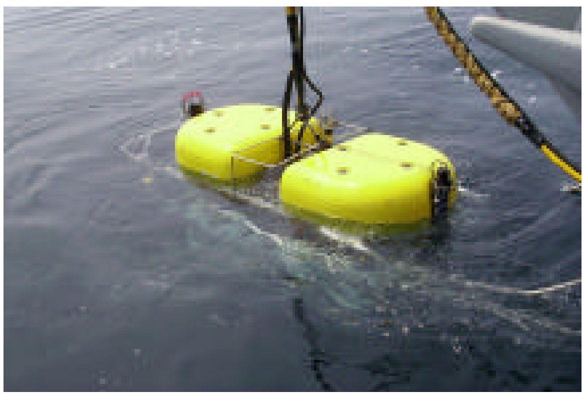
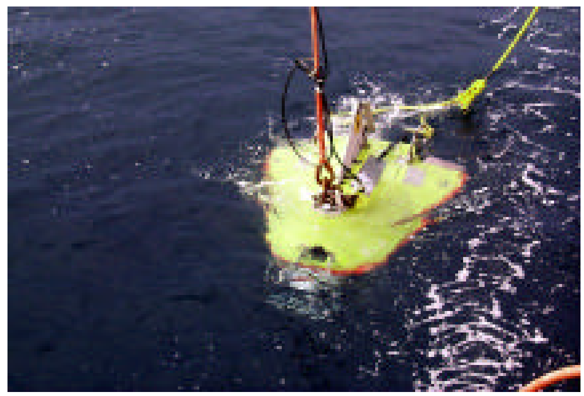
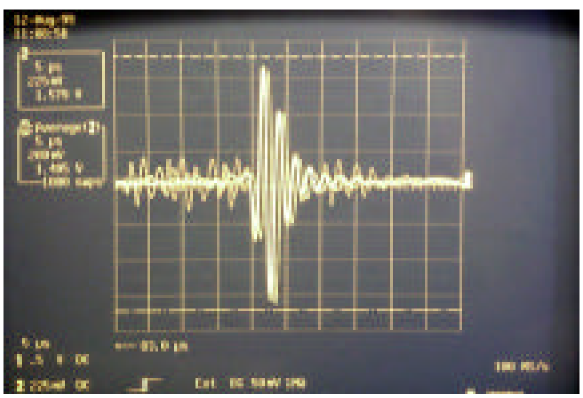
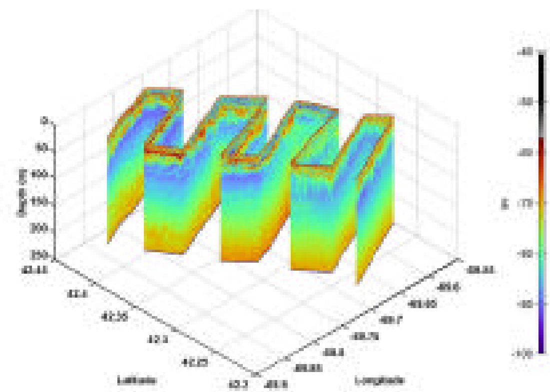
Cruise Report
F/V Isabel S and R/V Connecticut
Cruise NAGL-98-01B









August 11-18, 1999

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Mark Benfield, Peter Wiebe, Tim Stanton and Dezhang Chu prepared this report with assistance from Joe Warren, Ben Reeder, Malinda Sutor, Karen Fisher, and Cube Hamilton.

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1.0 Summary

This was the second cruise of a National Undersea Research Center for the North Atlantic and Great Lakes project: "Estimating the *in situ* acoustic target strength, distribution and abundance of diapausing *Calanus finmarchicus* and its invertebrate predators in the deep basins of the Gulf of Maine." The overall objective of the project was to collect in situ acoustic target strength data on the calanoid copepod *C. finmarchicus* and its invertebrate predators (the siphonophore *Nanomia cara* and the euphausiid *Meganytiphanes norvegica*). The first cruise (NAGL-98-01A) conducted in July 1998, deployed a multi-frequency acoustic array mounted on the front of the Kraken ROV. That cruise generated an oceanographic first: high quality, *in situ* measurements of the acoustical target strength of siphonophores and other macrozooplankton.

This cruise was equally successful. The objectives of this years cruise were: (1) to collect *in situ* forward acoustical scattering measurement from copepods and similarly-sized zooplanktors with the ROV; (2) to estimate the in situ velocity of sound in freshly caught zooplankton; (3) to survey the patterns of acoustical backscatter within Wilkinson Basin and Cape Cod Bay; and (4) to ground-truth selected acoustical features of interest using the ROV. Two vessels were used for this survey. The Kraken ROV was deployed from the R/V Connecticut (Fig. 1A) while a towed, down-looking acoustical system, nicknamed the Greene Bomber, was deployed from the F/V Isabel S (Fig. 1B).

 

Figure 1. The R/V Connecticut (left) that deployed the Kraken ROV. The F/V Isabel S (right), a commercial dragger, that deployed the Greene Bomber down-looking acoustic system.

We were able to collect live zooplankton including a sample composed almost entirely of *Calanus finmarchicus* (one of our target species) and we measured both forward scattering and sound speed velocities in those samples using an in situ chamber mounted on the ROV and on a platform attached to a hydrowire. The temperature and pressure dependence of those measured properties were also estimated. Until this cruise, most estimates of sound velocity contrast for zooplankton had been conducted under laboratory-style conditions using formalin-preserved specimens. Given the importance of the sound velocity contrast in predictive equations of acoustic target strength, the data collected on this cruise are both unique and of broad interest to the marine acoustic community.

We surveyed a large region of Cape Cod Bay, Massachusetts Bay and the Western portion of Wilkinson Basin with a down-looking acoustic system. The objective was to locate patches of high backscatter for ground-truthing by the ROV. Sea conditions were generally unfavorable for ROV operations during this cruise outside of Cape Cod Bay; however, we

did conduct ROV operations in Wilkinson Basin and were able to collect video ground-truth information on the vertical distribution of large organisms in the water column. These data will be analyzed and we expect them to assist us in interpreting the complex vertical structure observed with our two frequency echosounding system.

Perhaps the most interesting (and unexpected) finding of our acoustical surveys, came from replicated (in both time and space) observations of the propagation of soliton packets from Stellwagen Bank to the coast of Massachusetts Bay. We observed the same soliton packets during multiple passes along a transect line. Fluorescence and temperature data suggest that the solitons may be pumping cold water from a subsurface chlorophyll maximum to the surface as they near the coast and begin to break. Alternatively, they may be pumping nutrients to the surface and these may be stimulating primary production. Solitons were consistently associated with elevated backscatter intensity. Whether this is due to biological or physical factors has long been a subject of debate. We collected replicate net tows along one of the transects in the absence of solitons and subsequently in the middle of a soliton packet. These data should help us to determine the source of the elevated backscatter associated with solitons.

2.0 Personnel

Scientific Personnel

Mark C. Benfield (Chief Scientist)
Louisiana State University
Department of Oceanography & Coastal Sciences
218 Wetland Resources, Baton Rouge, LA 70803
Phone (225) 388-6372 Fax: (225) 388-6513
E-mail: mbenfie@lsu.edu Aboard F/V Isabel S

Peter H. Wiebe (Scientist)
Woods Hole Oceanographic Institution
Department of Biology
Mail Stop 33, Woods Hole, MA 02543
Phone (508) 289-2313 Fax (508) 457-2169
E-Mail: pwiebe@whoi.edu Aboard F/V Isabel S

Timothy K. Stanton (Scientist)
Woods Hole Oceanographic Institution
Applied Ocean Physics & Engineering
Mail Stop-11, Woods Hole, MA 02543
Phone (508) 289-2757 Fax (508) 457-2194
E-Mail: tstanton@whoi.edu Aboard R/V Connecticut

Dezhang Chu (Scientist)
Woods Hole Oceanographic Institution
Applied Ocean Physics & Engineering
Mailstop-11, Woods Hole, MA 02543
Phone (508) 289-3318 Fax (508) 457-2194
E-Mail: dchu@whoi.edu Aboard R/V Connecticut

Malinda M. Sutor (Graduate Student)
College of Oceanic and Atmospheric Sciences,
Oregon State University
104 Ocean Admin. Bldg., Corvallis, OR 97331-5503
Phone (541)737-3504
E-Mail:msutor@oce.orst.edu
Aboard F/V Isabel S

Joe Warren (Graduate Student)
MIT/WHOI Joint Program
24 Millfield St. Woods Hole, MA 02543
Phone 508-289-2471 Fax 508-457-2132
E-Mail: jwarren@whoi.edu Aboard F/V Isabel S

Ben Reeder (Graduate Student)
MIT/WHOI Joint Program
Woods Hole Oceanographic Institution
Woods Hole, MA 02543
Phone (508) 289-2437 Fax (508) 457-2194
E-Mail: breeder@whoi.edu Aboard R/V Connecticut

Karen Fisher (Graduate Student)
Cornell University, Geology Department
2154 Snee Hall , Ithaca, NY 14853
Phone: (607) 255-5449
E-Mail: kef10@cornell.edu Aboard F/V Isabel S

Henrique H. Hamilton (Undergraduate Student)
Louisiana State University
Department of Computer Science
4606 Y.A. Tittle Ave, # 43, Baton Rouge, LA 70820
Phone (225) 761-9575
E-Mail: hhamilt@worldnet.att.netAboard F/V Isabel S

ROV Support Personnel

Nick Worobey (Engineer & NURC Representative)
National Undersea Research Center
North Atlantic and Great Lakes
1084 Shennecossett Road
Groton, CT 06340-6097
Phone (860) 405-9135 Fax (860) 445-2969
E-Mail: worobey@uconnvm.uconn.edu
Aboard R/V Connecticut

Jamie Sherwood (Contract ROV Pilot)
Sherwood Underwater Systems Inc.
4 Centennial Drive
St. Catherines, ON L2N 6A4 CANADA
Phone/Fax (905) 934-8615
E-Mail: jbs@vaxxine.com
Web: vaxxine.com/sherwoodsystems
Aboard R/V Connecticut

Mike Slaney (ROV Technician)
National Undersea Research Center
North Atlantic and Great Lakes
1084 Shennecossett Road
Groton, CT 06340-6097
Phone (860) 405-9135 Fax (860) 445-2969
E-Mail: slaney@uconnvm.uconn.edu
Aboard R/V Connecticut

Chris Cooper (Contract ROV Support)
Jamestown Marine Services
1084 Shennecossett Road
Groton, CT 06340
Phone (860) 448-4850 ext. 17
E-Mail: ccooper@jmsnet.com
Aboard R/V Connecticut

3.0 Acoustic Systems

Acoustic Properties of Plankton (APOP)

Acoustic Properties Of zooPlankton (APOP) system is designed to measure acoustic transmission through (forward scattering) and backscattering by fluid-like zooplankton. The APOP acoustic chamber consists of cylindrical tube, made of Delrin, with an inner diameter of 1 inch. Two 500 kHz broadband transducers (300 - 700 kHz) are mounted at opposite ends of the chamber with a separation of 15 cm. A 2 cm-wide animal compartment (in the direction parallel to the axis of the cylinder) is located between the two transducers. The compartment is closer to one transducer in order to separate the direct transmission and the backscattering waveforms in the time domain (different arrival times). Two thin rubber sheets (natural latex sheeting) with a thickness of 0.004 mm are used on both ends of the animal compartment to confine zooplankton during the acoustic measurements. There are two openings on the animal compartment, on the opposite side of the compartment and facing each other. The two opening plane were oriented perpendicularly to the axis of the acoustic chamber. The operator controlled two solenoid-driven screen doors (mesh size of 333 μm) to remotely open and close the doors to the scattering chamber. The doors are normally open during animal collection and closes for acoustic measurements. To facilitate resistivity measurement, two electrodes are mounted on the other two sides of animal compartment, facing each other. The normal of the electrode planes is perpendicular to both the normal of the planes of two openings and the axis of the cylindrical acoustic chamber. Resistivity measurement is crucial for the future *in situ* measurements since it could provide an estimate of the animal volume fraction or compactness in the animal compartment, a parameter necessary to infer the sound speed contrast of the zooplankton. The system was mounted beneath the ROV (Fig. 2) in conjunction with a collection net designed to channel animals into the scattering chamber (Fig. 3). During the measurements, resistivity is measured with a multimeter. Analog acoustic forward- and back-scattering signals are carried through an 800 ft (262 m) cable, digitized (10 MHz and 12 bit A/D board), and stored on a computer hard disk. By comparing the data recorded with animals filled in the compartment with those recorded without animals, the sound speed contrast can be determined.

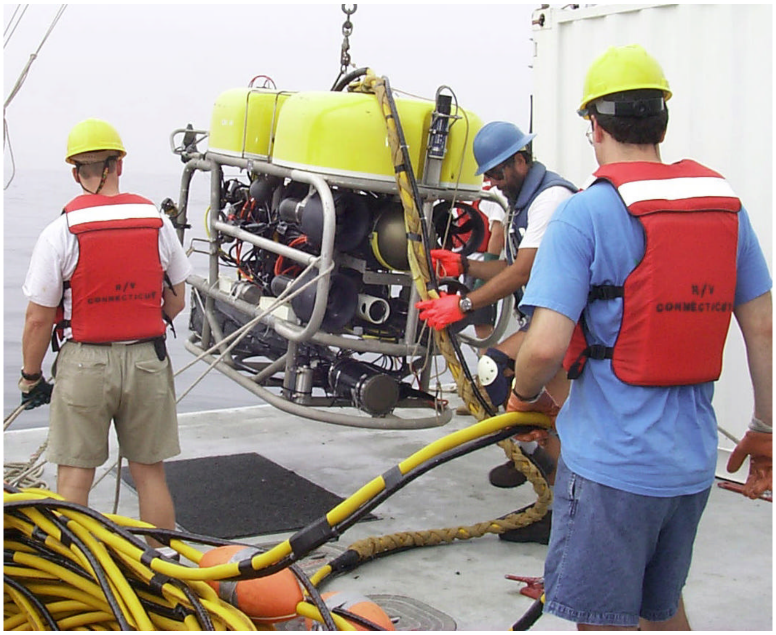

Figure 2. The Kraken ROV (MaxROVER Mk 1) being deployed by Tim Stanton (right), Nick Worobey (center) and Ben Reeder (left) from the R/V Connecticut. The APOP net and one of its pressure cans is visible beneath the vehicle.

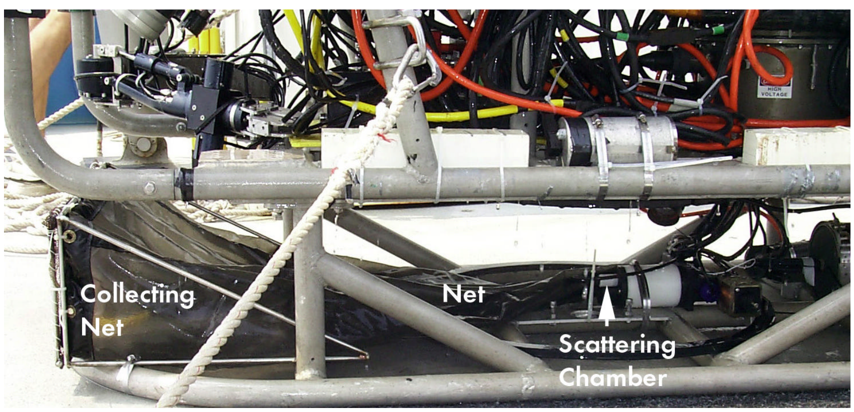

Figure 3. The Acoustic Properties of Plankton (APOP) collection and in situ measurement components mounted beneath the Kraken ROV.

Greene Bomber

The down-looking acoustics system consisted of a chartreuse, five-foot V-fin towed body (nicknamed the Greene Bomber), a Hydroacoustics Technology, Inc., Digital Echo Sounder (HTI-DES), several computers for data acquisition, post-processing of acoustic data, logging of GPS navigation data, recording of notes, plus some additional hardware. In the Greene Bomber (Fig. 4), there were two down-looking transducers (120 and 420 kHz, each with 3 degree beams), a multiplexor pressure case for multiplexing the data from the two transducers, and an environmental sensing system (ESS). The ESS was mounted inside the

V-fin with temperature, conductivity, and fluorescence sensors attached to a stainless-steel framework outside of the fiberglass housing. The vehicle also carried an acoustic transponder that would have proved useful in locating it if it had happened to break free of the towing cable. The Greene Bomber was deployed from an A-frame located amidships on the starboard side of the Isabel S. The usual towing speed was 4.5 kts.

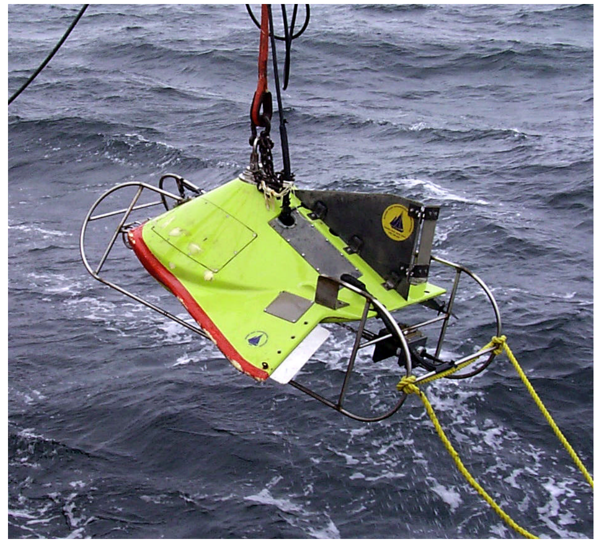

Figure 4. The Greene Bomber prior to deployment from the F/V Isabel S. The fluorometer is visible on the front of the vehicle. The echosounders and T/S sensors are mounted beneath it.

In the lab, the data came in on a single 24-conductor cable with separate shielded groups of wires, one for each transducer and one for the ESS. The HTI-DES has its own computer (PC104-80486-100 MHz) and five digital signal processors (DSPs). It receives the data from the transducers after passing through the MUX pressure case, does a series of processing steps, and then transfers the results to the surface Pentium PC over a local area network (LAN) where the data are logged to disk and displayed. Attached to the LAN was an HP LaserJet B&W printer. Large amounts of acoustic data (~1 GB h-1 raw; ~22 MB h^{-1} processed) were handled very efficiently by this system.

The ESS data came into a second PC and were processed, displayed, and logged to disk. Both the ESS and the navigational computer required GPS data and these were supplied by two GPS receivers mounted on the roof of our portable laboratory van. Periodically, the ESS data were transferred to a third PC for post-processing. After this stage we were able to begin to see the acoustic patterns in our surveyed areas.

To enable easy cross-correlation between the data files from the ESS and acoustic computers, a log was kept of the start and end times of computer files along with their identity and comments (Appendix B).

4.0 Summary of Major Findings

APOP

The cruise was a great success. The ROV was used in a wide variety of ways in order for us to achieve our goals. It was used to test and evaluate the APOP system that is in a prototype form. By directly inserting the (bongo-sampled) animals into the ROV deployed chamber, the system was used to make fundamental measurements of the acoustic properties of copepods and other animals for target strength prediction. These measurements, in combination with the cast-mode measurements will help further our understanding of the acoustic properties of the animals. This is a first-of-a-kind set of measurements. All other studies conducted to date have been performed under laboratory-style conditions. In addition, the system was used to conduct a survey of the water column that helped us visualize the distribution of animals, both "background" smaller animals as well as layers of larger ones.

Two parameters in acoustic target strength equation that can strongly influence the predicted estimate are the sound speed contrast (h), which is the ratio of the speed of sound in seawater and in the organism, and the density contrast (g), which is the ratio of the density of seawater and of the organism. Our dives provided estimates of these parameters for live or freshly-caught zooplankton assemblages dominated by copepods and decapod larvae as well as the dependence of these parameters on pressure and temperature. Our estimates of the speed of sound in deep, cold water were in general agreement with published estimates, while the data at shallow, warmer temperatures were significantly different. The major findings were that the sound speed in organisms is found to be strongly dependent upon temperature and weakly (but not insignificantly) influenced by pressure (Fig. 5). This information will permit major refinement of the target strength estimates for marine zooplankton.

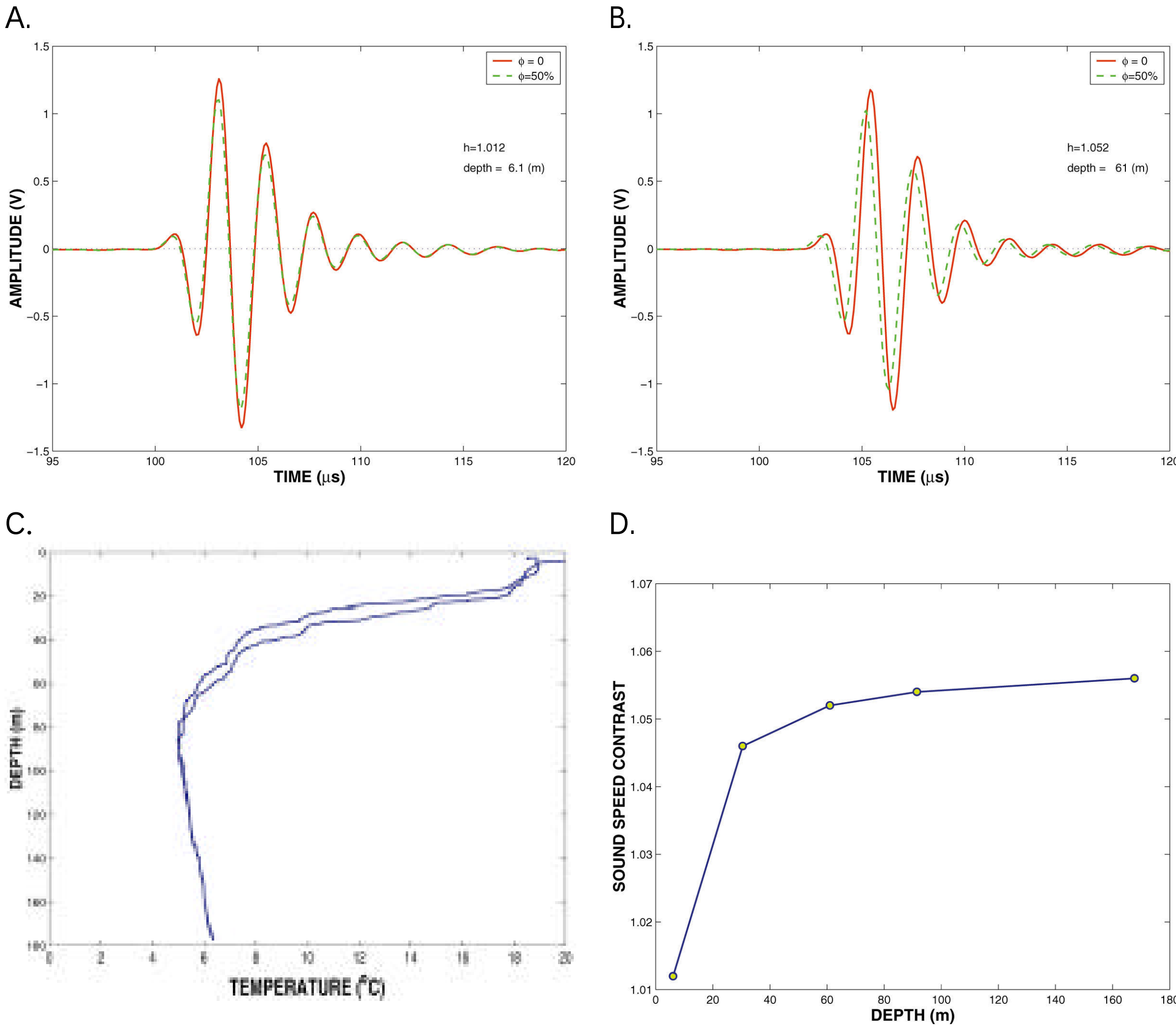

Figure 5. Top: Plots of echo returns from zooplankton samples at 6 m (A) and 60 m (B) collected during an APOP cast to 160 m over Wilkinson Basin. Note the divergence between the trace for an empty chamber (red) and a chamber containing zooplankton (dashed green). This represents a substantial shift in sound speed. Bottom: The water column was thermally stratified (C) and data were collected both above and below the thermocline. Estimates of the sound speed as a function of depth show the strong temperature dependency and the weak pressure dependency of the property.

Greene Bomber

On the Isabel S cruise, we conducted a series of three surveys with the Greene Bomber on a line transect which extended between Stellwagen Bank and Scituate MA. The objective was to track solitons generated by tidal flow over the Bank as they propagated west from the Bank to the shoal waters off the coast at Scituate. This was done by steaming at 4 to 5 knots back and forth between Stellwagen Bank and a point next to the coast 4 to 6 times over a time interval long enough to have a soliton formed and propagate across the Bay. The period of a survey was 6 to 8 hours.

This site is ideal for such a study. When the water column is stratified as is common during the summer period, internal wave packets or solitons can be generated from lee waves which develop as the tidal flow is moving across Stellwagen Bank to the east. The generation region is just beyond the Bank where the off-bank tidal velocity has a downward component. This depresses the density surfaces (isopycnals) and creates a source of potential energy. The depression created by the tidal flow is trapped near the steep incline of the Bank if the group velocity of the depression is slower than the off-bank tidal velocity. On Stellwagen Bank, this condition is generally met since typical off-bank tidal velocities are ~30-50 cm/sec (0.6 to 1 knot) and typical internal solitary wave velocities at the place of origin are 24 to 37 cm/sec (0.46 to 0.72 knot). The depression is in fact an "internal solitary wave" or "soliton" in the process of formation. It has energy at all frequencies and when released by the tidal flow change from the offshore direction, it propagates up onto the Bank and over into Massachusetts Bay where the lower frequency (higher energy) portions of the wave move faster than the higher frequency portions. Within a few hours and a few kilometers, the solitary wave becomes transformed into a form with the largest amplitude waves leading smaller amplitude waves (Fig. 6). They are termed "waves of depression" because the density interface (pycnocline) separating the thinner surface mixed-layer from the thicker lower layer moves downward from its equilibrium position as the wave passes. In Massachusetts Bay, a soliton moves as a unit at speeds of 1 to 2 kts, until reaching the shoal waters of the coastal shelf. There, the wave must disintegrate and its energy is dissipated, but details of how that happens have been lacking. The mapping surveys were designed to: (1) look at the process of formation, propagation, and dissipation of the waves in this region; (2) examine the contribution of biological and non-biological sources to the total backscattering observed in the waves; and (3) to examine the impact of the dissipation process on the local physics and biology in the region.

The surveys took place on 12/13, 14/15, and 17 August. The first two were done mostly at night and the third done mostly during the day. During the last survey on the 17th, the R/V Connecticut was working along the trackline taking Bongo Net tows and conducting CTD profiling. In addition, when the last survey was completed, a zig-zag course leading to the east entrance of the canal was run along the shelf break to look for evidence of soliton dissipation beyond the study site.

Survey 1

This survey started on the shoal area near Scituate with the ship steaming east towards Stellwagen Bank. Almost immediately, we encountered a zone of high volume backscattering extending from the surface to near the bottom over the shoal shelf area (Fig. 6 top panel). Further along the transect line, the backscattering diminished, especially on the

120 kHz echogram. Near the end of the transect, the first well-defined soliton was observed propagating to the east. It had approximately eight distinct crests and troughs. On the return transect to the west, only the first two or three wave troughs were distinct (Fig. 6, second panel from the top). Also quite noticeable was the absence of strong backscattering over the shoal areas near the coast which had been the previous "hot spot".

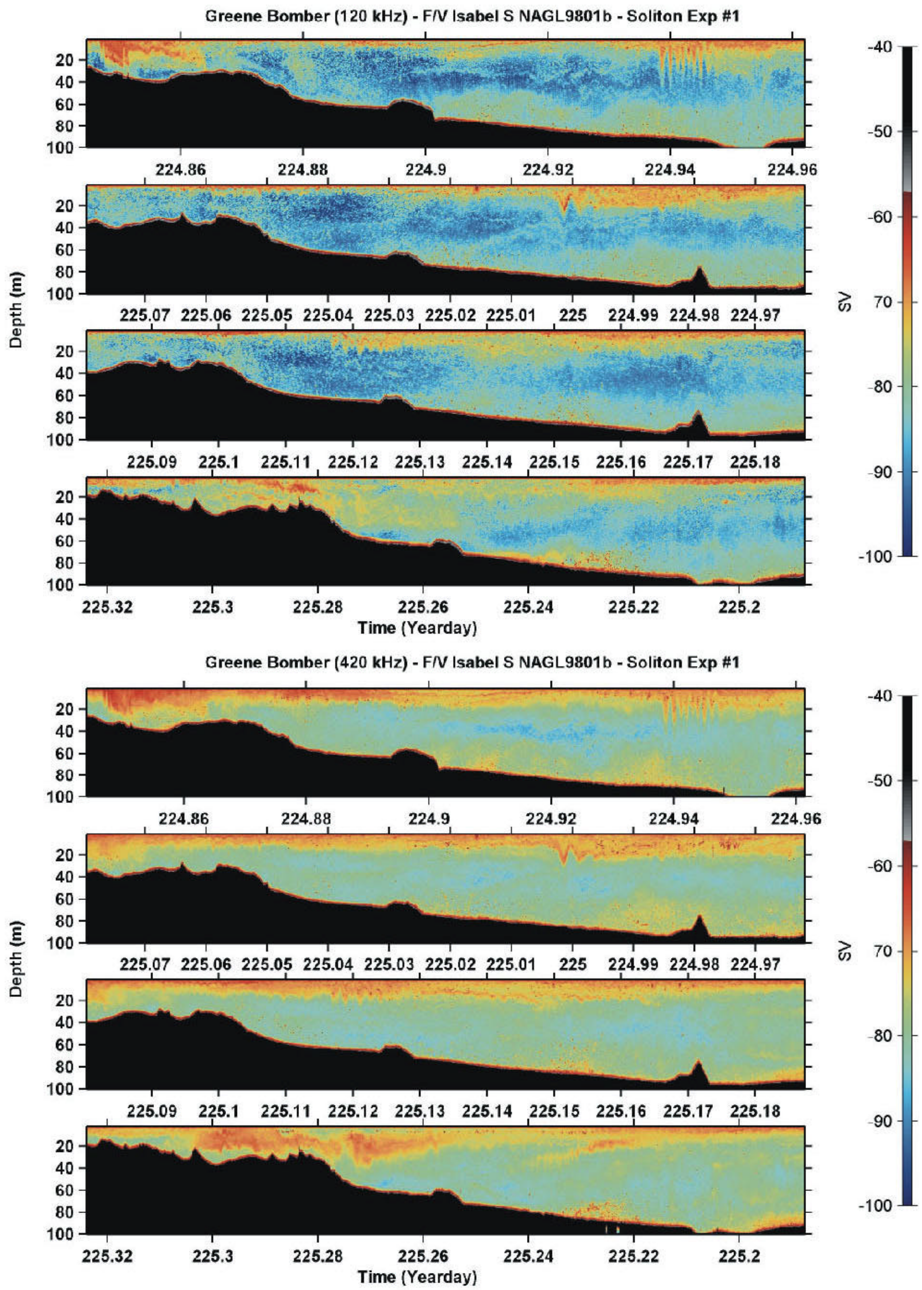

Figure 6. The first acoustic survey between Scituate, Massachusetts and Stellwagen Bank. Data from the 120kHz echosounder are in the top four panels while the 420 kHz data are displayed in the bottom four panels. The survey began in the top panel with the ship steaming east towards Stellwagen Bank (left to right).

During the third pass back to the east along the survey line (Fig. 6, third panel from top), the shoal area remained low in backscattering. The soliton was encountered just beyond the point where the topography shoaled rapidly and the classic soliton form was much less apparent, although the feature was still easily identifiable. Backscattering in the vicinity of the packet was higher than it was before the wave came into the region. On the last transect back to the west (Fig. 6, lower panel), backscattering in the surface waters over deeper reaches of Massachusetts Bay were lower than when the soliton was present while more intense Backscattering was observed over the shoal section of the transect next to the coast where the soliton was in the process of dissipating.

Survey 2

This survey, done two nights later, paralleled the first, but was for a longer duration. Five full transects and a sixth partial transect were run (Fig. 7). These were followed by a period of slow jogging of the ship to the west while waiting for another soliton to propagate through the region.

The first transect was from Stellwagen Bank to west to the shoal area near Scituate. Significant backscattering was observed along the transect which appeared unstructured in the 120 kHz echogram, but was clearly due to an internal wave packet that was moving up into the shoal area and breaking up. Also apparent was a strong backscattering feature intersecting with the bottom between the areas where the hummocks occurred.

On the second transect to the east, a patch of high backscattering remained in the shoal area where the soliton dissipated. The deep feature, however, had largely disappeared. On the approach to Stellwagen Bank, a newly formed soliton was encountered which had as many as 18 crests and troughs. Also evident in the 120 kHz echogram very close to the steep rising face of the Bank was what appeared to be a lee wave depression. This feature may have been the precursor of an internal wave packet that would propagate to the east out into Wilkinson Basin.

On the third pass back to the west, the internal wave appeared to have stretched out with large lead waves advancing faster than the smaller waves at the back of the packet. Noticeable especially in the 120 kHz echogram was the very low backscattering values ahead of the packet. These were much lower than observed during the first transect in the series. This stretching of the packet continued to be observed in the fourth pass and the lead waves continued to leave the smaller waves at the back of the packet behind.

During the fifth transect, the wave had entered the much shallower shelf region next to the coast. The structure of the wave was strongly distorted indicating that the dissipation process was started. Strong backscattering occurred in this region where previously there had been much lower backscattering. On the return pass (transect six), the area of intense scattering had moved towards the coast and the wave structure of the soliton had disappeared for-the-most- part.

This transect was stopped about halfway to Stellwagen Bank and the Isabel S jogged slowly to the east while waiting for a daytime soliton to appear. About noon, another internal wave packet was observed, but its acoustic backscattering was substantially weaker. Further, the 120 kHz scattering from particular depth strata in the packet was markedly different from the pattern seen on the 420 kHz echogram. Some strata that had high backscattering on the 120 kHz had weak backscattering on the 420 kHz and vice versa.