

Novel Acoustic Techniques for Assessing Fish Schooling in the Context of an Operational Ocean Observatory

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LONG-TERM GOALS

Fish aggregation is important in terms of biology, fisheries, and measurement, quantitative analyses of gregarious movement behaviors remain relatively rare (Turchin 1989). Fish aggregation has most often been studied in easily accessed fish or fish easily maintained in the laboratory such as minnows and dace (see a review in Pitcher and Parrish 1993). Measurements of fish aggregations are often difficult, particularly in pelagic environments. Our goal is to develop new acoustic techniques that have the potential to serve as measurement tools to quantify this ubiquitous and important behavior.

OBJECTIVES

This project brings together a team with expertise in acoustics, engineering, biology, fisheries, and oceanography to develop and apply acoustic techniques to measure schooling in pelagic fish.

We combined traditional, split-beam fisheries echosounding techniques and direct sampling with new acoustic techniques and new platforms in a study area monitored by an existing operational ocean observatory. To measure synoptic distributions of fish schools we collected mid-frequency back- and bistatic-scattering from fish using a unique horizontally oriented multibeam system. We will experimentally evaluate the use of ship-board and moored mid-frequency sonar for the detection and resolution of fish schools at long range (kilometer scale) in the context of propagation and scattering in a shallow water waveguide. Toward the goal of integrating mid to geometric frequency scattering measurements, we will observe the relationship of high frequency echosounder and multibeam measurements to mid-frequency short-range measurements (direct path scattering) and mid-frequency long-range measurements (waveguide scattering). In doing so, we will correlate the results of the longer-range measurement (less understood and more complex scattering geometries) with more traditional (better understood) higher frequency and geometric scattering regimes and techniques. We will also investigate the ability of higher frequency multibeam techniques to assess the internal structure of detected schools. A 200 kHz multibeam capable of collecting water column data will be integrated into an autonomous underwater vehicle (REMUS). Deploying this cutting edge instrument on an autonomous platform will allow us to access fish at greater depths, while sampling the high spatial resolution necessary to measure the geometry of fish in an aggregation. All field sampling will be conducted within the New Jersey Shelf Observing System (NJ SOS), which provides real-time data throughout the Mid-Atlantic Bight (MAB). The surveys will be positioned adaptively using real-time data collected with the international constellation of ocean color satellites, a nested grid of HF radars, and an operational fleet of autonomous Webb Gliders. The goal is to use the environmental data to optimize ship and AUV acoustic surveys by using the observatory to identify specific water masses, frontal boundaries, and subsurface phytoplankton plumes. The surveys will then identify and track schools of fish associated with this hydrographic and biological structure. This approach will provide a context for the fish schooling information, allowing us to begin to look for correlations between the fish biology and environmental variability.

APPROACH AND WORK PLAN

- *Develop new acoustic techniques to measure aggregations of fish*
 - High-frequency multibeam sonar on autonomous underwater vehicle (AUV)
 - Observe individual schools over short ranges
 - Quantify geometry inside of school
 - Mid-frequency multibeam sonar
 - Image large volume of water
 - Quantify gross school movement
 - Back and bistatic-scattering
- *Relate mid-frequency acoustic bistatic and back scattering to high-frequency multibeam and split-beam backscatter and both to fish activity*
 - Determine how fish distribution (school structure) is related to long-range acoustic scattering
 - Use traditional techniques with new methods to determine which fish are present, in what numbers, and how they are distributed
 - Determine how variability within a school affects acoustic scattering

- *Relate fish causing acoustic scattering to physical and biological oceanography*
 - Characterize environment for different fish schools using the New Jersey Shelf Observing System
- *Obtain time series data*
 - Diel patterns in distribution of fish
 - Changes with physical environment

During the next year, we will complete the second field season, our primary focus of effort for the project.

WORK COMPLETED

The first field effort for this project was completed in September, 2006. The New Jersey Shelf Observing System was used to choose offshore stations. The experimental box in which sampling was to be conducted was within the grid of the Nonlinear Wave Internal Wave experiment (NLWI) which had been heavily sampled with moorings, ships, satellites, HF CoDAR and fleets of 7 Webb Slocum Gliders. The initial station was chosen based on the real-time data that was available when the ship left the docks. (Figure 1)

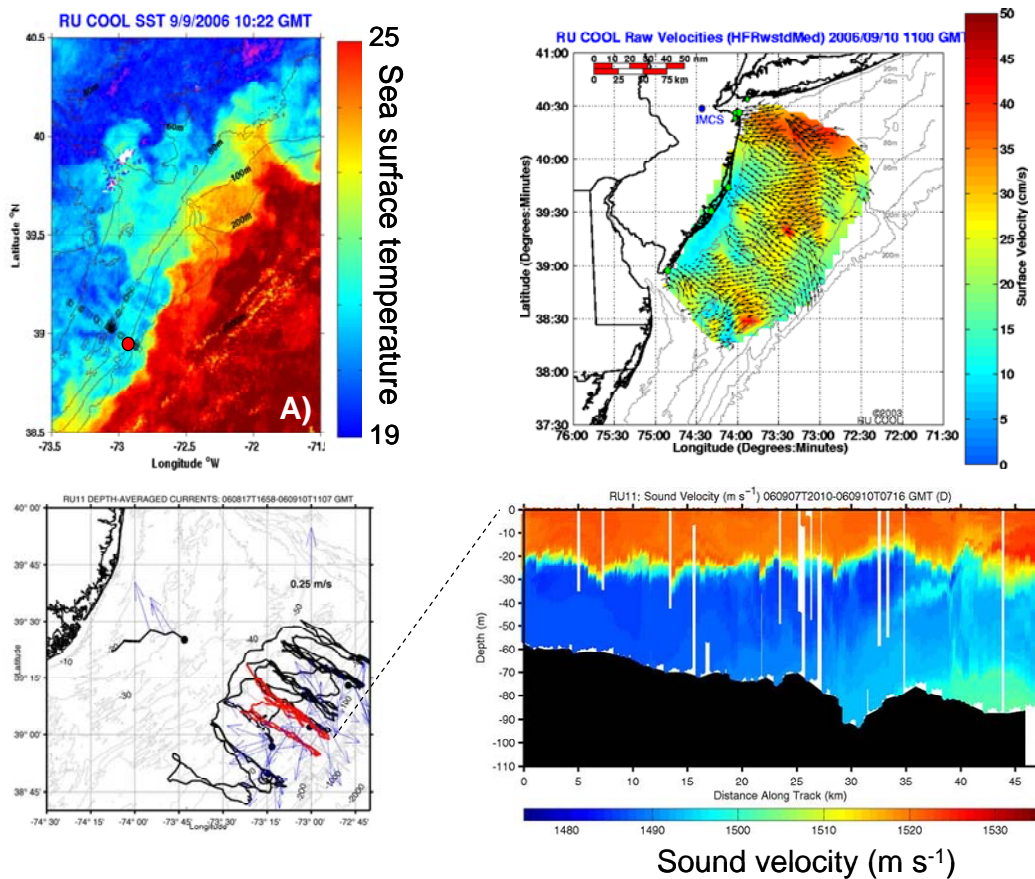


Figure 1. A) AVHRR sea surface temperatures showed a frontal boundary on the offshore southern edge of the NLWI experimental box and therefore the initial station was chosen on the outer edge of the NLWI mooring array. B) During the day of the September 10th when we arrived at the station long range HF CODAR indicated persistent onshore flow, advecting the frontal boundary across our station. C and D) One of the NLWI Gliders indicated strong strongly stratified water with a pycnocline range between 20 to 30 meters. Excursions of the thermocline appeared to be driven by the passage of internal waves. The subsurface variability in the glider sound velocity profiles were largely associated with the deep slope water creeping up on the shelf.

One day into the field effort, the station was strongly impacted by Hurricane Florence (Figure 2). The science team and ship's captain determined that it was necessary to move the R/V Sharpe into shallow water. Given the wave height and wind speed predictions, the science team elected to complete the sampling effort in the Chesapeake Bay. We completed 3.5 days of sampling in the bay, representing 3 full replicates of our sampling design.

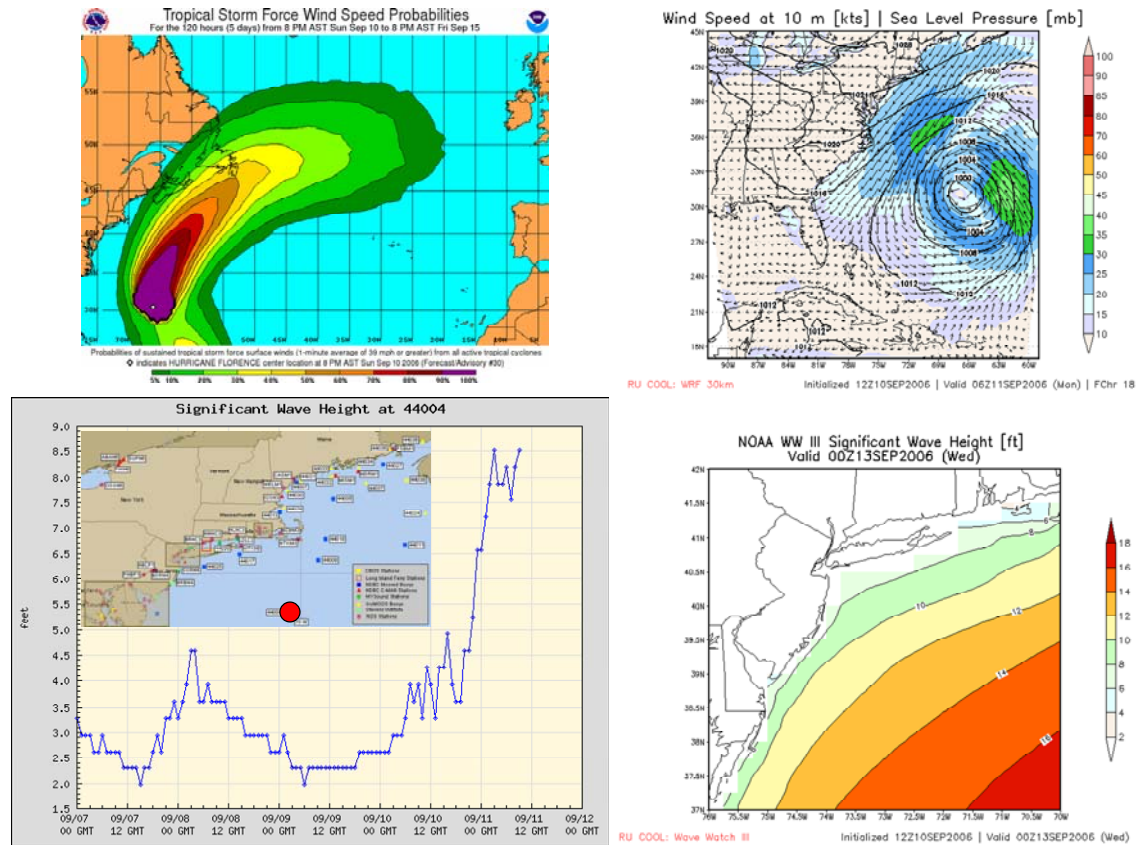


Figure 2. The NLWI site sampling after the initial station was disrupted by Hurricane Florence. A) Even though the storm was centered in the Sargasso Sea it was sufficiently large to impact field operations on the Mid-Atlantic Bight. B and C) Field conditions deteriorated on late Sunday afternoon. This forced the RV Sharp inshore. D) Rutgers ran a high resolution forecast of the wave heights. Wave heights were not predicted to decrease for at least three days which represented the majority of time available for sampling. Therefore a series of water stations were chosen inland of the coast in the Potomac and Chesapeake River/Estuaries. Weather conditions validated that the forecast and wave heights would have eliminated our ability to deploy the Applied Physics Lab acoustic array.

In both sites, we conducted sampling in a 2 km by 2 km box consisting of on station acoustic sensing using the mid-frequency multibeam, grid sampling using downward looking high-frequency acoustics, CTD casts, and net tows (Figure 3).

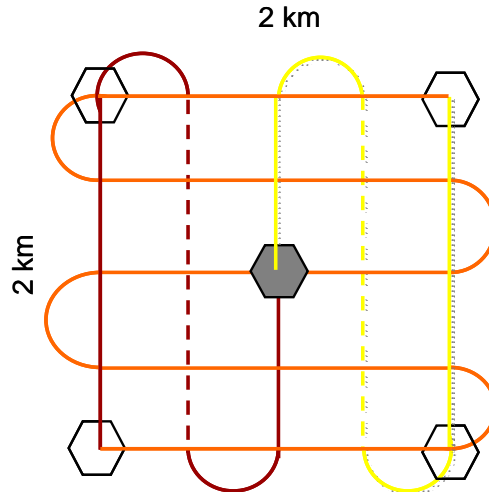


Figure 3. Sampling design. Each replicated consisted of one daytime and one nighttime survey of the box consisting of a CTD cast (grey box), followed by on station acoustic sensing with the mid-frequency sonar, running of the grid (red, orange, then yellow lines) stopping to do CTDs at corners (solid lines – acoustic surveys, dotted lines – trawls, boxes – CTD casts), on station acoustic sensing with the mid-frequency sonar, and finally a CTD cast .

RESULTS

Development of a mid-frequency multibeam system:

APL-UW has completed the design and fabrication of the mid-frequency multi-beam sonar (PIMMS – Pelagic Imaging Mid-frequency Multibeam Sonar). Initial system fabrication, testing in local waters, and calibration at the APL acoustic calibration facility was completed summer 2006. Our primary goal for the first field season for this project was to test the new instruments and integrate all sampling effectively. The mid-frequency multibeam sonar (APL/UW) was successfully deployed for approximately 20 hours of sampling (Figure 4).

The circular array images a 360 degree sector simultaneously (so it doesn't need to be pointed in a particular direction). It is relatively smaller (~1.5 meters in diameter) and designed to be deployed from a standard CTD winch and cable. The system consists of a circular receiving array and a line transmitting array. The present number of receiving hydrophones used will be 64, creating beams with a 5 degree horizontal resolution, as illustrated in Figure 3. The transmit array has 16 elements creating a projected beam that is narrow (9 degrees) in the vertical dimension and omni-directional (360 degrees) in the horizontal direction. The vertical imaging resolution of the system (as illustrated in the profile view of Figure 5) is defined by the intersection of the receiver and transmitter beams.

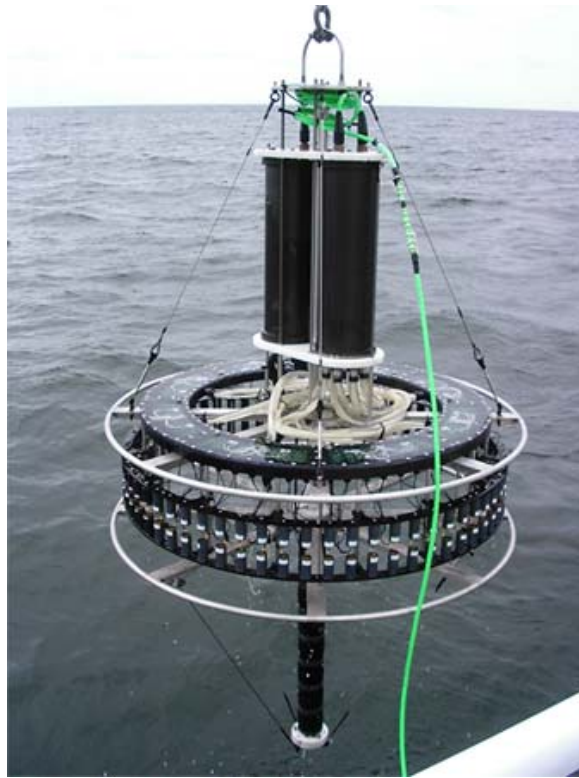


Figure 4. The Pelagic Imaging Mid-frequency Multibeam Sonar (PIMMS) being deployed off the R/V Sharpe.

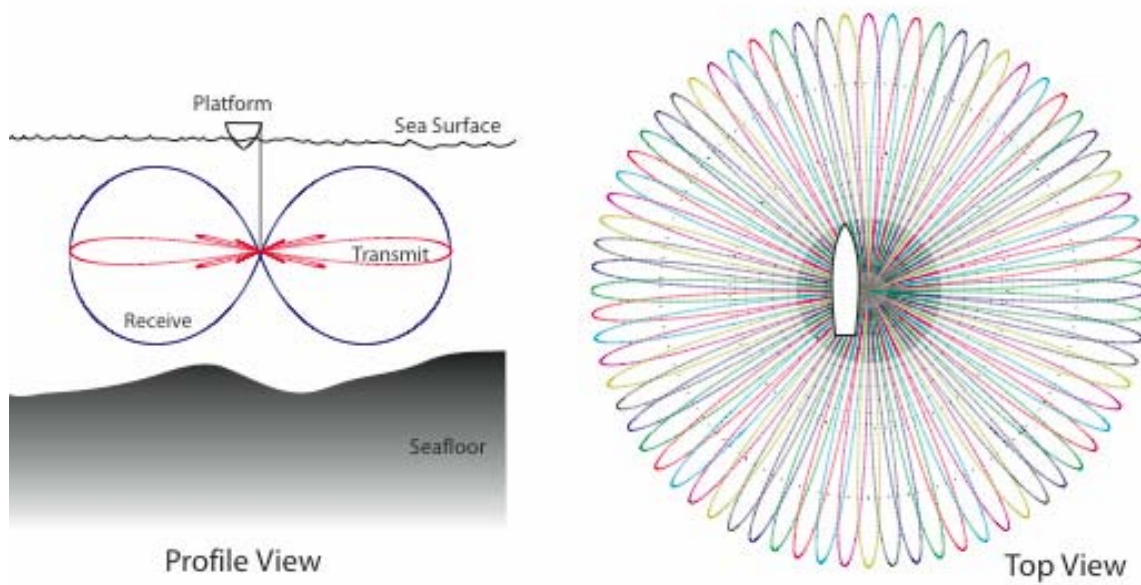


Figure 5: Deployment geometry and imaging volume of the mid-frequency circular array illustrating the receive and transmit beams patterns.

The PIMMS transmitter and receiver electronics are contained in two cylindrical housing (Figure 4). The receiver simultaneously records all 64 dipole receiving elements and stores the data internally. The data acquisition control processor run Linux and communicates to the top-side controller (laptop) via 10baseT Ethernet. The transmitter is a custom design 8 channel pulse width modulation (PWM) design capable of generating arbitrary transmit signals on 8 channels enabling transmit beam steering. Therefore, vertical imaging resolution can be achieved by either steering the narrow transmit beam in elevation or by moving the whole system up and down through the water column (like a profiler).

Preliminary field tests of the PIMMS system in the Chesapeake Bay:

PIMMS was successfully combined with downward looking split-beam echosounders (38, 70, and 120 kHz) and a 200 kHz downward looking multibeam sonar. We also conducted groundtruthing using a variety of trawls, determined by target size. Initially, completion of a complete sampling session took approximately 10 hours, limiting us to one nighttime and one daytime replicate per 24 hour period. Experience throughout the cruise enabled us to cut that time in half which will allow us to complete 2 full daytime, and 2 full nighttime replicates per 24 hour period during sampling next year.

Sampling in the Chesapeake Bay revealed much more variable acoustic scattering from diffuse layers, to strong scattering layers, to discrete aggregations of high scattering. These patterns varied with time of day and tidal cycle. Direct sampling revealed correlations between scattering profile and the dominant scatterer. Weak scattering was correlated with the presence of zooplankton. Strong scattering in both layers and discrete aggregations was correlated with the presence of large numbers of bay anchovies in the trawl samples (Figure 6).



Figure 6. Contents of a single net tow showing a nearly mono-specific catch of bay anchovies.

Preliminary analysis of the PIMMS acoustic data recorded in the Chesapeake Bay show potential imaging of bay anchovy aggregations (Figure 7) corresponding to observation made with downward looking multibeam sonar and groundtruthing using a variety of trawls. Figure 7 illustrates one example of a circular horizontal image of a region of the Bay with several “target” aggregation. Each aggregation in the image is approximately 10M in diameter. In this example aggregation were imaged maximum ranges of approximately 100 m. The water depth in this area was approximately 10-20 meters. Imaging at ranges of 100 meter in such shallow water is a good illustration of the experimental waveguide imaging geometry, as illustrated schematically in Figure 5.

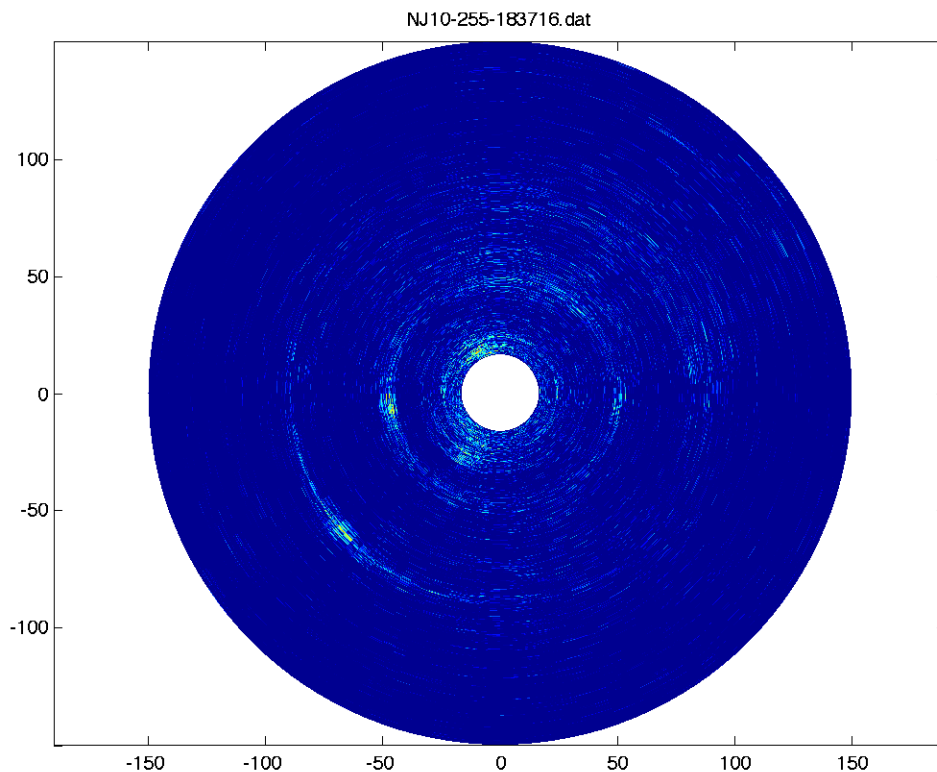


Figure 7. PIMMS image of possible aggregations of bay anchovies in the Chesapeake Bay. Several aggregations are show in the backscatter image at ranges up to 100 meters from the PIMMS array. The water depth was 10-20 meters.

Analysis of all data is currently preliminary given the recent completion of the field effort. However, strong relationships between the acoustics and biology are apparent. We are working to integrate these results with the results from PIMMS. This will assist us in interpreting this new type of data and will give us a synoptic picture of the distribution of biology in the water column not possible with other techniques.

Preliminary field results on the New Jersey Shelf:

During our short residence at the NLWI station, we observed the passage of a strong front through the sampling grid, indicated in both the physical and biological data (Figure 8). Due to conditions, we were unable to continue tracking the changes in relation to the frontal boundary.

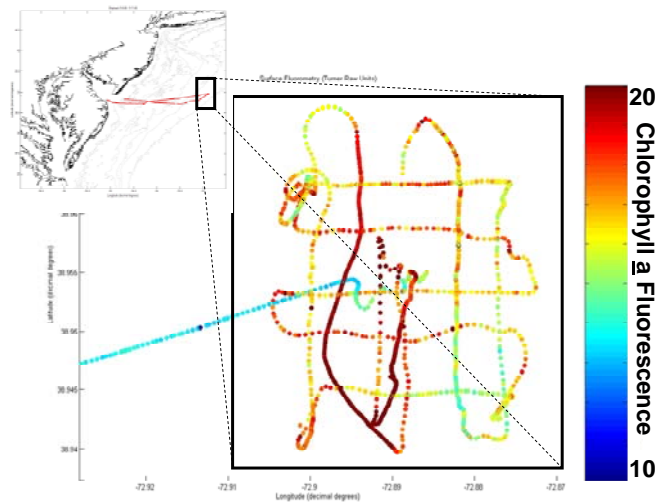


Figure 8. The ship track of the R/V Sharp heading to and from to the NLWI station is shown in the upper corner inset. The surface track of chlorophyll fluorescence during the transect was measured using the ship's surface flow through Turner fluoremeter. The chlorophyll values were low inshore. At the time of the initial station at the center of the station survey grid the chlorophyll fluorescence showed a 4-5 fold increase. This increase was associated with the offshore front array being advected into our station.

Sampling from downward-looking acoustics showed that this site was dominated by extensive, relatively weak scattering layers. Direct sampling showed that the biology was dominated by zooplankton, primarily copepods, shrimps, and euphausiids.

Preliminary analysis of the PIMMS acoustic data recorded on the New Jersey Shelf at station NLWI show no obvious “target” aggregations of fish in the water column (Figure 9). The image in Figure 9 is taken from the center of the survey grid shown above. Acoustic data analysis is very preliminary, however. The long range backscatter images do reveal reverberation from the bottom corresponding to the topography of the area, indicating that long range imaging is possible. Further signal processing and comparisons with the other down-looking sonar data taken during the grid surveys are planned.

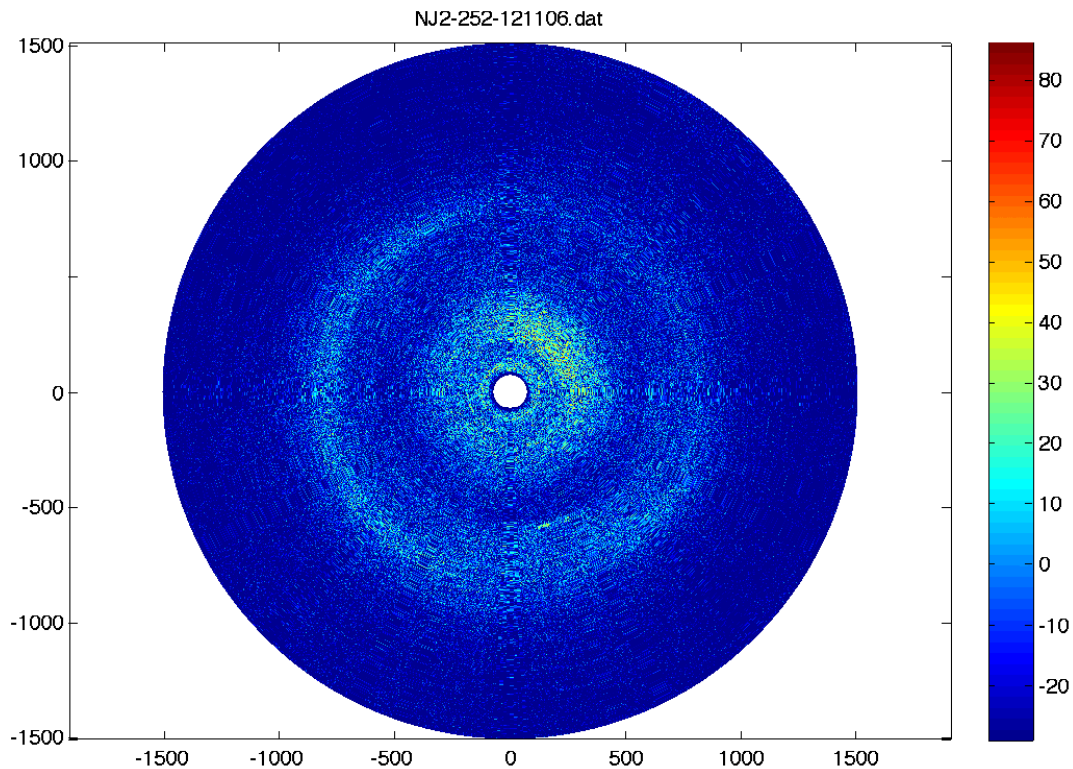


Figure 9. PIMMS image of New Jersey Shelf at station NLWI. No large aggregations are seen in the backscatter image at ranges up to 1500 meters from the PIMMS array. The water depth was 100 meters.

IMPACT/APPLICATIONS

The distribution of fish and the variability in their distribution has implications for fisheries, stock assessment, and operational acoustic techniques. This is particularly true in continental shelf regions where fish densities are high and their distribution is highly patchy.

National Security

This work will provide basic information on the structure of fish aggregations, the effects of fish aggregations on both mid and high frequency acoustics, and the relationship between mid frequency acoustic scattering and more traditional, relatively well-understood high frequency acoustic scattering. This will contribute to our efforts model scattering from biological sources. We expect this work will allow us to develop new acoustic techniques, that expand our understanding of the basic biology of fish, understand the relationship between fish aggregation characteristics and acoustic scattering at mid and high frequencies, relate more traditional high frequency techniques to more complex scattering at mid frequencies, and explore the potential of mid frequencies in both direct and waveguide scattering for application to fish. This has important application to operational acoustic techniques as biological sources of clutter are not

well understood but can cause significant errors in interpretation of these important defense systems.

Quality of Life

In this study, we will examine the correlation between fish and environmental variability by utilizing the existing resources of the New Jersey Shelf Observing System (NJ SOS). An understanding of the relationship between fish and their habitat will provide the opportunity to make predictions about the distribution of fish aggregations at the scale of the study region and the distribution of fish within an individual aggregation. These results will provide critical information for fish stock assessment and will allow us to assess the effects of fish schooling on traditional survey approaches.

Science Education and Communication

This project will provide data to support education at the Ph.D., masters, undergraduate, and K-12 levels. The Rutgers PIs on this proposal are collaborating with the K-12 outreach group at Rutgers (see <http://www.coolclassroom.org>). This close link will ensure that the results of this proposal will be used by the Rutgers outreach group. The Mid-Atlantic Center for Ocean Science Education Excellence (COSEE) promotes awareness and understanding of ocean sciences by integrating research and education programs and resources to encourage lifelong learning experiences for a broad audience including K-12 teachers, students (K-16), coastal managers, families, and diverse populations, especially underrepresented groups in the marine sciences. They have as an ongoing effort to involve gliders in their education outreach. In 2002, a contest was held, in which over 30 public schools, proposed names for the 2 Rutgers gliders. Our glider fleet has since then grown to 6 gliders and given the positive response we will continue this precedent and hold a national K-12 competition for naming and monitoring the MAB glider fleet. We will conduct a similar exercise that entrains the wider community in the development and deployment of the REMUS system.

REFERENCES

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- Turchin, P. 1989. Population consequences of aggregative movement. J. Anim. Ecol. 58: 75-100.*