ENDEAVOR 286 CRUISE SUMMARY: PRIMER III

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The third PRIMER cruise was carried out aboard R/V ENDEAVOR from 19 July--9 August, 1996. This was an intensive field study of the shelfbreak current south of Cape Cod during the strongly stratified summer season. (A second, analogous program will be carried out in winter 1997.) The cruise included three major components: acoustic tomography, SEASOAR operations, and hydrography/tracers. An AXBT flight was also conducted during this time period, as well as a SUS charge fly-over. Accordingly, a considerable amount of logistics went into this study, and a total of 32 people sailed over three separate legs. Despite the inherent size limitations of an intermediate class vessel for such a complex operation, and despite several days of inclement weather at the beginning of the cruise, the experiment was successful in nearly every aspect.

The cruise was roughly divided chronologically as follows. During the first leg (5-days), most of the tomography moorings were set and two long-term moorings re-furbished. During leg two (9-days) the remainder of the tomographic array was deployed, and the high-resolution SEASOAR survey grid was occupied continuously for nearly a week. On leg three (7-days) the tomography moorings were recovered, and the TOPEX shelf/slope CTD line was re-occupied (having been done previously during the PRIMER I and II cruises). Figure 1 (station map) shows the configuration of the experiment and the relationship of the three components to each other.

Below is a short break-down of each component, including a few glimpses of the various data products obtained. It is already evident that the combination of techniques and scales involved will provide a unique view of the coupled shelf/slope system.

TOMOGRAPHY

The acoustics portion of the experiment consisted of three components: 1) the moored acoustic transmission array, or ``tomography array", since all measurements with it were taken with sufficient accuracy to perform tomographic studies, 2) the moored physical oceanography array, which provided detailed time series of the oceanographic conditions along our major acoustic path, and 3) the broadband (SUS shot) source component, which provided a diversity of frequencies and source locations for various ONR 6.1 and 6.2 propagation studies. All of these components were quite successful.

(I) Moored Acoustic Array

Our tomography array consisted of two vertical line arrays (VLAs) positioned to the northeast and northwest of the SEASOAR domain, and four sources to the south, i.e. three transceivers at 400 Hz and one pure source at 224 Hz. Figure I1 shows the array configuration. With the exception of one 400 Hz transceiver, all the instruments worked well, giving us both 3-D coverage of the region and a two-frequency inter-comparison of propagation conditions. The VLAs worked extremely well, gathering 90 Gigabytes of acoustic data from 23 July to 4 August, a total of more than twelve continuous days. To our pleasant surprise, the signal to noise ratio (SNR) levels were 20-30 dB before processing, which will give us an extra 45 dB of gain. We thus should be able to exploit both the low and high acoustic modes in our data. Figure T1 shows a spectrogram of some of our acoustic signals at 224 Hz (16 Hz bandwidth) and 400 Hz (100 Hz bandwidth) illustrating the high SNR. Figure T2 shows a preliminary ``modal arrival structure" in which both pulse compression and modal beamforming have been applied to the raw signals for a small piece of 224 Hz data. The dominance of the low mode energy and the temporal spreading of the arrival structure (due to the front, internal waves, and processing mismatch) are readily evident. We are especially encouraged that in collecting these data, we had complete overlap with the moored physical oceanographic sensors, the SEASOAR survey, and the broadband source deployment. These individual elements, when combined together, should lead to a very complete acoustic and oceanographic picture.

(II) Moored Oceanographic Sensors

To better understand the acoustics transmissions as well as the physical oceanography, we deployed a number of oceanographic sensors on the acoustic source and receiver moorings and on a line of moorings along the western edge of the SEASOAR domain (see Figure I1). These sensors included: temperature pods and thermistor strings, Sea Cats, an upward looking ADCP, and a pressure sensor. The preliminary data from these moorings is quite interesting and exciting. In Figure T3 we show Sea Cat data from 60m depth which clearly depicts an in initial intrusion and later exit of warm, saline water from the slope onto the shelf in the southwest quadrant of our domain, in agreement with the SEASOAR observations. In Figure T4 we show the temperature records from three thermistors (near bottom, mid column, and near surface) also in the southwest quadrant. This record very clearly shows the presence of a ``solibore internal tide", a seemingly significant feature on the continental shelf. Figure T5 shows this same thermistor record for the entire water column over a day and a half, i.e. several tidal cycles. The solibore internal tide, including what appears to be a higher mode in the bottom water movement, is very apparent. These rapidly sampled time series measurements on the cross-shelf transect should be very useful in supplementing and interpolating the SEASOAR daily surveys, and in giving us a much better picture of the overall frontal evolution.

(III) Broadband Source (SUS/shot) Deployment

On 27 July, multiple lines of SUS charges were deployed in the area by aircraft drop and were successfully monitored by our VLAs. The WHOI VLA, which could be commanded by radio link from the ship, was adjusted to sample from 0-1500 Hz (three times its normal rate) during this exercise. The northeast listening array stayed at 500 Hz maximum frequency, as it did not have the telemetry option. An example of a shot arrival on one phone of the WHOI VLA is shown in Figure T6.

(IV) Other Issues

Due to a release failure, we will have to return to the PRIMER site to drag for the 400 Hz tomography transceiver mooring. Tentative cruise dates are September 19-20, 1996 for this operation. We also need to pick up the guard buoy for this source, assuming it survived Hurricane Eduoard.

SEASOAR

SEASOAR operations were directed toward resolving the thermohaline and velocity fields within the area defined by the tomographic mooring array (Figure I1). During the seven day deployment, we typically occupied four cross-shelf transects daily, roughly 45 km in length, which extended from the 85 m isobath to the 500 m isobath. The cross-shelf sections were separated by 10 km in the alongshelf direction so that the alongshelf structure of the features would be resolved. The bottom avoidance system was extremely successful and we consistently came within 10 m of the bottom in shallow water.

The presence of fishing gear, both fixed and drifting, was a severe constraint on when and where we could sample. Because of numerous lobster pot lines, as well as free-drifting near-surface long-lines between the 150 to 200 m isobaths, we needed to have visual sightings from the bridge to enable the ship to steer around gear or to notify the watchstanders to raise the SEASOAR to the surface. This meant that we were unable to cross the surface outcrop of the front at night. For the first two nights, we did along-isobath sections over the upper slope, but the long-line activity became quite intense after this point. We then switched so that we spent the night doing various along-isobath sections between the 85 m and 125 m isobaths, where the fishing gear was not in abundance. At one point we did become entangled in a long-line and were forced to recover the vehicle, and several other times the trajectory of the SEASOAR was affected by a brief snagging of a line.

The SEASOAR allowed us to sample the thermohaline structure of the shelfbreak front on horizontal scales of roughly 0.5 km, the first time such resolution has been obtained. This enabled us to produce extraordinary sections showing the complex nature of the frontal boundary. Figure S1 shows a dramatic example of the sharpness of the front, with horizontal temperature contrasts as large as 7 degrees C over scales of 2 to 3 km. Note the apparent downwelling of warm near-surface slope water beneath the offshore edge of the cool shelf water (which is apparent in the salinity field as well). The front during this time period was distorted by a small eddy which was a remnant of a warm-core ring absorbed by the Gulf Stream (Figure S2) along with a corresponding streamer of shelf water moving to the southwest. Typical frontal jet velocities were on the order of 30 to 50 cm/s, and streamer velocities were similar but oriented offshore.

In addition to the cross-shelf sections, several along-shelf sections were also sampled at night and showed strong alongshelf gradients in temperature and salinity (Figure S3) near the western edge of the streamer. Also evident in many of the along- and cross-shelf sections were strong perturbations of the pycnocline associated with internal solitons.

Overall, SEASOAR operations were quite successful, particularly with regard to the limitations imposed by the presence of the fishing activity, and we will have a large data set resolving the thermohaline and velocity fields within the box on essentially a daily basis for seven days.

HYDROGRAPHY/TRACERS

This component of the cruise consisted of a hydrographic re-occupation of the long-term mooring line set during PRIMER I (Dec 95). The array is situated along the TOPEX altimeter sub-track 126, and consists of two shelfbreak moorings (upward looking ADCPs 5 m above the bottom), and three tall VACM moorings over the slope (instrumented at various levels throughout the water column). Figure I1 shows the locations of the moorings, which are scheduled to be in the water until Dec 97. During the first leg of the cruise the two shelfbreak moorings were re-furbished. The shallower instrument had malfunctioned and hence was replaced (a tide gauge was also added to this mooring), and the deeper instrument, which returned a complete data set, was turned around. Bio-fouling on both instruments was moderate.

The hydrographic section occupied during PRIMER III was essentially the same as that occupied during the first two PRIMER cruises (and will be occupied during PRIMER IV and V as well). It consisted of a shelf portion (stations spaced 3.5 km apart, extending to ~ 3 m off the bottom), and an adjoining slope portion (25-30 km station spacing). The only significant difference during this cruise is that we occupied three additional stations on the outer slope (9 stations total), extending the section into the Gulf Stream proper. Originally it was planned to do a complete outer box survey encompassing the SEASOAR region, but because of time lost at the start of the cruise due to weather as well as unexpected delays in the other components, we clearly did not have time to complete such a survey. It was thus deemed most prudent to use our diminishing amount of extra time by extending the TOPEX slope line, rather than starting (and not finishing) another line. It should be remembered, however, that completion of the TOPEX line was our highest priority and as such the hydrographic component of PRIMER III was indeed successful.

As with the other PRIMER cruises, CFCs were collected during the slopewater section by W. Smethie of LDEO, and direct velocity measurements were made using the combination of the lowered ADCP and acoustic transport floats. Additionally, tritium/helium measurements were made by P. Schlosser's group at LDEO. These tracer data will be valuable in interpreting the slopewater circulation and water mass structure in this portion of the mid-Atlantic Bight. They will complement nicely the moored data from the long-term current meters.

The joint slopewater and high-resolution shelfbreak section of Figure I1 provides an upstream inflow condition for the SEASOAR domain. What is particularly nice about this boundary condition is that it extends far enough across the slope (unlike the SEASOAR lines) so that it will help address the offshore forcing. Together with the satellite AVHRR and altimetry we will be able to understand better the conditions in the slopewater during the SEASOAR and tomographic surveys. Figure H1 shows the shelfbreak salinity section from EN286 in comparison to the two previous PRIMER occupations. The three sections were taken in different seasons (winter, spring, fall) and accordingly are quite different. A couple features of note are the strong warm, salty intrusion beneath the shelfbreak front (centered at 130 m) during the December occupation, and the cold, fresh feature embedded in the offshore side of the front (centered at 50 m) during the latest occupation. In both instances the slopewater extensions of these sections will shed light on the nature and causes of these features.