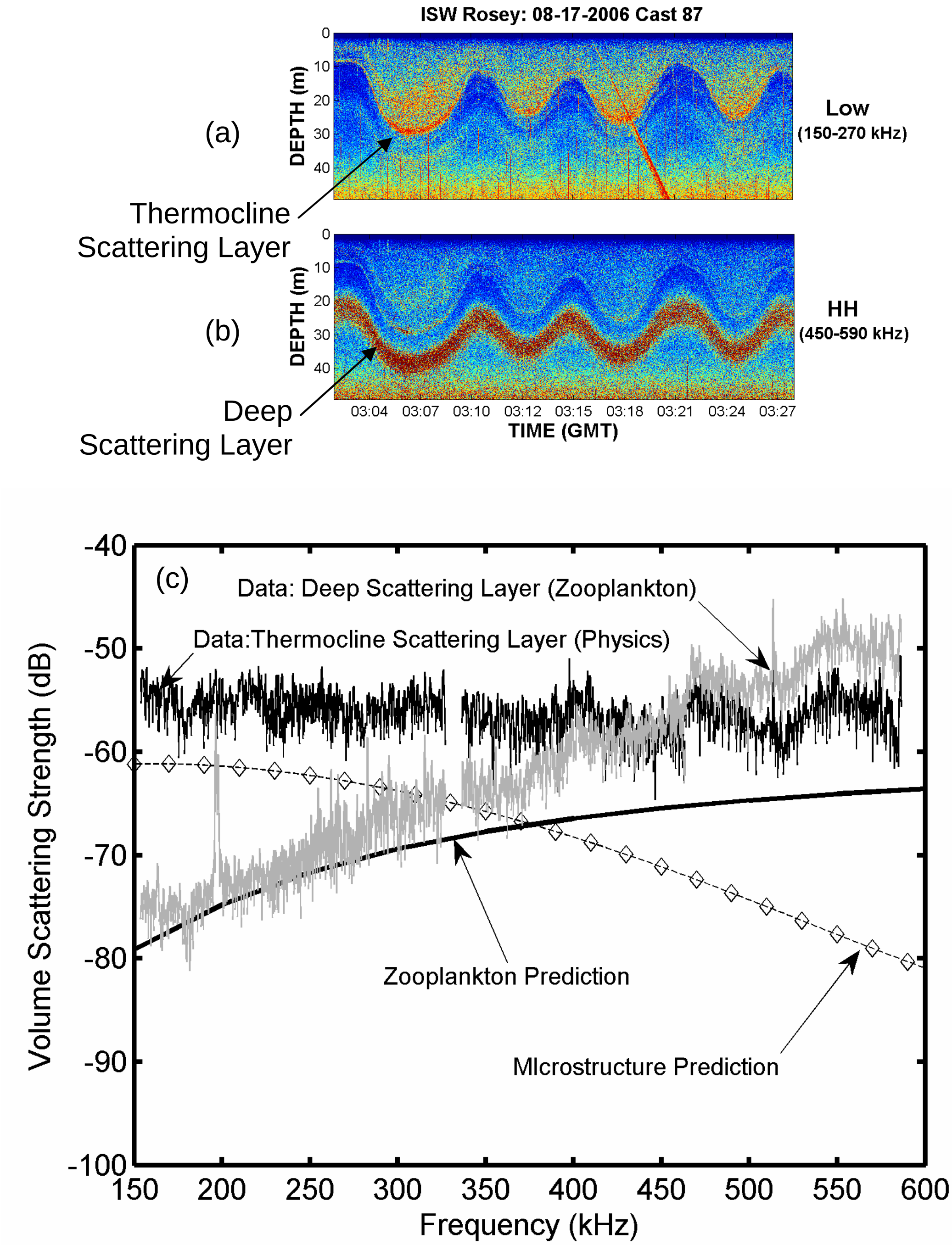

Figure 3: Compressed pulse output for the (a) LOW (150-270 kHz) and (b) HH (450-590 kHz) frequency channels during the passage of non-linear internal wave "Rosey" on 17 August 2006. A strong scattering was observed at all frequencies at depth where temperature and salinity gradients were largest, as well as a deeper scattering layer which was strongest at higher frequencies. (c) Broadband spectra of the two layers showing different frequency responses. Microstructure predictions are dominated by temperature microstructure and are based on almost coincident microstructure measurements performed by Jim Moum (OSU). Zooplankton scattering predictions are based on zooplankton information collected on 26 August 2006 during MOCNESS 5.