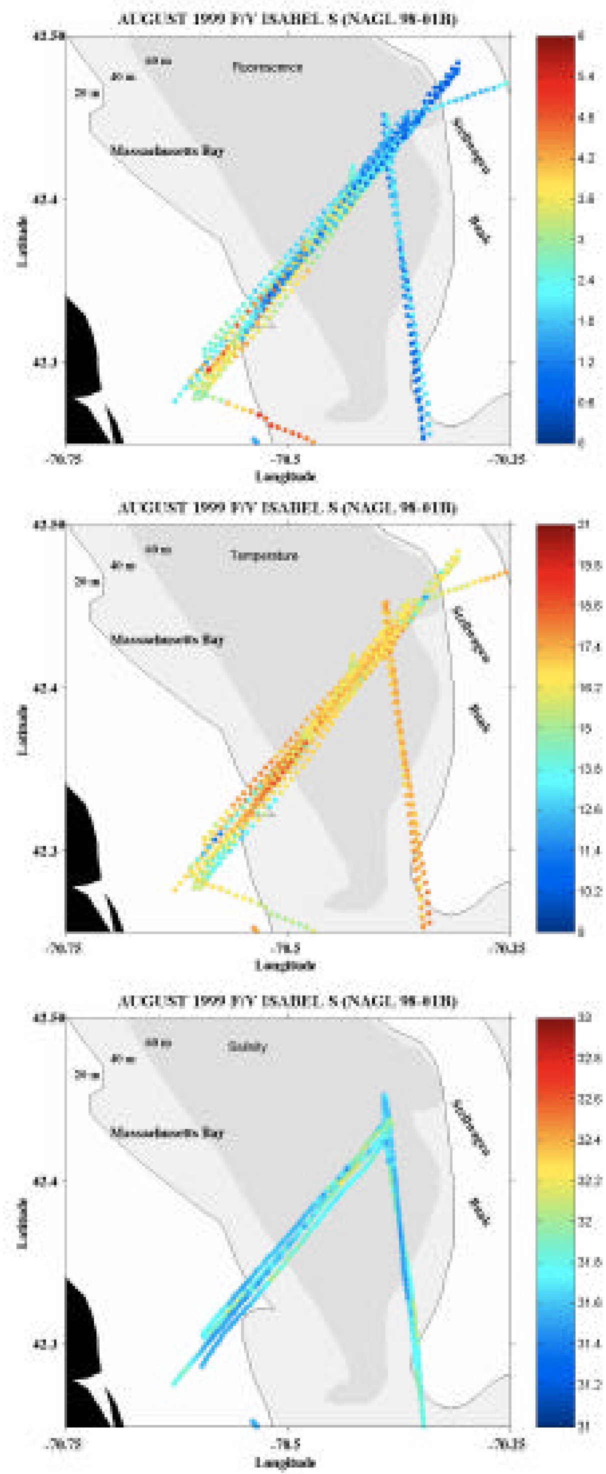

Figure 8. Trackline plots of fluorescence (top), temperature (middle), and salinity (bottom) measured within two meters of the surface by sensors on the Greene Bomber. Only a small subset of the observations are plotted. Note the low temperature and corresponding high fluorescence values at the western end of the transect lines. These correspond to times when dissipating solitons were present.

During the jogging period, a strong layer of backscattering developed at depths where during all transect lines except the first of the series, there was no strong scattering. This bottom feature was similar to the one seen on the first series of observations.

Surface Temperature, Salinity, and Fluorescent Patterns

Surface water temperatures varied in the soliton study site between 11.5 and 18.8 C, salinity varied between 31.45 and 32.03, and fluorescence 0.61 and 5.12 volts. This substantial range in temperature and fluorescence (the salinity changes were much smaller) was associated with the presence of dissipating solitons in the shoal area of the survey line next to the coast (Fig. 8). It was in this area that the greatest range in variation in temperature and fluorescence occurred. During periods when the acoustic backscattering was low in the shoal area, temperature tended to be high and fluorescence low. When solitons were dissipating in the shoal area, temperature was usually substantially lower and fluorescence values much higher.

Preliminary Conclusions

The two surveys described above provided striking imagery of the time evolution of the backscattering field as a soliton propagated across Massachusetts Bay. Three features were similar in both the 120 and the 420 kHz echograms: intense scattering in the vicinity of the wave packet; lower backscattering in regions where the soliton was absent; and intense backscattering in the shoal area where the packet energy was dissipated. There were, however, differences. The overall backscattering at 120 kHz was lower than at 420 kHz, and in some areas, backscattering contrasts were more evident in the 420 kHz echograms.

There were several other features of importance. The first was a marked cooling of the water temperature in the shoal region next to the coast where the soliton dissipated. This we conjecture was caused by a breakdown in the stratified water column where the internal wave packet was breaking. Second, surface fluorescence was elevated in the same area where cooling was observed. This may have been due to a mixing up of higher chlorophyll concentrations that normal build up in a subsurface chlorophyll maximum typical of summer conditions. It may also have been enhanced by increased primary production stimulated by mixing of higher concentrations of nutrients normally in and below the thermocline into the surface waters when the waves broke. Our survey was not designed to provide information about the horizontal extent along the coastline that this apparent process was having an effect on the surface water properties, but after the last survey was completed, a zig-zag course to the south was done to gain some idea of its horizontal extent in the downstream direction. In deed, fluorescence values were high along the shelf down to a point in Cape Cod Bay where we ceased operations and brought the Greene Bomber on board.

A third feature concerned some evidence for an interaction between the passing soliton and the bottom, especially on the 420 kHz echogram. Backscattering "clouds" were evident on the sloping bottom between the small hummocks which appeared to be coming up off the bottom (Fig. 6). This feature was generally observed after the soliton had passed the area and was in the process of dissipating in the shoal area next to the coast.

5.0 Cruise Narrative

August 9, 1999

R/V Connecticut

The R/V Connecticut arrived in Woods Hole on the morning of August 9, 1999. They had to offload from their previous cruise and were not available for loading until the morning of August 11. This worked out well because Dezhang Chu, Ben Reeder and Tim Stanton needed to make a few more adjustments to their in situ collection and acoustic measurement system (APOP). They had discussed mating it to the ROV with the ROV group throughout the design phase and did not anticipate problems in that area. Malinda Sutor assisted them in attaching the nets to the collection frame.

F/V Isabel S

The Isabel S was in dry dock completing a propeller shaft replacement. We had been told by Chip Ryther (the science charter representative) to expect her arrival in Woods Hole by early the next afternoon. In the meantime, Peter Wiebe's group had placed most of the Greene Bombers' equipment in the portable van and the Greene Bomber had been assembled on the dock. A dip test was not possible because the hydraulic hoist over the wet bay on the dock had a broken switch. We were able to connect to the Greene Bomber and test most systems. This could not be completed due to power fluctuations in the van and uninterruptable power supply (UPS) failures. We decided that it was essential to isolate the air conditioning unit from the rest of the power distribution to the van. We suspended work at approximately 22h00 and left a utility program running to diagnose the computer problems.

August 10, 1999

R/V Connecticut

Loading commenced aboard the R/V Connecticut. By mid-morning the ship had to move locations. Apparently there had been a breakdown of communications somewhere and the WHOI dock was had not been aware that the Connecticut was going to be loading. Space was made for the vessel behind the R/V Oceanus and loading continued after lunch. The APOP was attached to the ROV and system tests commenced. No faults were detected and a dip test was performed at approximately 17h00 without incident. APOP was deemed ready for field testing. By 21h00 hours, most of the equipment was aboard. Some small tests and final tying down were all that remained and departure was scheduled for 10h00 the next day.

We had some discussions with the Captain of the R/V Connecticut and the owner of the F/V Isabel S regarding transference of people at sea. We discussed concerns for safety and decided that providing that both Captains, Nick Worobey and the Chief Scientist felt that the seas were calm enough, transfers were possible. Transfers were important because the Connecticut only had bunk space for three scientists and none of them were biologists. In order to conduct bongo net and other biological sampling, it was desirable to place a trained person aboard. Malinda Sutor had the requisite skills and was nominated to work aboard as a "visiting biologist."

F/V Isabel S

Early in the morning, WHOI dock personnel decided to move our van, which had systems running. Without checking, they disconnected the power supply and moved the van to another location on the dock. When Peter arrived, he found the acoustics computer running on a UPS. Steps were taken to have the van moved back and reconnected. The hydraulic hoist was repaired and the Greene Bomber was tested. The system appeared to be working well. The F/V Isabel S arrived at approximately 14h30. WHOI dock personnel had not been informed that she would be arriving and a small space was made available between the R/V Knorr and a visiting sailing ship. The van was placed aboard within an hour. The Greene Bomber was loaded by 16h30 and we worked to complete tying down our computer systems. By 21h00, it appeared that we would be ready to sail the next morning after life boats and provisions had been delivered to the ship.

August 11, 1999

R/V Connecticut

Final tying down and stowage of gear was completed in the morning and the ship was ready to sail at 10h00. Their objective was to steam into Cape Cod Bay and locate a patch of copepods for the first tests of APOP. Malinda sailed with the ship in order to assist Tim's group with their first task of locating copepod patches with the bongo nets. We planned to rendezvous both ships at 18h00 to return her to the Isabel S. The ship left Woods Hole at 10h15 bound for Cape Cod Bay via the Cape Cod Canal.

Once in Cape Cod Bay, we conducted a bongo net tow to determine the kinds of animals present in the water column and then conducted ROV/APOP tests in water for three hours. With cameras mounted looking both forward of the ROV and inside the net, we were able to observe the zooplankton within the net. The acoustic and resistivity measurements showed no significant change in signals within the APOP chamber. Once we retrieved the system, we observed few animals in the chamber.

F/V Isabel S

Final tie-down of equipment was completed early in the morning. Our departure was delayed until lifeboats and provisions arrived and were loaded. We were ready to leave at approximately 11h30, but had to wait until a crewmember's car was moved to a satellite parking lot outside of Woods Hole Village. The ship departed at 12h53 and steamed to Cape Cod Bay via the Canal. Our plan had been to begin acoustic operations in Massachusetts Bay in an area where solitons were common.

By the time we reached Cape Cod Bay, it was clear that it in order to pick up Malinda by 18h00, we needed to begin acoustic operations in Cape Cod Bay. We decided to steam towards the Connecticut and deploy the Greene Bomber at 17h00. After picking up Malinda we planned to survey a transect between Cape Cod Bay and Stellwagen Bank. That transect had been surveyed twice during our previous years cruise and contained striking acoustic patterns that were present on both nights.

We reached the Connecticut at approximately 16h45. She had the ROV in the water and indicated that they planned to operations for another two hours. We deployed the Greene Bomber at 17h28 (Fig. 9) and steamed around the Connecticut while we started the acoustic systems. Seas were calm and we made arrangements to bring Malinda over from Connecticut at 18h00 in a small boat. After dinner, we began to steam towards the transect line that ran from Cape Cod Bay to Stellwagen Bank.

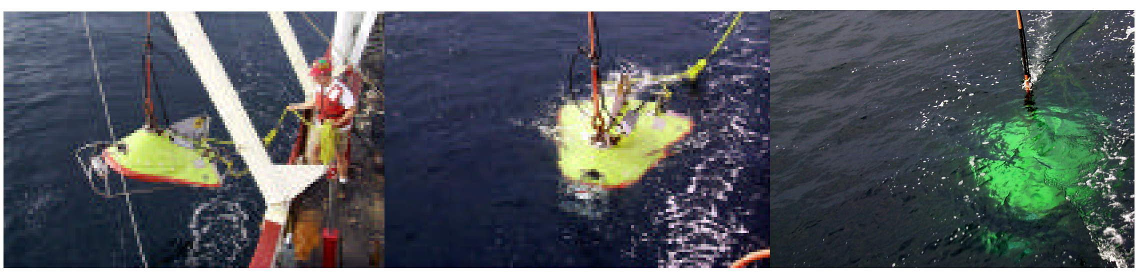

Figure 9. Initial deployment of the Greene Bomber from the Isabel S in Cape Cod Bay.

A radio discussion with Tim and information provided by Malinda indicated that the ROV operations were proceeding with some success. Their bongo tow collected small copepods that were dominated by *Centropages* and some pteropods. Small animals including copepods were present in the net, but the current velocity inside the net was too slow to push them into the scattering chamber. Our acoustic data suggest that there wasn't much backscatter in these waters. There was a diffuse band approximately 1 m thick that varied in depth between 9–14 m. We passed this information to Tim and recommended that we conduct a survey of the backscatter in the outer part of Cape Cod Bay to locate a better location for ROV operations.

The acoustic transect began at 19h57 and we reached the Stellwagen Bank endpoint shortly after midnight. The patterns of scattering appeared to be different from those observed during our prior cruise (NAGL-98-01A), but we needed to post-process the data to really determine what they looked like. We surveyed the transect at approximately the same time of day as on the prior cruise, so the comparison will be quite interesting.

August 12, 1999

R/V Connecticut

We repeated the bongo survey and ROV/APOP measurement sequence that were conducted on the 11th. This time, we configured the APOP net first with no front excluder mesh and then with the front mesh oriented in a concave rather than a convex shape. Although the flow seemed to be improved in each case, we still observed no significant build up of animals in the chamber and no significant change in signals from chamber sensors. In order to obtain measurements (of any kind) in the chamber, we then directly placed the zooplankton collected with the bongo net into the chamber while the ROV was on the deck. Once deployed, we observed significant changes in the acoustic signals.

F/V Isabel S

The ship then steamed back to Cape Cod Bay and arrived at the transect starting point at 06h27. From there we began to steam a rectangular track to survey the backscatter within Cape Cod Bay. This information was intended to assist Tim and Chu in locating an area of elevated copepod densities for animal collections. That track was completed by early morning.

We spoke again with Tim at 0800. He indicated that they were having difficulty with the net on the ROV. Bongo casts confirmed the presence of animals in the water, but the video camera in the net didn't show appreciable flow of animals into the cod end. He was concerned that the coarse (3 mm) deflector cover over the front of the net was preventing flow through the net. To test that, they had run a bongo with the deflector over one net. There was no appreciable difference in the catch between the two nets suggesting that the deflector wasn't the problem. I went over to the Connecticut at about 10h00 to take a look at the net configuration.

The Connecticut was located in Cape Cod Bay just south of Provincetown and the seas were calm when I transferred over from the Isabel S. After showing me the configuration of their lab and the "gadget" as the APOP unit and net was termed, the ROV was deployed. Tim and Chu had several hypotheses to explain why zooplankton were not being captured. First, since the net was a custom design, they thought that some design flaw might reduce its zooplankton capture capability. Second, video images suggested that there was not much flow towards the cod end and that this was why the animals were not accumulating in the acoustic chamber (cod end) of the net. Was it likely that either the deflector cover, or insufficient tow speed were responsible for the lack of directed flow within the net?

The APOP net is a flattened, rectangular design that tapers to a collecting chamber over a distance of approximately 1 m (Fig. 1). It has a mouth area:net area ratio of approximately 1:5. It has about half the mouth area of a bongo net and I could not see any obvious design flaws that would prevent it from collecting zooplankton effectively. The tow speed might have explained the low flow within the net, but the comparable catches of zooplankton in the bongo nets with and without the coarse mesh excluder suggested that the excluder wasn't the problem. I felt that the small diameter of the collection chamber (essentially the cod end of the net) and fine mesh over the chamber doors would make that section of the net susceptible to clogging. In such an event, water flow to the collection chamber would be restricted and that might explain the low animal accumulations in the chamber. We decided to deploy the

ROV with the excluder in a convex orientation over the front of the net and monitor accumulation of animals via a video camera mounted inside the front of the net.

Launch and recovery of the ROV from the R/V Connecticut are very rapid operations (Fig. 10). In a matter of a few minutes the vehicle was in the water and positioned to collect animals. The methodology was to steam the vessel forward at approximately 0.8 kts using the bow thruster. The ROV then swam behind the vessel at the same speed. Speeds of up to 0.8 kts were possible.

Figure 10. Launching the Kraken ROV from the R/V Connecticut in Cape Cod Bay on the morning of Aug 12, 1999. The F/V Isabel S can be seen in the background.

The video camera in the mouth of the net faced backwards towards the collection chamber. It generally provided a good field of view inside the net (Fig 11). Plankton in the copepod size range could be resolved as small objects. The flow inside the net was initially fairly strong and plankton appeared to be carried towards the cod end. The density of plankton within the net increased during the first 45-60 min of the dive; however, during this time, the flow appeared to diminish and the net surface became visibly clogged. I felt that given the degree of clogging of the net, it was likely that the mesh on the rear door of the chamber was also too clogged to allow water to pass through. Chu didn't think the back door was clogged. His resistivity readings suggested that the chamber was not accumulating many animals. After about 2 h we decided to recover the ROV and examine the net and chamber.

On recovery, it was clear that although the net was clogged with what appeared to be gelatinous material and algal flocs, the doors to the collection chamber were relatively clear. Very few animals had accumulated in the chamber. We washed the contents of the net into a bucket and collected a lot of algal debris that contained very few copepods. My impression was that the net clogged with algae, and although it contained a high concentration of zooplankton during the dive, the majority of these were lost during recovery. The failure of animals to flow into the collection chamber was puzzling, but may have been due to the overall clogging of the net coupled with the small diameter of the collection area. The flow rate may have been a bit low too. I suggested that we have Peter Wiebe join us for a discussion and he arrived at approximately 14h15.

Peter felt that the net problems were due to several factors: progressive clogging of the net by algae from the cod end forward; folds in the net that interfered with normal flow towards the cod end; and possibly, restriction of flow by the screens in the collection chamber. He agreed that it was highly unlikely that there was anything fundamentally wrong with the design of the net that would render it ineffective. One solution may have been to connect a pump to the system downstream of the collection chamber. The combination of pressure from the front of the net and suction behind the chamber might have facilitated collection of animals. That would have taken some time and Tim wanted to get some animals in the chamber as soon as possible to obtain some estimates of the sound velocity and resistivity. While it was important to make the net work, one workaround was to collect animals with the bongo net and rapidly transfer them to the collecting chamber and send it down on the ROV. Chu, on the other hand, felt that the primary objective should have been to get the net working properly so that animals could be collected *in situ* without artifacts of mortality or bubbles. In the end, they decided to attempt to collect animals with bongo nets in-order to get some idea of what the data should look like with animals in the chamber.

Peter and I returned to the Isabel S and Malinda went over to the Connecticut to assist with the bongo tows. We had replaced one of the 335 µm bongo nets with a 505 µm net to reduce problems associated with algal clogging and small animals. While they collected animals and tested them in the chamber, we drifted in the general area with the Greene Bomber in the water. Diagnosing and recovering from several crashes of the Environmental Sensing System (ESS) computer occupied most of that time. Malinda returned to the Isabel S at 18h45. She said that they had collected live animals and successfully measured their acoustic properties in the laboratory.

Figure 11. View inside the APOP collecting net.

After Malinda returned, we recovered the Greene Bomber and steamed to a point off Scituate. There, the Greene Bomber was redeployed and we began night operations. We steamed a transect between the coast and Stellwagen Bank to locate internal waves propagating off the Bank towards the coast. That transect was mapped 4 times during the night. A large packet of internal waves was located and mapped as it moved towards the coast. We picked up that packet again on the return leg and it had moved shoreward at approximately 1.4 kts – a velocity consistent with wave propagation. In each case, the internal wave packets were associated with high backscatter. The intensity was greater on the 120 kHz frequency rather than the 420 kHz and appeared to be localized around the wave packets. These factors suggested that we were seeing scattering from turbulent rather than biological sources. As the packets approached the coast, we saw increased fluorescence and decreasing surface temperature suggesting that as the waves break, they introduce cold, nutrient rich water to the surface. It is also possible that if there's a subsurface fluorescence maximum, that layer is brought to the surface. We needed to spend more time looking at this, but it was time to move out into Wilkinson Basin.

August 13, 1999

R/V Connecticut

We reconfigured APOP system on ROV so that the slurp pump could be used to draw water from the net and into the acoustic chamber. Upon deployment, we observed that we could not draw a significant number of animals into the chamber. Our conclusion after 2.5 days of trials was that the nets seemed to clog, regardless of configuration, and this prevented us from being able to amass sufficient animals inside the acoustic chamber In order to obtain some critical basic data, we then proposed to reconfigure the APOP system onto a vertical cast platform, separated from the ROV. Although this was not ideal (we had to use zooplankton collected in the bongo net), this provided valuable information on the acoustic scattering properties of the animals. In addition, the values will help in the design of the next version of the APOP system.

F/V Isabel S

The weather forecast called for winds out of the S becoming SW at 20-25 kts. It didn't sound promising for work offshore; however, when we had finished the internal wave transects, the seas were very calm and we decided to steam offshore and conduct a fine-scale survey of a western section of Wilkinson Basin. We hoped to locate patches of strong backscatter within water containing less phytoplankton so that Tim could join us offshore. The survey grid consisted of 5 nmile lines separated by 2 nmile. We recovered the Greene Bomber at 07h40 and steamed to the start point of the transect. Several finback and humpback whales were observed along the way. At 11h52 we redeployed the Greene Bomber and began the Wilkinson Basin survey (Fig. 12).

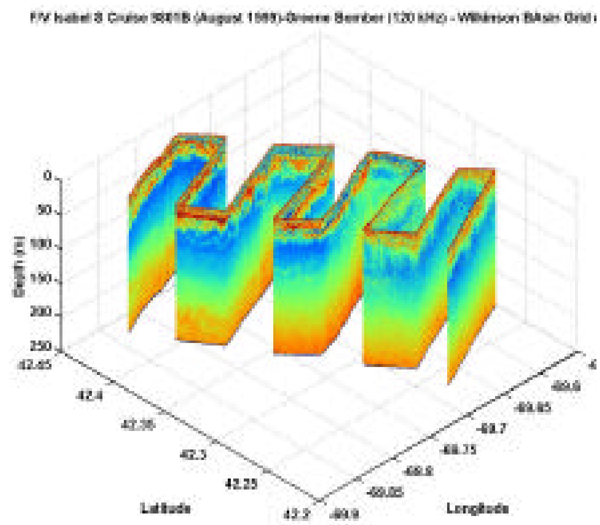

Figure 12. Acoustic survey of part of Wilkinson Basin showing the backscatter from the 120 kHz transducer. The survey began in the NW corner and the first four legs were surveyed during daylight. Note the intense, narrow subsurface scattering layers during daytime.

Sea conditions were initially excellent but deteriorated as the wind freshened. By early evening the ship was rolling appreciably and the seas increased over the course of the night. When I got up at 11h30 to relieve Peter's watch at midnight, the bow of the vessel was pitching to the point that I was almost weightless in the forward cabin. Almost everyone was feeling the effects of the motion and shortly after I took started my watch, I was compelled to visit the rail on a several occasions. I wasn't alone! We decided that upon completing the last line of the survey, we'd steam towards the coast while towing the Greene Bomber and look for some sheltered water.

August 14, 1999

R/V Connecticut

We reconfigured the APOP system onto a vertical cast platform as described above. Over the next two days, we conducted a series of measurements involving bongo net sampling, acoustic casts, and CTD's. On Sunday morning, we began bongo net surveying at Stellwagen Bank, but had to return to Cape Cod Bay because of weather and we resumed the bongo net and acoustic cast work in Cape Code Bay. These data sets provided replicates of acoustic sound speed in zooplankton (including copepods) for two different depths – 20 and 80 feet. These depths were chosen because they were above and below the thermocline.

F/V Isabel S

By early morning, we were off the tip of Cape Cod and the waters were still quite rough. Our options for work were limited. I spoke with Tim on the Connecticut at 07h00. They were completely weathered out in Cape Cod Bay. The wind was out of the south and even the Bay waters were quite rough. They were going to attempt to collect animals with a bongo net, place them within APOP and then lower it on the hydrowire. Tim inquired about mounting the APOP net on the Greene Bomber, but logistically it would have been almost impossible.

We spent the morning processing data that had accumulated during the preceding days. The seas subsided over the course of the day and by noon, it was reasonably calm. We spoke to Tim again. They had steamed to the mouth of the Cape Cod Canal to ride out the rough weather and were heading back to Cape Cod Bay to try and collect some data. We had decided continue to steam east along the tip of the outer Cape until we intercepted the Cape Cod Bay – Stellwagen Bank transect line. At that time, we would follow the transect to Stellwagen Bank. That would give us a daytime measure of the backscatter along the transect.

We had another conversation with Tim in the afternoon. They had moved back into Cape Cod Bay and were working without the ROV since conditions were still marginal for its deployment. They had been collecting animals with the bongo nets and were spooning them into the APOP chamber that was mounted on the hydrowire. Chu and Tim still felt that the failure of the net to collect animals was due to problems associated with the ROV – either low tow velocities or deflection of the flow into the net associated with some flow field around the front of the Kraken. They had mounted the APOP net on the bongo net frame and towed it with a bongo net. The catches were similar which they felt supported their argument.

Peter and I felt that the comparison was not compelling because the APOP chamber had not been on the net. In our opinions, clogging was the cause of the flow problems and the APOP chamber was a narrow orifice blocked with a fine mesh. That bottleneck led to the diminished flow and the problem was exacerbated by the presence of diatoms and gelatinous material in the enriched waters of Cape Cod Bay.

We wanted them to mount a flow meter inside and outside of the APOP net when it was on the ROV. That information would tell them whether the flow really was different. I suggested moving the net mouth forward so that it projected out in front of the ROV, away from any deflecting flow field. Tim requested that either Peter or I come over to the Connecticut to help them diagnose the problem. We gave them the coordinates of our Stellwagen Bank end point and agreed that they would steam to that area in the evening when they were finished in Cape Cod Bay. The next morning we would contact them and transfer Peter over to work with them. I would stay with the F/V Isabel S and move out towards Wilkinson Basin to begin locating suitable patches of backscatter for them to attempt to collect.

Following that we turned around and moved to the Stellwagen Bank end of the soliton transect. On Aug 14th, we had been fortunate to observe soliton packets as they propagated from Stellwagen Bank towards the coast. This time we were also fortunate and again we observed the phenomenon of elevated fluorescence and diminished temperature towards the coast. We steamed the transect three times (round trips) and the dataset should be one of the most complete acoustic assessments of internal wave propagation and breaking ever made.

August 15, 1999

R/V Connecticut (see August 14)

F/V Isabel S

We continued steaming the soliton transect during the rest of the night. The fluctuating temperature and fluorescence in the shallows was incredible. Shortly after 08h00 we ended our soliton transect and met the R/V Connecticut in the middle section of the transect. Our plan was for the Isabel S to sit and wait for a soliton packet to arrive at our location. The Connecticut would collect bongo samples from either end and within the soliton packet guided by our echosounder. The first bongo tow was made at 10h42 in a non-soliton area (Fig. 13). Unfortunately, the waves had picked up and seas made the bongo casts from Connecticut too dangerous. Bongos were suspended and the Connecticut was released to find sheltered water to continue APOP studies (using the hydrowire to deploy APOP).

Figure 13. The R/V Connecticut conducting a bongo in 6' seas. This was the only cast that could be conducted due to the sea state.

We remained in the middle of the transect waiting for the next soliton packet. The seas were quite rough and some of our off-duty personnel used the cabin closest to the galley to avoid the near weightless conditions that prevailed in the forward cabins. The soliton arrived around noon and we collected good time-series data on its passage past us. At 13h30 we recovered the Greene Bomber and steamed to Cape Cod Bay for sheltered water. We remained just off Provincetown for the remainder of the day with the Greene Bomber in the water while we processed data.

August 16, 1999

R/V Connecticut

After steaming overnight, we conducted a new set of measurements over Wilkinson Basin. Here we conducted a vertical survey using the ROV's video camera from the bottom to the surface of the basin. The survey was conducted after an initial set of bongo tows which yielded too few animals for an acoustic test). In the ROV survey, we were able to visualize both the background population of marine snow and small zooplankton as well as layers of larger animals, including siphonophores and amphipods. After the ROV survey, we then did a full ocean depth oblique bongo tow to provide information supporting the ROV survey as well as to provide animals for the acoustic cast. The cast was performed successfully with the animals that consisted mostly of copepods along with a few dozen 5 mm long amphipods and assorted other animals. Then the acoustic cast was done in the full ocean depth. The sound speed contrast was measured as a function of depth. We then unsuccessfully attempted to collect euphausiids with a light trap.

F/V Isabel S

The seas were supposed to subside after midnight as the winds diminished. At 13h18 we recovered the Greene Bomber and began to steam for Wilkinson Basin. The steam would take us about 3-4 h and once there, we planned to assess the sea state. If it was favorable for ROV operations, we would call for the Connecticut to join us for the last weather window into Wilkinson Basin. The steam out had been fairly rough, but the seas were calming and I felt optimistic that it would become workable. At approximately 05h00 I called the Connecticut and instructed them to steam out and meet us.

We arrived at our target location in Wilkinson Basin at 06h00 and deployed the Greene Bomber. There was a 3 foot swell with a slight chop and the marine forecast called for 1-2 foot seas. We started to steam the section of the transect that had previously been covered at night. Connecticut was about 11 nmile away at 07h00 and they were experiencing similar seas.

There were some interesting layers that were potential survey sites for the ROV. Both frequencies indicated a layer at approximately 30m that contains periodic strongly returning patches. Within Wilkinson, we began to search for patches that resembled the strong, narrow layers that we'd seen a few days earlier. Most of the scattering was weak in comparison to our earlier survey and the layers weren't as well defined. We spoke to Connecticut at 09h15 and I initially set at deadline of 10h30 to begin work. At 10h30 I still wasn't satisfied with the intensity of the layers in the area and we turned to the west to look for better patches. By 11h30 things hadn't changed and we had to begin work as our weather window was expected to close by early evening.

We rendezvoused with Connecticut around noon and Malinda and I went over in their zodiac. The plan was to conduct bongo tows (Fig. 14) followed by an APOP cast on the hydrowire (Fig. 15). Then we would deploy the ROV and conduct ground truthing of the scattering layers. Peter took the Isabel S and began an box-shaped survey around Connecticut to try and better define the pattern of scattering. The bongo tows were very disappointing with little in them, although the hyperiid amphipod *Parathermisto* was fairly common. We decided that given the time required for an APOP cast (+2h) we had better deploy the ROV.

Figure 14. Bongo nets deployed from R/V Connecticut on August 16, 1999.

The Kraken went into the water around 13h30 and descended to the bottom. The bottom in this area (near Wildcat Knoll) appeared to be relatively undisturbed by trawling. There were some large boulders and cobble. Lots of fish were present including quite a number of *Sebastes* sp. and hake. The abundance of euphausiids near the bottom was quite striking and in the short time that the ROV was stationary, large *Meganyctiphanes* were all around our lights. We started with a 10 min horizontal transect just above the bottom at a depth of 550 feet (164 m). We didn't observe

Figure 15. APOP mounted on a bracket for deployment from the R/V Connecticut hydrowire.

many euphausiids in the transect so it is likely that they had been drawn down to the ROV by the lights. The ROV then ascended in 25 or 50 foot increments and conducted 10 min horizontal surveys. The most striking thing about the entire dive was the nearly uniform high abundance of copepods and marine snow throughout the water column. Given this background level of scattering, what we observe with the echo sounder has to be due to the stratified presence of larger, less abundant taxa. Some notes on the dive are summarized in Table 1. The notes on the abundance of various taxa are subjective, not quantitative, and it is important to emphasize that more careful analysis of the tapes is required to determine the actual vertical distributions of larger scatterers.

Table 1. Summary of large taxa observed during daytime ROV dive over Wilkinson Basin on August 17, 1999. Copepods were abundant in all strata that we could observe.

Depth (m/ft)	Abundant Large Taxa
182/557	Fish: Sebastes
164/500	Hyperiids
156/475	Marine snow
148/450	Euphausiids and Siphonophores
131/400	Siphonophores
115/350	
98/300	*Clione*: all in a heads up orientation
82/250	*Clione*
66/200	Chaetognatha
49/150	
33/100,16/50, 6/20	Ambient light was too bright to effectively resolve smaller organisms. No large organisms noted.

At the end of each horizontal transect, we switched the camera to the inside of the APOP net and observed the contents and the rotation of a General Oceanics flowmeter while the ROV moved forward. The net was clearly capturing large numbers of animals and didn't appear to be clogged. The animals didn't accumulate near the cod end of the net, possibly because the net was not stretched taut and had a lot of folds and pockets for animals to accumulate in. The animals were frequently ejected from the net when the ROV reversed or was pulled backwards by the tether. The next APOP net should be made of a coarser mesh (505 µm) and must have a rigid frame that pulls it into a taut conical shape.

At 17h30, we returned to the Isabel S and left Tim, Chu, and Ben to conduct their APOP cast. They did a bongo cast from the bottom to the surface and obtained a large number of animals that kept them busy until late in the evening. Another shallower cast after dark yielded large numbers of euphausiids and hyperiids. They were collecting data with those animals until late in the evening.

During the late afternoon, we collected acoustic data along a diamond within a box pattern. After dark when vertical migration had ceased, we steamed another transect around the Connecticut. This survey had the same geometry as the daytime one – a diamond within a box – and should provide us with excellent spatial coverage for interpolation.

August 17, 1999

R/V Connecticut

This work was conducted over Massachusetts Bank. Bongo net tows and CTD's were done in concert with Greene Bomber surveys of internal waves. We conducted the work at stations along a straight line transect. After the third station, we began to observe what we thought was an internal wave (by monitoring the onboard Furuno echosounder, 50 and 200 kHz). We then did a CTD and turned the boat around and drove it along a path in the same (assumed) direction of the wave and did bongo net tows. During the first tow, we observed a strong internal wave on both frequencies. On the next tow, the scattering layers were flat (i.e., no internal waves). After the net tows, we transferred Malinda back to the Isabel and steamed back to Woods Hole.

F/V Isabel S

At about 01h00, we completed the grid and started off towards Stellwagen Bank with the Connecticut following. We hoped to locate solitons again on both sides of the Bank and then would have the Connecticut ground truth them with replicate bongo casts in front of, behind, and within the soliton packets. Our transect across Stellwagen did not conclusively locate any solitons to the NE of the Bank though we did cross one section that appeared to have a subsurface oscillation. We then crossed Stellwagen heading SW towards Scituate and reached the end of the transect line about 08:50. No internal waves were observed on that transect. The Connecticut was going to collect bongo tows from 0-50 m at four locations along the transect line prior to the arrival of the solitons. Once we located a soliton packet, they would then sample within it. Connecticut arrived at our location at the end of the Scituate transect and we sent Malinda over to the Connecticut to assist with bongo tows.

We began to steam back towards Stellwagen while the Connecticut was conducting net tows. On the top of the Bank, we observed some internal waves. Then we turned around and made three short passes across the edge of the Bank. We located the wave packets over the Bank on each short pass and provided Tim with their position. Based on a 1.4 kts velocity, he was able to estimate when they would arrive near his ship. We then steamed to NE end of the transect and sat there until we saw the wave pass. After the packets had passed us we started to steam SW following the waves to observe them as they propagated off the Bank into Massachusetts Bay. Meanwhile, Connecticut used its echosounder (with the gain turned up) to locate the internal wave packet, and they were able to collect one oblique tow through the packet but were unable to locate the soliton for a second pass. They rendezvoused with us and returned Malinda to the Isabel S via zodiac before departing for Woods Hole.

We remained in place waiting for the waves to travel further SW and then resumed our transect run towards Scituate. By 17h30 we still had not intercepted the wave packet that

Tim's group had sampled. The seas had increased and our ride was not as comfortable as it had been, but it was still quite workable. No coherent internal wave activity was noted along the entire Scituate transect during this final run. At 21h27 we completed that transect and began to zigzag along three lines towards Cape Cod Bay. These lines were designed to cover the waters south of our transect lines. If solitons were pumping colder water from the chlorophyll maximum and/or nutrients up to the surface, we hoped to be able to detect enhanced fluorescence within the bathymetric confines of Massachusetts Bay. We did detect high fluorescence that remained elevated until we entered the shallows, but we also detected solitons and the pattern of fluorescence was spatially more complex than simple bathymetric steering of solitons might explain. SEAWiFs satellite imagery may help to clarify what is going on.

That was the end of the scientific portion of our cruise. We recovered the Greene Bomber and began to process data, write reports, and stow gear while we steamed towards Woods Hole via the Cape Cod Canal.