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NOAA Ship Thomas Jefferson Deepwater Horizon Response Mission Report

Interim Project Report-Leg 2, June 3-11, 2010

Smith, Mayer, De Robertis et al.

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Background

The NOAA Ship *Thomas Jefferson* is operated by NOAA as a hydrographic survey ship. She is home ported in Norfolk, VA, and carries a complement of 36 crew and scientists. Most of the scientific staff is permanently assigned to the ship. For this project, several experts were invited to join the ship to provide critical support to this inter-disciplinary mission.

In addition, the ship enhanced its capabilities by adding additional sonars, a water sampling and deep cast system, and adding an additional sensor to the Moving Vessel Profiler.

Objectives

1) Establish a methodology for detection of submerged oil with sonar and *in situ* measurements.
2) Study the movement and structure of submerged oil in the vicinity of the wellhead.
3) Conduct baseline transects from 100m to 1200m isobaths west of the spill site.

Scientific Staff

The following team led the scientific program of this project and jointly authored this report

- CDR Shepard Smith, Commanding Officer, Chief Scientist
- Dr. Larry Mayer, Director, UNH/CCOM, data integration, visualization, adaptive mission planning
- Dr. Alex De Robertis, NMFS/AFSC, bioacoustics, data processing, custom scripting
- LT Mike Davidson, Operations Officer, TJ
- Dan Torres and Brian Guest, Research Associates, WHOI, CTD Operations
- CST Dan Wright, Chief Survey Tech, TJ
- Jennifer Cragan, NRDA/NOAA, chemist
- Mark Stead, EPA, Chain of Custody
- LT Mark Blankenship, CTD Operations
- ENS Jasmine Cousins, water sampling

- ENS Lindsay Morrison, documentation and copy editing

Capabilities for Water Column Mapping

1) Fisheries Echosounders-12 kHz, 38 kHz, and 200 kHz-these sounders have a wide dynamic range ideal for detection of scattering in the water column.
2) Moving Vessel Profiler with a multi-sensor freefall fish and a Turner crude oil fluorometer. This device can deploy a sensor to make *in-situ* measurements to a depth up to 200m while the ship is underway.
3) Standard oceanographic CTD with water sampling rosette. The instrument is equipped with a CTD, Dissolved Oxygen, a CDOM fluorometer, a Turner crude oil fluorometer, and a turbidity sensor. The rosette contains 12 teflon-lined bottles. The winch has enough cable to cast to 1200m.

Daily Chronology

June 3-

Departed New Orleans 0600, transited down the Mississippi. Installed the new multi-sensor freefall fish and Turner crude oil sensor on the Moving Vessel Profiler. Tested the MVP off SW pass, verified data was received and logged and mechanical portion performed as expected. Conducted a shallow (20m) then a deep (600m) CTD cast to test winch, brakes, CTD and all sensors, and hone water sampling protocols. Began transit to spill site at 2200.

June 4-

Tied into NOAA Ship Gordon *Gunter* data by repeating three transects in the vicinity of natural gas seeps and taking a CTD at a site *Gordon Gunter* reported high fluorescence at around 1100m. Echosounder records were considered comparable. Interestingly, TJ's cast did not show a comparable fluorescence anomaly. Additional sonar work in the vicinity of GU "hot spots." Requested permission from SIMOPS to enter 5 NM circle to increase the probability of finding higher concentrations of oil from which to derive a sonar signature. Permission was denied. Last cast of the day (Cast TJ-07) showed a prominent anomaly at around 1100m with high CDOM and low DO. Recognition of pattern in sonar return hypothesized to be indicative of the anomalous water mass.

June 5-

Additional sonar work outside 5 NM, looking for patterns consistent with previous observations. First cast of the day (TJ-08) showed a prominent anomaly at around 1100m. Bow thruster inoperable part of the day, making precise cast placement difficult. Transfer of water samples to shore via crew boat. Permission granted to enter to 3 NM. Perimeter sonar and MVP line at 3NM.

June 6-

Block of transects conducted SW of wellhead. One CTD cast inside this area was negative. Similar acoustic signature not seen in this area. Returned to area of high fluorometer hits (TJ07, TJ08). Repeat cast in this area showed no anomaly. Took on water from crew boat. Zig-zag search pattern toward the SW, in the direction of the ADCP deep current. Faint acoustic anomaly detected along slope. CTD Cast 13 in this area showed traces of fluorescence and a distinct layer of low DO at depth. Departed area to transit inshore for 100m transect.

June 7-

Begin 100m transect, first east to Mobile, then west to the Mississippi Delta. Casts conducted about 6 times per hour. Refined on board processing and visualization tools. Took one cast in an area of anomalous fluorescence at around 40m depth. High CDOM and low DO to match. MVP casts continue to west.

June 8-

Decontaminate TJ hull, transfer samples ashore, exchange crew, press visit. Depart 1100 to begin baseline transects west. Additional MVP fluorescence anomalies noted. No time to investigate.

June 9-

Baseline transects moving west. Calibrated the echosounders so absolute values can be compared between vessels and over time. Slip ring failed on CTD winch, last cast of transects skipped to stay on schedule and fix the slip ring while transiting.

June 10-

Winch level wind failed on first cast of the day. Instrument recovered by manually moving the level wind. Cannot be repaired on board without appropriate parts. Remaining casts cancelled. Extra few hours spent finishing hydrographic surveys in fairways and approaches to Galveston.

June 11-

Arrive in Galveston 1000

Configuration and Collection Procedures

Echosounder installation and operation

A Simrad ES60 single beam echosounder with hull-mounted transducers operating at 12, 38, and 200 kHz was operated continuously throughout the mission (Figure 1). The ES60 received a navigation feed from the POS MV (Applanix 320 version 4), and the data acquisition computer's clock was synchronized to the ship's timeserver every 10 min in order to provide a precise timestamp.

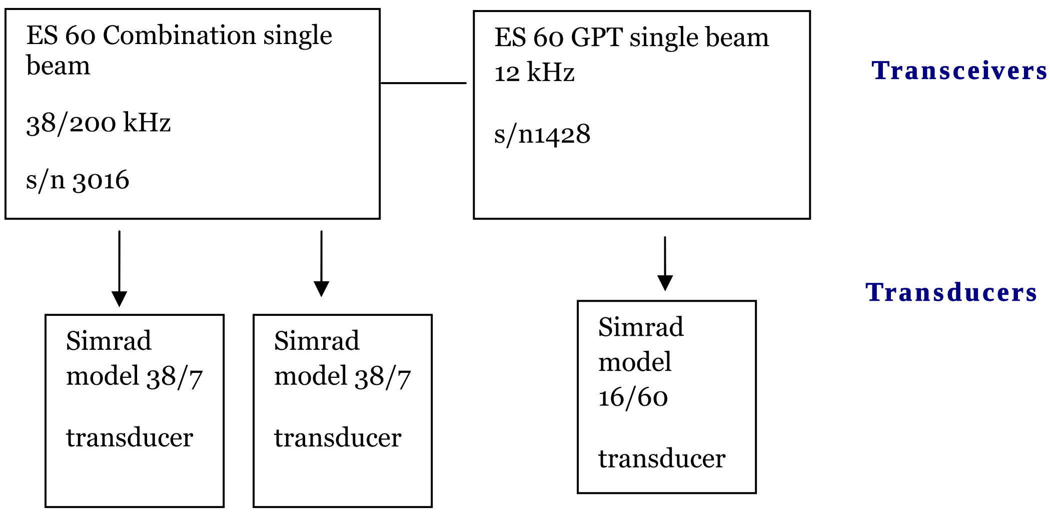


Figure 1. Block diagram of Simrad ES60 installation. Serial numbers for the transducers were not available.

The power values were selected so as not to overdrive the 200 kHz transducer, the pulse lengths should be appropriate for the water depths, the equivalent beam angles were nominal values for the transducers, and the gain is the nominal value for the transducer, as these systems had not been calibrated. Variable ping repetition intervals (ranging from 1-4 seconds) were used during data acquisition. All timestamps were in UTC. Other interfering echosounders were turned off. Overall, data quality was good, and free of major sources of acoustic or electrical interference, with the exception of noise from hydraulics during CTD casts.

Two configurations (Table 1) were used to acquire the ES60 data based on nominal values for this make and model equipment. A maximum power of 100 Watts was used at 200 kHz to minimize biases due to harmonic distortion at high power at this frequency (Tichy et al., 2003). During future post-processing, the gains resulting from the sphere calibration should be applied.

Table 1. System settings for ES60.

Configuration A: shallow water (<200m)

Frequency	Power (watts)	Pulse length	Equivalent beam angle (dB)	Gain (dB)	s_A correction (dB)
12	2000	1 ms	-14.0	16.9	0
38	1000	1 ms	-20.6	26.5	0
200	100	1 ms	-20.7	27.0	0

Configuration B: Deep water (>200m to 2,000m)

Frequency	Power (watts)	Pulse length	Equivalent beam angle (dB)	Gain (dB)	s_A correction (dB)
12	2000	4 ms	-14.0	18.5	0
38	1000	4 ms	-20.6	26.5	0
200	100	1 ms	-20.7	27.0	0

System settings:

- From start of mission to 800 AM GMT on 6/4/2010 configuration A was used.
- Configuration B was used from 6/4/10 from 0800 until 6/7/1- 10:35 while sampling in deep water near the Deepwater Horizon site.
- Configuration A was used from 6/7/1 – 10:36 until the end of the mission
- A variety of settings was used during calibration (15:36- 18:00 6/9/10)

Data Processing – Echosounder

The ES60 output (*.raw files) were processed in parallel with Echoview 4.90 and the Fledermaus midwater tool. The nominal settings used for data acquisition (see table 1) were used for processing. The data were displayed as echograms of either amplitude or volume scatter (S_v), and were examined for relevant features and anomalies. A variety of exploratory analyses (e.g. analysis of frequency response, use of different color maps, echo integration, smoothing of data, feature extraction, and thresholding) were applied to the data. The acoustic backscatter was examined by experienced analysts of geophysical (Mayer), and biological (De Robertis) acoustic records. Relevant features were interpreted and discussed jointly. Ultimately, the presence of gas seeps as well as an anomalous bottom-following reflector was extracted for integration with other data and visualization (described below).

Rolls Royce Naval Undersea Systems – Moving Vessel Profiler and Sensors

The Moving Vessel Profiler (MVP) is a self-contained profiling system capable of sampling water column profiles to 100m depth while operating at speeds up to 10kt. The MVP-100 was mounted at the transom port side of centerline. It consists of a computer-controlled high speed hydraulic winch, a cable metering, over-boarding and docking system, a conductor cable and a single sensor freefall fish (SSFFF) housing an Applied Microsystems "time of flight" SV&P Smart Sensor (see SV&P below) . The system as configured aboard the *Thomas Jefferson* collects vertical profiles of sound velocity data while the ship is underway at survey speed. The unit is located on the fantail and controlled remotely from the ship's acquisition room. On June 2, 2010, the SSFFF was removed from the MVP to accommodate a larger Multi-sensor freefall fish (MSFFF), which could house additional sensors necessary to conduct the mission.

Figure 2. Moving Vessel Profiler

Figure 3. Multisensor Freefall Fish

AML – Sound Velocity & Pressure Smart Sensor (SV&P)

The SV&P Smart Sensor is the main instrument housed on the MVP free fall fish; it is designed to directly measure sound velocity and pressure in water. The sensor has internal calibration coefficients and outputs real-time data to allow a "plug and play" environment.

The Applied Microsystems Smart SV&P Sensor was calibrated by the manufacturer during the 2009-2010 winter import. The sensor used for S-K919-TJ-10 was maintained as a spare for the unit installed on the SSFFF. Upon receipt of the MSFFF, the spare AML SV&P sensor was installed to provide the depth below surface measurement necessary for the system to deploy and recover safely.

Figure 4. AML SV&P sensor (on single sensor fish)

Turner Designs Cyclops7 Crude Oil Sensor

Thomas Jefferson was outfitted with a multi-sensor free-fall fish (MSFFF) for the MVP during this project. The MSFFF was specifically outfitted with a Turner Designs Cyclops7 Crude Oil Sensor (Cyclops7) for the Deepwater Horizon project. Oils are typically excited using ultraviolet wavelengths (300-400nm) and fluoresce in the visible wavelength range from 400-600nm.The Cyclops7 emits an ultraviolet light that excites fluorescent matter in the water. The Cyclops7's optical sensor is specifically tuned to detect the fluorescent signature of crude oil (Polycyclic Aromatic Hydrocarbons (PAH) are the primary contributors to the fluorescent signature). As the fluorescent light enters the optical sensor, it passes through a specialized band pass emission filter that filters out wavelengths not associated with the crude oil signature. The light that does make it through the filters is registered as a voltage by the instrument. The higher concentrations of hydrocarbons generate higher voltages. The voltage is output in ASCII format. The response time of the Cyclops7 is 300 microseconds. (Turner Designs, 2010)

Figure 5. Turner Cyclops 7 Fluorometer

Data Acquisition Methods

Prior to mounting the Cyclops7 into the MSFFF, calibration was conducted and a procedure was established. The calibration, procedure, and results can be found in Appendix IV. The Cyclops7 was mounted in the nose of the MSFF. The MSFFF was deployed from the MVP to a depth of 100m while underway at speeds of about 9kts. MVP casts were initiated every 15 minutes and the data was written in ASCII file format with metadata including: data/time in GMT, position, bottom depth, and vessel speed. The ASCII files generated for each cast were logged directly to the ships network. Data was logged on the down cast and the up cast, but the up cast data is considered to be a better representation sample due to higher data density as a result of the slower rate of recovery vs. freefall deployment.

MVP data acquisition and processing

The Moving Vessel Profiler (MVP) was used to acquire sound speed and fluorescence samples at approximately 10-15 minute intervals while the ship was underway. A typical "cast" or deployment extended to 100m depth and recorded approximately 3500 measurements.

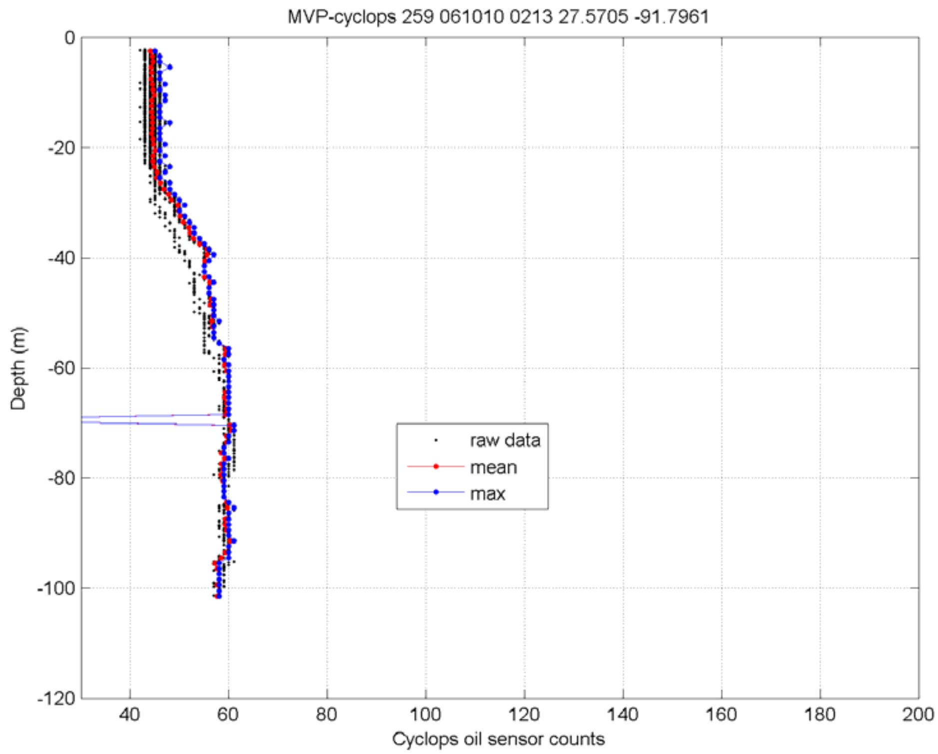


Figure 6. Data collected offshore in area of low fluorescence

Position approximation

The position of the MVP is recorded on deployment, which represents an almost vertical decent to the designated braking depth. During the retrieval portion of the cast, the forward movement of the ship is not incorporated into the cast position. On casts to 100m depth, retrieval may take 6-7 minutes, such that the data on retrieval will be collected over approximately 1NM at typical survey speeds of 9-10kts.

Data Processing – Moving Vessel Profiler

Initial data processing was performed using Excel to plot consecutive casts, and to look for significant anomalies between casts or groups of casts. Data processing was further refined using a matlab program which extracted relevant position, depth and fluorescence data. The raw data were averaged into 1m bins for each cast and plotted, showing the raw, mean and max data points. In order to detect anomalies, each retrieval was summarized as the maximum value observed at < 20m, and >20m, as fluorescence records were often high at the surface and a subsurface peak was often observed.

The raw data from the moving vessel profiler were averaged into 1 m bins for each cast, and plotted. In order to detect anomalies in near-time, each upcast was summarized as the maximum value observed at ≤

20m, and > 20m, as fluorescence records were often high at the surface and a sub-surface peak was often observed.

CTD Operations

In support of the efforts of NOAA to understand the extents of the oil leak as a result of the sinking of the oil rig Deepwater Horizon, the Woods Hole Oceanographic Institution (WHOI) supplied the NOAA ship *Thomas Jefferson* with CTD equipment and technical support personnel.

The CTD, which is an acronym for Conductivity (salinity), Temperature and Depth was equipped with a suite of sensors to aid in the measurement of potential deep water oil plumes as well as the ability to recover water samples from targeted depths. This instrument package contained:

- SBE 9plus CTD
- Seabird conductivity sensor
- Seabird fast response temperature sensor
- Seabird dissolved oxygen sensor
- Wet Labs CDOM fluorometer model no. CD2000
- Seapoint Turbidity Sensor
- Turner Designs Cyclops-7 crude oil fluorometer
- Seabird Model 32 pylon
- 12 ea. 4 liter Niskin bottles

The CTD has the ability to stream real time data through the 3 conductor .322" armored cable. The cable is wound on a winch, data is transmitted to a computer aboard the ship, as it is lowered then raised through the water column. CTD cast locations at preselected stations or based upon data collected by towed and hull mounted systems. The CTD was lowered to within 5 meters of the ocean floor or to its maximum wire out (approximately 1200m depth). During the ascent, as the CTD reached a level in the water column that was of interest, the winch would stop and a 4 liter Niskin bottle would close and trap the water. This could be repeated at various depths up to 12 times. Once back aboard, the water samples were drawn under strict guidelines to insure the integrity of the samples collected. See water sample procedures in Appendix II.

To ensure that the system remained free from contamination, numerous steps were taken. The Niskin bottles were coated with a spray on Teflon coating. Once the samples had been drawn, the bottles were cleaned with a solution of Dawn dishwashing liquid and water. The complete system was rinsed with fresh water after each cast and washed with Dawn as needed. The conductivity sensor, temperature sensor and dissolved oxygen sensor were cleaned with a 1% solution of Triton-X by flushing 5-6 times then rinsing with distilled water. Clean water was left in the sensors until the next station was reached. During deployment in areas that had a sheen on the water, the vessel used prop wash to create upwelling to clear the sheen just prior to lowering the instrument into the water, bringing up clean water from below. Since the sensors rely on a pump to move sampled water through the system, the pump was turned off during launch and recovery to eliminate pumping contaminated water over the sensors.

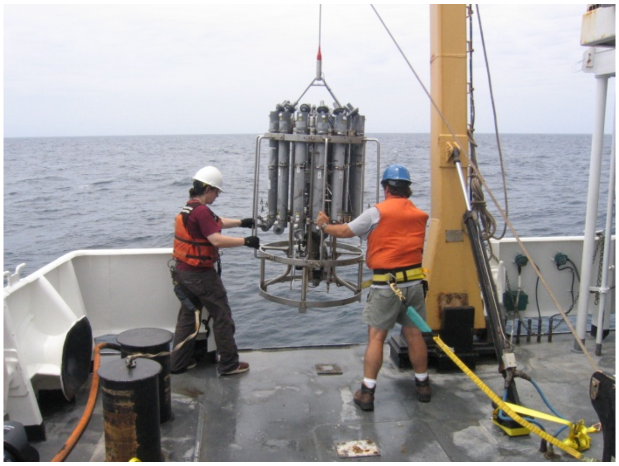


Figure 7. CTD Deployment

Due to the good weather that we had during the mission, launch and recovery aides were not needed. All that was required were 2 people to steady the instrument. During inclement weather, a pair of slips lines should be incorporated during the launch and poles equipped with a hook and line should be used to steady the instrument during recovery.

Results

ACOUSTIC AND CTD ANOMALIES

A primary objective of the *Thomas Jefferson* program has been to test the feasibility of using surface-ship borne, acoustic sensors to locate submerged oil (if present) at depth. Recent work with water-column imaging multibeam sonars has demonstrated that it is relatively simple to image gas plumes at depths as great at 2000 m, but given the unknown nature of the of the state or properties of oil at depth (with or without dispersant), it was unclear whether conventional surface-ship deployed acoustic techniques would be useful in detecting submerged oil near the Deepwater Horizon site. The potential benefits (in terms of ease of deployment and areal coverage) of acoustic detection, however, deemed it well worth exploring the feasibility.

Thomas Jefferson, with help from many others around the country installed an ES-60 fisheries sonar and made it operational on board the *Thomas Jefferson* in a matter of days. This system was selected because of the presence of compatible transducers on the *Thomas Jefferson* hull, the range of frequencies available (12, 38 and 200kHz), the high dynamic range, and its ability to be calibrated. The details of this system, its operational settings, and calibration procedures are presented in the echo-sounder installation and operation and calibration sections of this report.

The strategy behind our effort was to attempt to locate regions where there was direct evidence (from previous CTD casts) of indicators of submerged oil (e.g. high CDOM fluorescence and low dissolved oxygen), verify the presence of these indicators with our own CTD casts, and then examine the sonar records to see if there was an acoustic signature that was coincident with these direct indicators. Unfortunately by time we arrived at the site, we had no information from others about their findings. Fortuitously, the chemist on board (from ASA Associates) had been involved in earlier CTD operations and reported that anomalous CTD measurements had been discovered southwest of the well-head. Following up on this information we occupied our first deep CTD station (3) to the southwest of the well site at the 5 mile limit of our access. This first deep cast (to 1200 m – the maximum depth achievable with the wire on board the *Thomas Jefferson*) showed no indicators of submerged oil. Aside from several natural seeps (Figure 8), no other anomalies were observed in the acoustic records at this site (Figure 9).

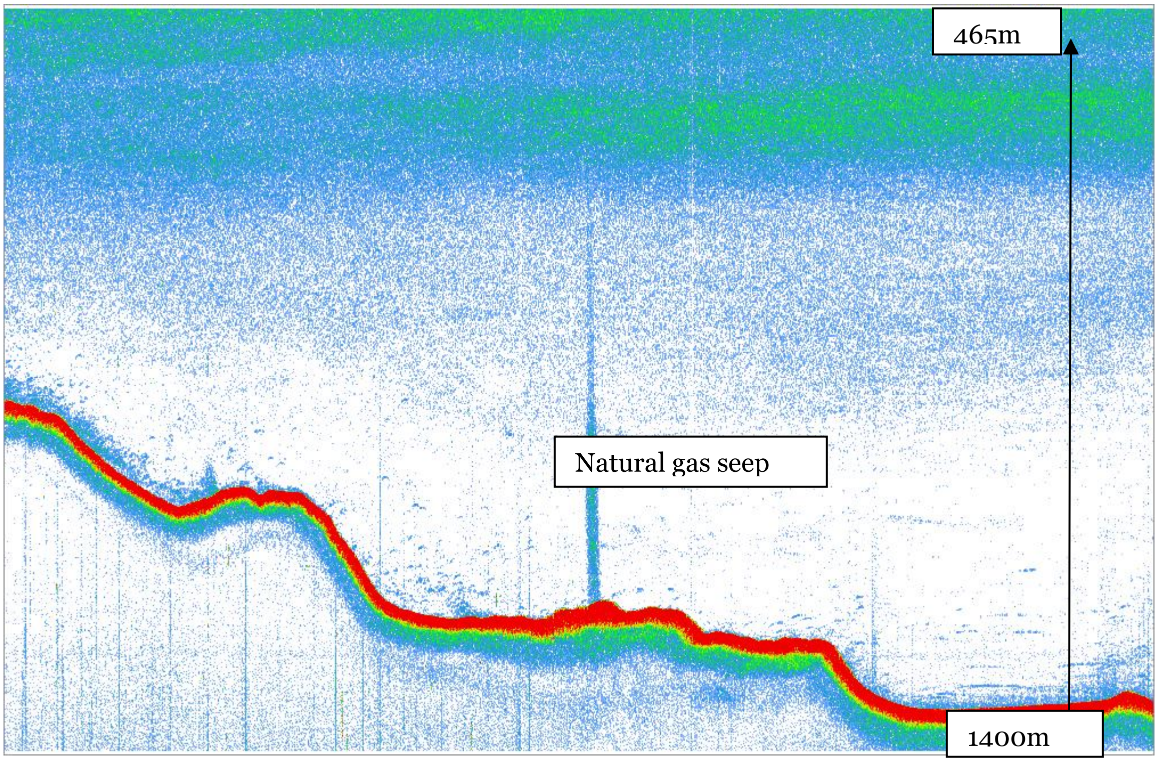


Figure 8. One of many natural seeps found during acoustic survey ES60 at 38kHz.

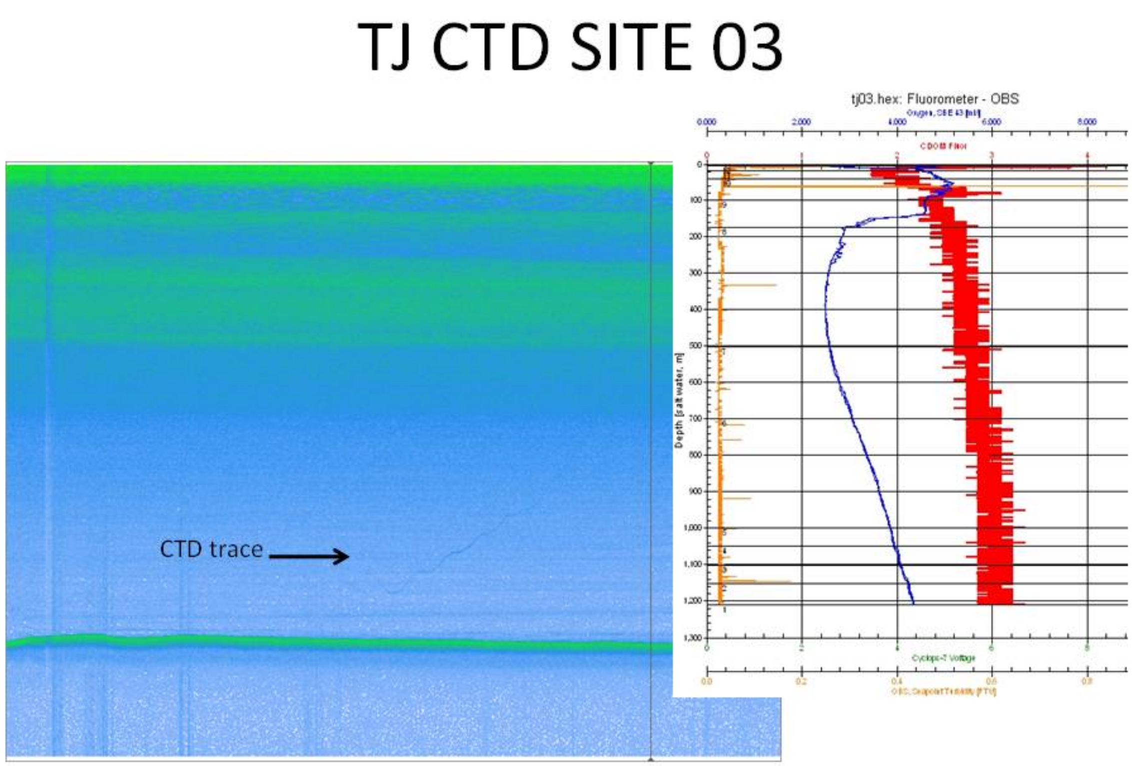


Figure 9. ES-60 38 kHz acoustic profile and CTD trace at CTD Site 03 – CDOM fluorescence (red), dissolved O2 (blue) and optical backscatter (brown)

After receiving information from the *Gordon Gunter* on the location of their CTD's, we re-occupied (approximately – all position of the CTDs are subject to some uncertainty) the site of their two highest deep-water fluorescence observations (which were found at approximately 1140m depth). The *Gordon Gunter* took two sequential casts (19 and 20) on 2 June at 0233Z and 0405Z respectively; we made our measurement on 4 June at 2339Z, approximately 68 hours after the *Gordon Gunter*'s measurements. In contrast to the *Gordon Gunter* profile, our measurements showed neither elevated fluorescence values nor other anomalous properties anywhere in the profile. It should noted , however that the final calculation of the position of CTDTJ06 at depth was approximately 1.6 km from the nominal starting position of the *Gordon Gunter* cast. Again, aside from seeps, no acoustic anomalies were observed at this site (figure10).

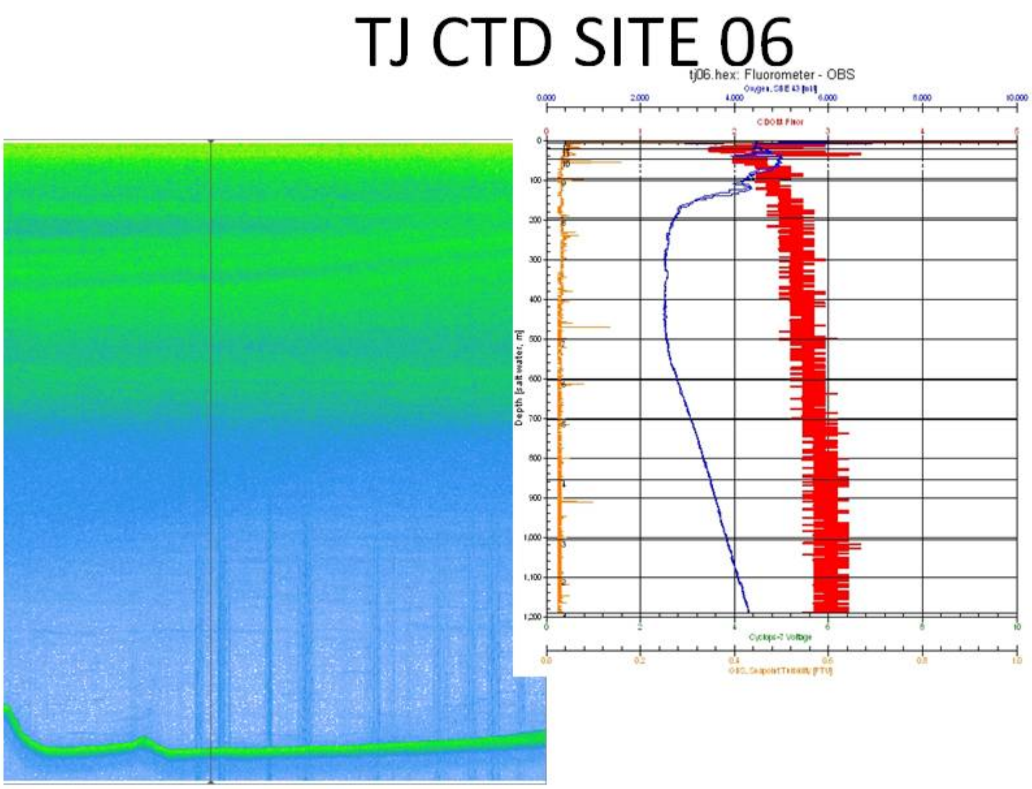


Figure 10. ES-60 38 kHz acoustic profile and CTD trace at CTD Site 06 – CDOM fluorescence (red), dissolved O2 (blue) and optical backscatter (brown)

Failing to find indicators of submerged oil on our first several CTD casts, we conducted an acoustic survey, focusing our attention on the area of the water column around 1100 m where others had found evidence for high fluorescence. During the course of this survey, we noted an acoustic signature at that depth (particularly at 38 kHz) that did not seem to follow the pattern of biological scatters. This signature was a sloped reflector that appeared to follow the bottom topography and was distinct from the base of the scattering layer; it became most apparent during turns on a sloping surface where the symmetry of turn resulted in a "dome" like appearance to the reflector. A zone of reduced backscatter was evident below the sloping surface. Given the bottom-following behavior of the reflector (we will call them Bottom Following Reflectors – BFRs) we examined the possibility that that they represented a multiple of the seafloor echo but do not believe this to be the case (Figure 11).

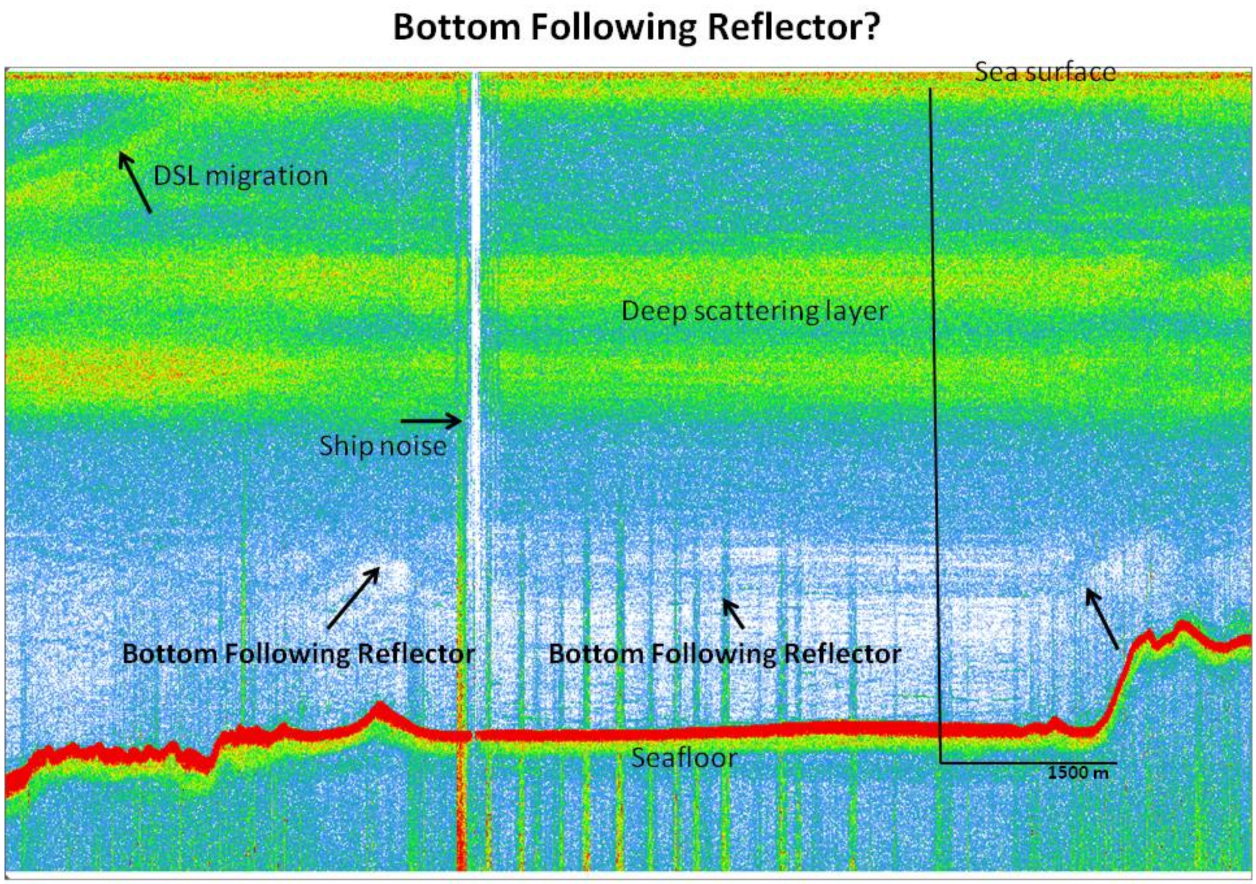


Figure 11. Example of Bottom Following Reflector (BFR) at approximately 1100 m depth as seen on the 38 kHz ES-60.

A CTD cast at this site (CTD 07) resulted in our first indication of high fluorescence, high optical backscatter and low dissolved oxygen. The depth of this anomaly coincided with the top of the BFR (Figure 11).

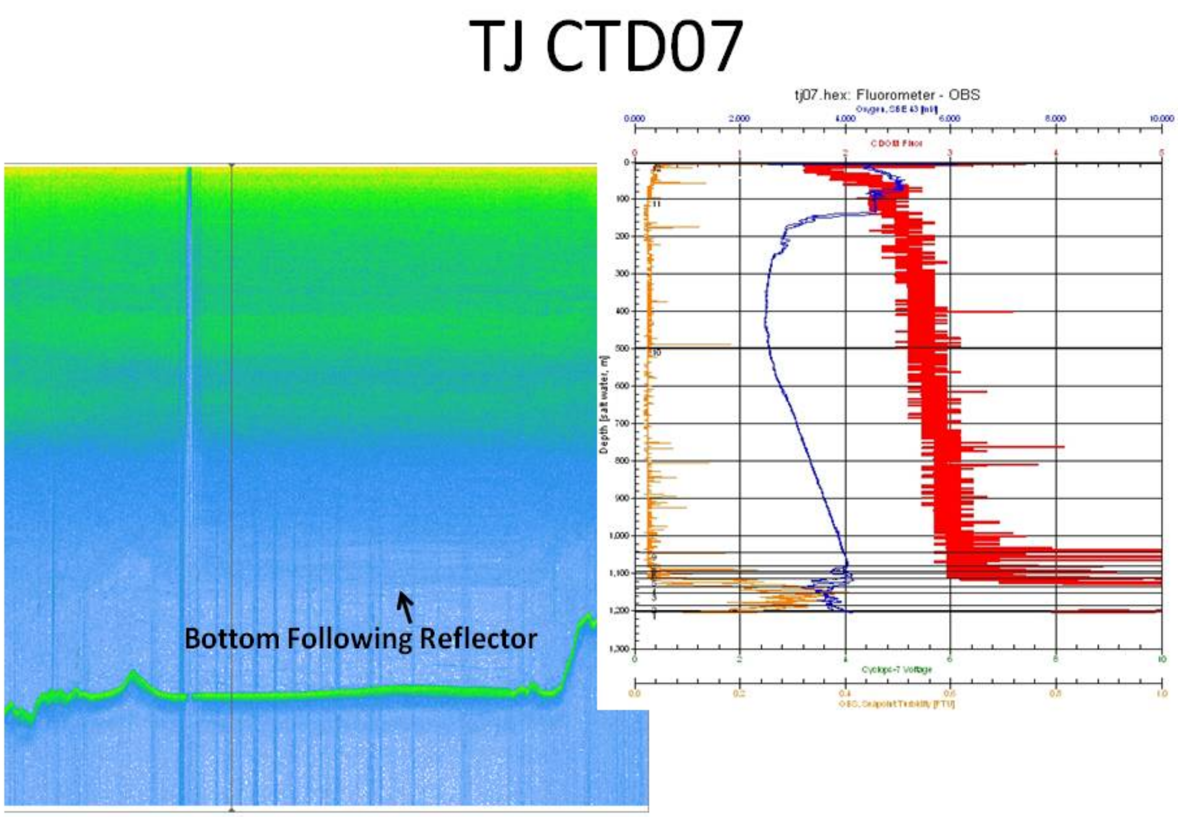


Figure 12. ES-60 38 kHz acoustic profile and CTD trace at CTD Site 07 – CDOM fluorescence (red), dissolved O2 (blue) and optical backscatter (brown).

Figure 12 illustrates the first site to show very high fluorescence and optical backscatter readings along with a dissolved oxygen anomaly. This anomaly seemed to coincide with the level of the BFR on the sonar profile.

To test this apparent relationship we conducted a 12 hour acoustic survey noting areas that showed the BFR acoustic signature and those that did not. These areas clustered in a small region on the slope of a topographic high to the southwest of the well site (see discussion section below). We then took a CTD at a site that showed a well-developed BFR approximately 2 km to the southwest of CTD 07. This CTD (08) also showed a very well developed fluorescence and optical backscatter peak and an associated dissolved oxygen low correlating with the depth of the BFR (FIG 13).

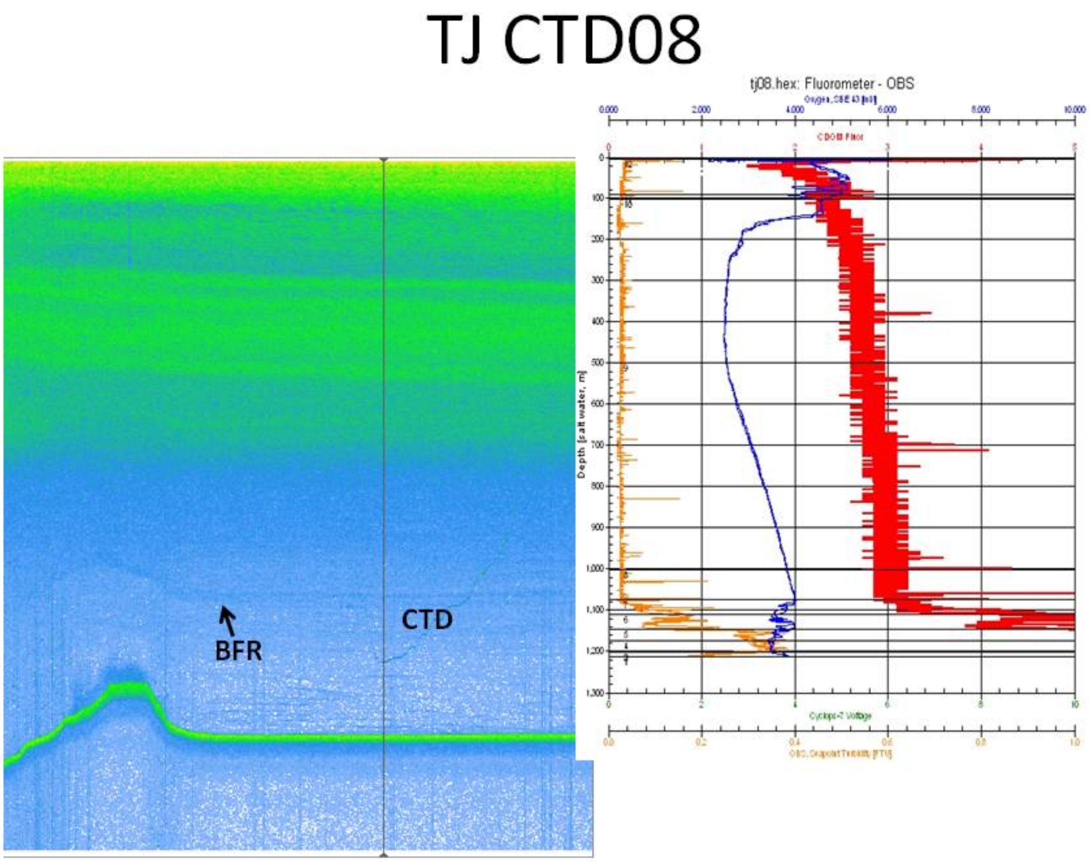


Figure 13. ES-60 38 kHz acoustic profile and CTD trace at CTD Site 08 – CDOM fluorescence (red), dissolved O2 (blue) and optical backscatter (brown). Again the high fluorescence and optical backscatter and a dissolved oxygen anomaly were coincident with the presence of the BFR.

CTD Site 09 was another attempt to sample a BFR but while occupying the site the vessel lost its bow thruster and was unable to maintain station. We drifted from the original site and sampled an area ~ 1.5 km away where no BFR was visible. The resulting CTD had a very small and narrow fluorescence spike, but no other indicator of submerged oil (Figure 14).

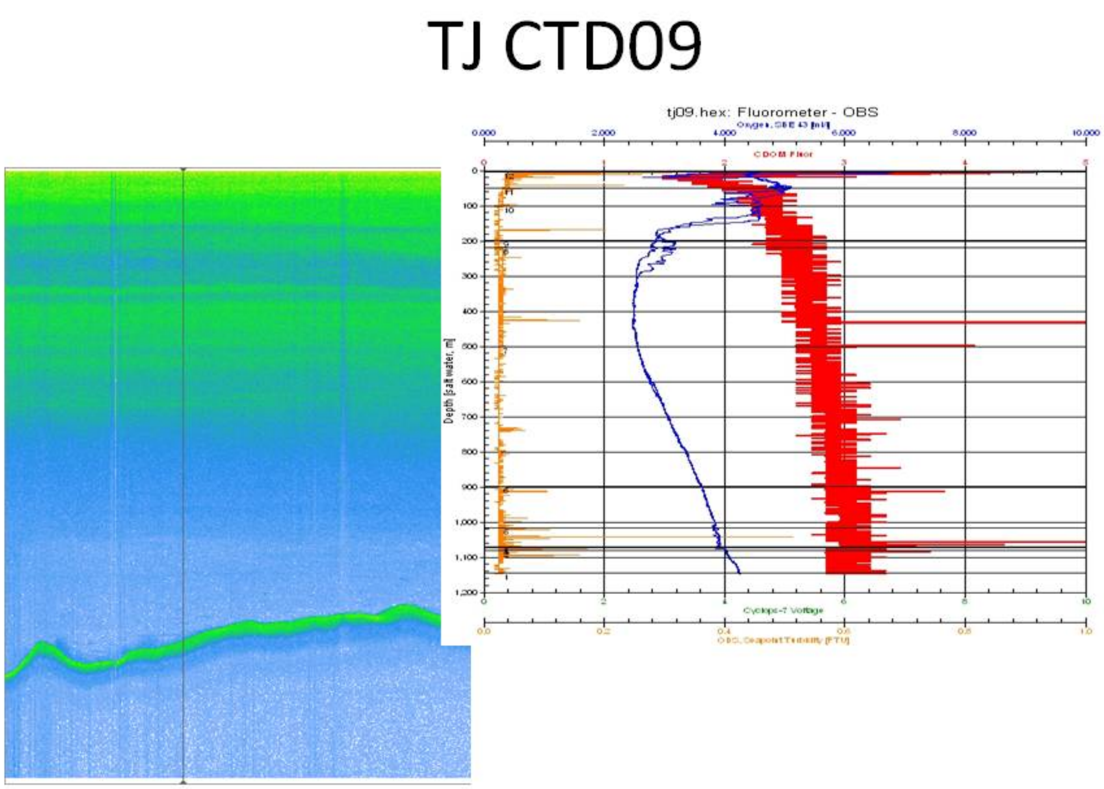


Figure 14. ES-60 38 kHz acoustic profile and CTD trace at CTD Site 09 – CDOM fluorescence (red), dissolved O2 (blue) and optical backscatter (brown).

Continued surveying did not find further evidence of a Bottom Following Reflector, however a very sharp acoustic boundary was observed at approximately 1000 m depth. Unlike the BFR, this horizon maintained a constant depth, did not follow the topography and was contiguous with the bottom edge of the deep scattering layer (Fig 15). CTDs 10 and 11 both sampled this horizon and neither showed high fluorescence values though both showed very small depletions in dissolved oxygen at the level of this reflector (Figures 15 & 16).

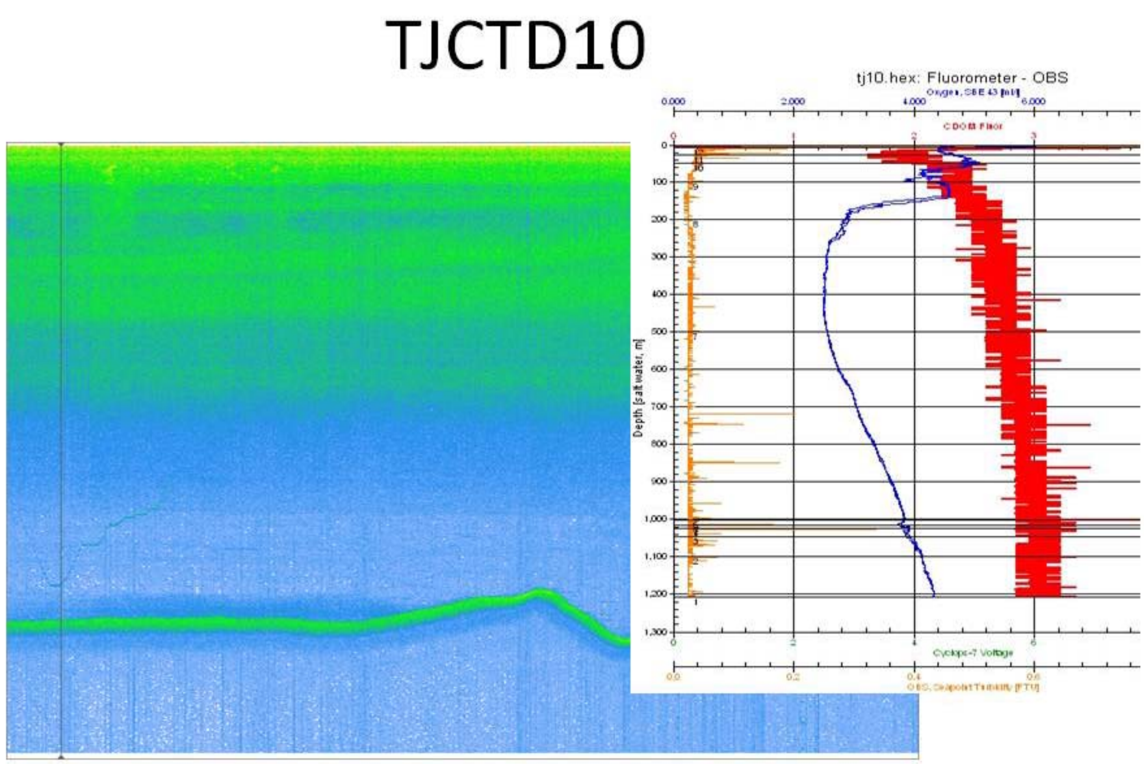


Figure 15. ES-60 38 kHz acoustic profile and CTD trace at CTD Site 10 – CDOM fluorescence (red), dissolved O2 (blue) and optical backscatter (brown).

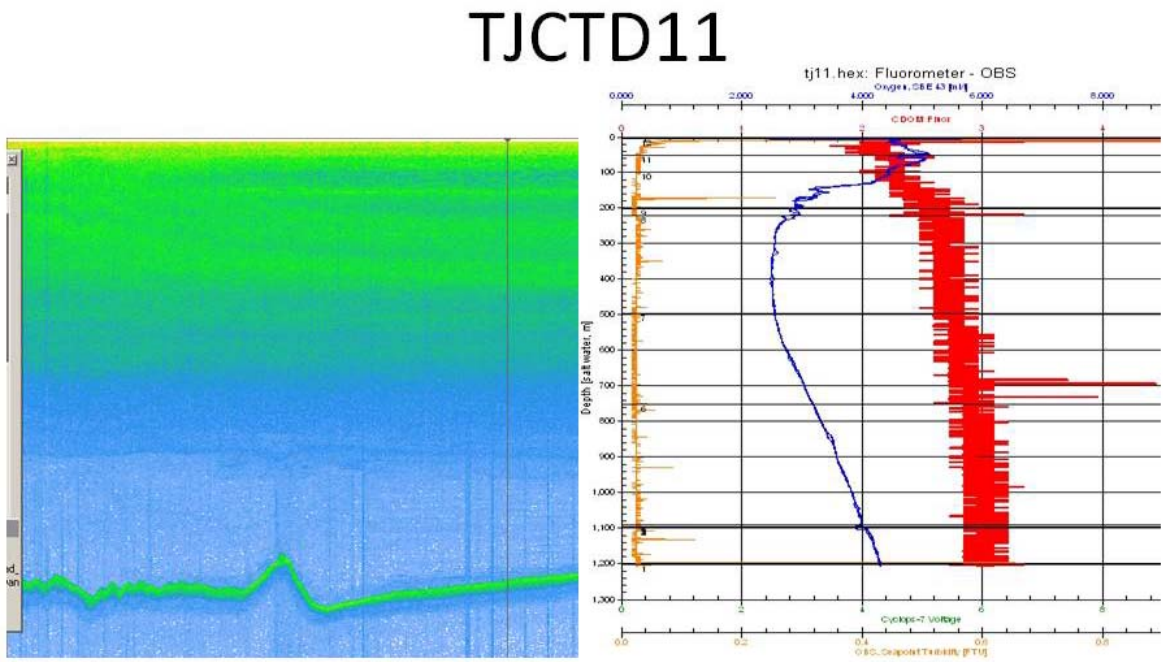


Figure 16. ES-60 38 kHz acoustic profile and CTD trace at CTD Site 03 – CDOM fluorescence (red), dissolved O2 (blue) and optical backscatter (brown).

To look at the temporal variability of both the acoustic signature and the CTD results, we re-occupied CTD Site 08 (where our highest values of fluorescence and optical scattering and lowest dissolved oxygen values were found), 30 hours later. Our survey at site 12 revealed no evidence of a BFR; the CTD revealed only a small narrow fluorescence peak and very small dissolved oxygen drop at approximately 950 m depth which was within a dense acoustic scattering layer of presumably biological origin (FIG X17).

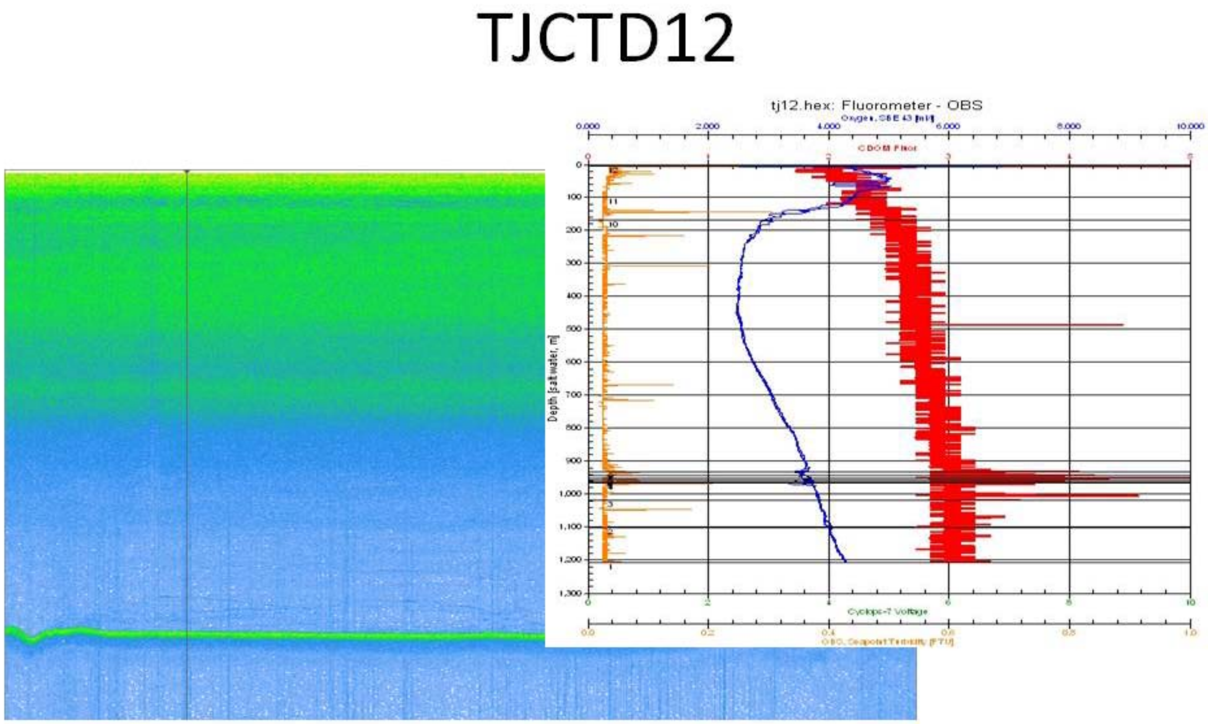


Figure 17. ES-60 38 kHz acoustic profile and CTD trace at CTD Site 12 – CDOM fluorescence (red), dissolved O2 (blue) and optical backscatter (brown).

Having seen a strong fluorescence signal diminish over a 30 hour period and not seeing an acoustic signature in the region where it was so prevalent the previous day, we decided to spend our final hours around the well site surveying "downstream" (to the southwest) of the apparent bottom flow as determined from ADCP measurements made on the rig drilling the relief well. During this survey we encountered a small region with a weak or whispy BFR and took our final deep-water CTD cast there (Site 13). At this site the CTD revealed a very small fluorescence and optical backscatter peak with a coincidental decrease in dissolved oxygen at a depth corresponding to the BFR (Figure X18).

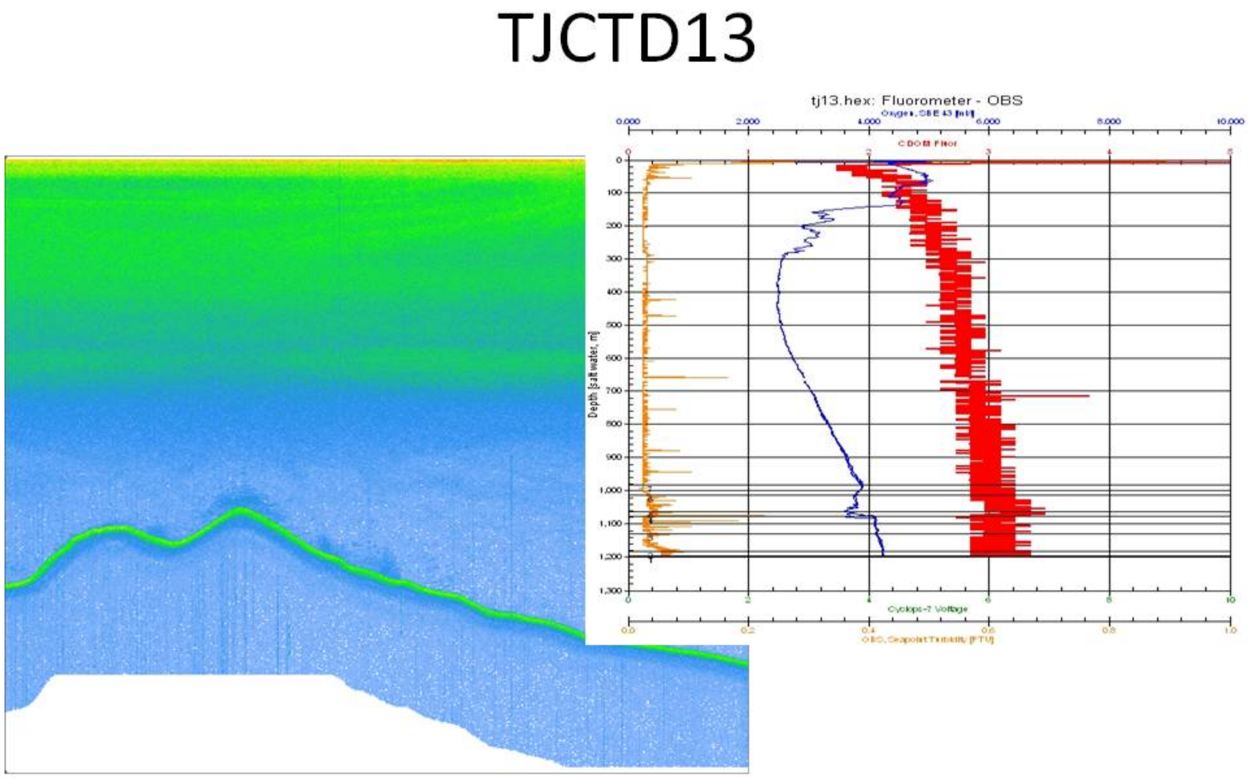


Figure 18. ES-60 38 kHz acoustic profile and CTD trace at CTD Site 13 – CDOM fluorescence (red), dissolved O2 (blue) and optical backscatter (brown).

Discussion

The very small sample set that we have obtained implies that there may be an association between a very subtle acoustic signature and potential indicators of submerged oil (high fluorescence and optical backscatter and low dissolved oxygen). Our analyses are very preliminary and our sample set is very small so the results must be interpreted cautiously. There can be little question, however, that the CTD measurements indicate that high values of fluorescence and optical backscatter can be highly variable in space and time. We are likely seeing a more diffuse, cloud-like structure that varies with bottom flow and perhaps with changes at the source.

The geographic distribution of the Bottom Following Reflectors may offer some insight into what we are seeing (Fig 19). The occurrence of BFR's seems to be concentrated along the western slope of a passage between two bathymetric highs to the southwest of the well-site. ADCP data from rigs at the wellhead imply that bottom currents flow in this direction and the sloping nature of the BFR and the fact that it appears to follow the topography implies that what we may be seeing acoustically is a water-mass boundary that has become the locus for concentration of oil particles. The highest values of fluorescence on both our leg and on the *Gordon Gunter* mission were found in proximity to this passage. It is important to note though that this same area is also the locus of a large number of natural seeps (Figure 20) that may also be contributing oil to the bottom waters. Until the chemical analyses of the water samples taken in the areas of high-fluorescence are complete, we cannot unequivocally say that the Deepwater Horizon well is the source of the acoustic or CTD signatures.

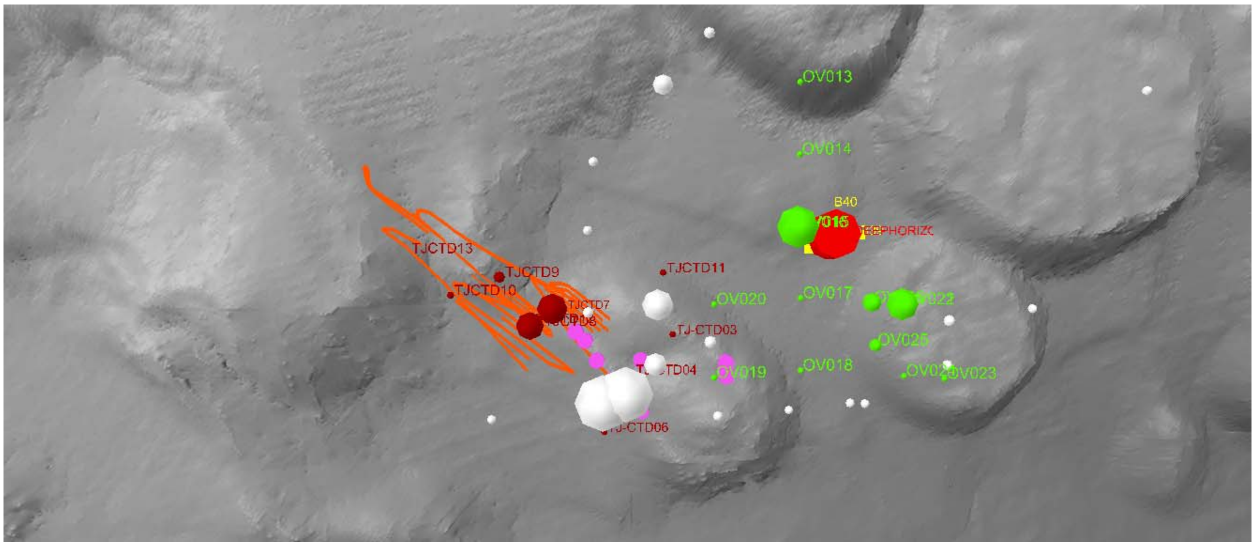


**Figure 19. Geographic distribution of BFR's (orange lines).
Note that they are clustered in along the western slope of the passage between two bathymetric highs that surround the well site (red cylinder).**

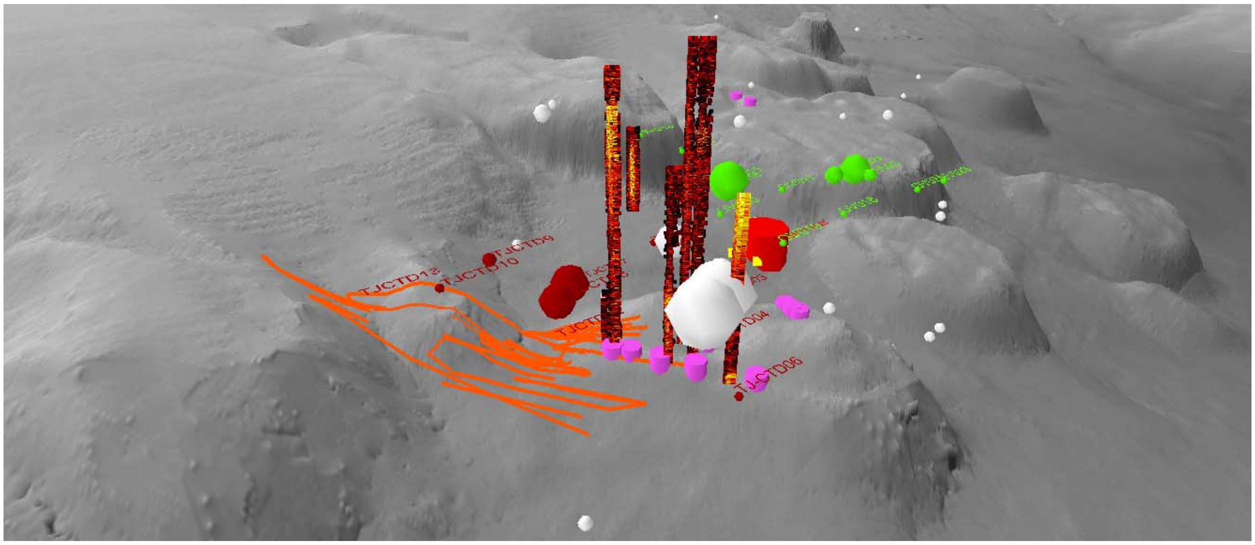


Figure 20. Natural seeps (red and yellow columns) mapped by *Thomas Jefferson*, and by *Gordon Gunter* (purple cylinders) along with CTD stations showing high fluorescence (brown, green and white spheres). Deepwater Horizon well site is in background (red cylinder) and distribution of Bottom Following Reflectors is represented by orange lines.

Anomalies on the 100m Coastal Transect

Shallow-water acoustics

In shallow water (i.e. during transects away from the spill site), the primary approach used to review the shallow-water ES60 acoustic data at sea was to 1) conduct a preliminary review of the acoustic data to identify anomalies, and 2) carefully review areas where the Moving Vessel Profiler observed subsurface areas of fluorescence with the Turner Designs crude oil sensor.

Backscatter in shallow water was often elevated compared to observations in deeper water, which may have masked weak signals. Although we observed apparent correlations with MVP fluorescence signals at times, these were not consistent: as the signal often persisted for longer or shorter distances than the MVP signals, or did not follow the changes in depth of the MVP fluorescence peak. A 400 kHz Reson 7125 multibeam system was also used periodically during the shallow-water work, but these measurements were not analyzed at sea due to time constraints. See Appendix V for configuration and data logging procedures.

While there is interesting structure evident in the fluorometer data in various places along the 100 m transect, there are four areas in particular that we wish to highlight for further work. In all the figures, the cylinders in the 3D scene are scaled and colored by maximum fluorescence deeper than 20m. There is a similar analysis available for the top 20m.

Area 1-South of Mobile Bay

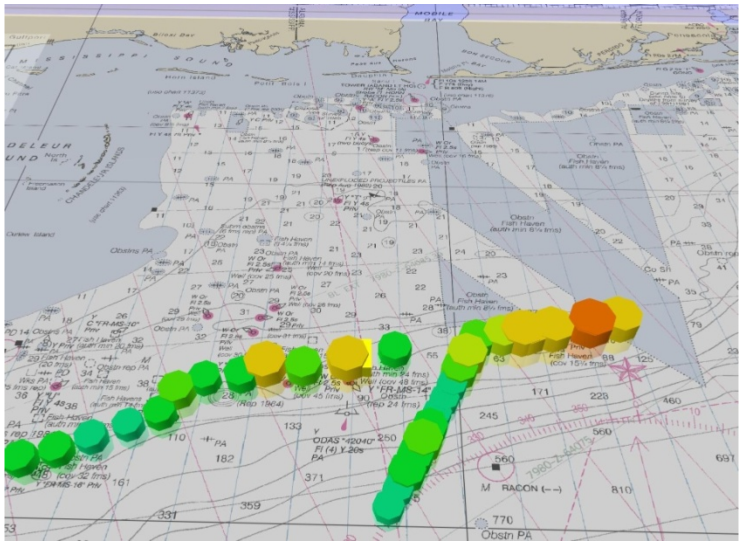


Figure 21. Orange cylinder to the east corresponds to the cast below.

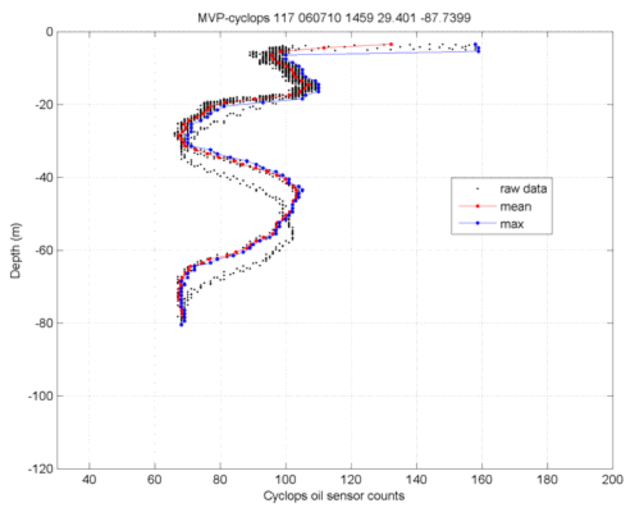
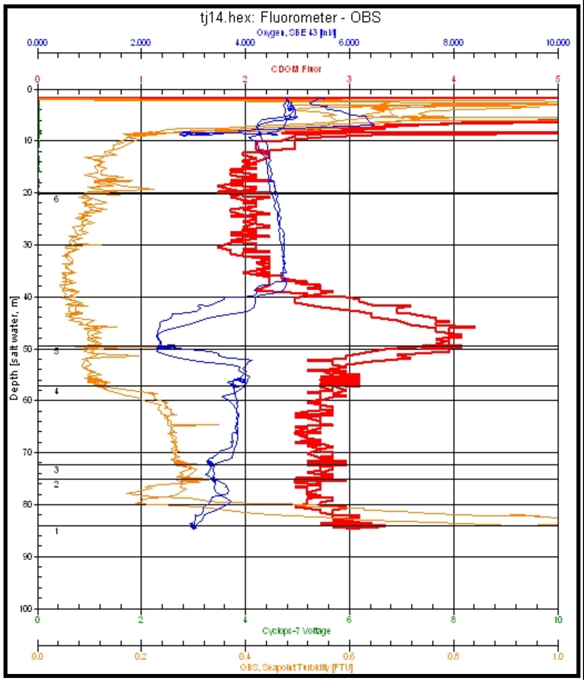


Figure 22. Fluorescence anomaly at 40-60m depth.

Area 2-CTD Comparison

Figures 23 and 24 shown example of a fluorescence anomaly observed with the MVP and a CTD Cast (TJ 14) with water samples. Water sampling locations noted by the horizontal lines on the CTD graph. The fluorescence anomaly corresponds to low dissolved oxygen.



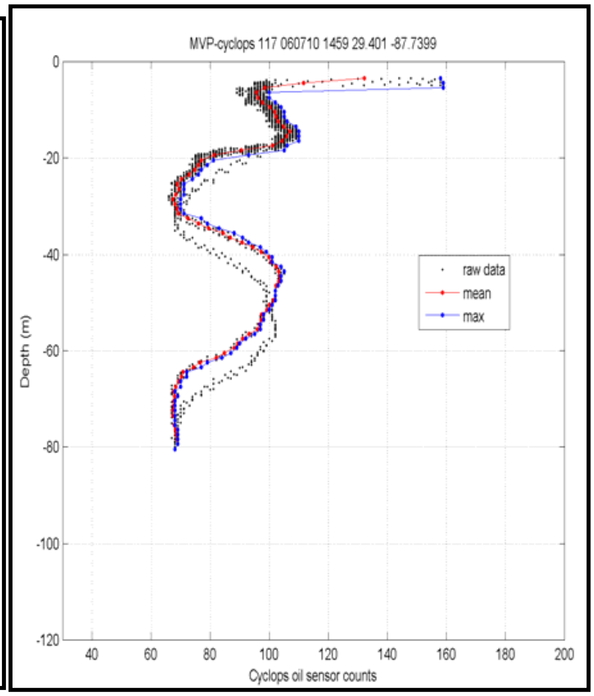


Figure 23. CTD cast in comparison area. **Figure 24. MVP Crude Oil Fluorescence.**

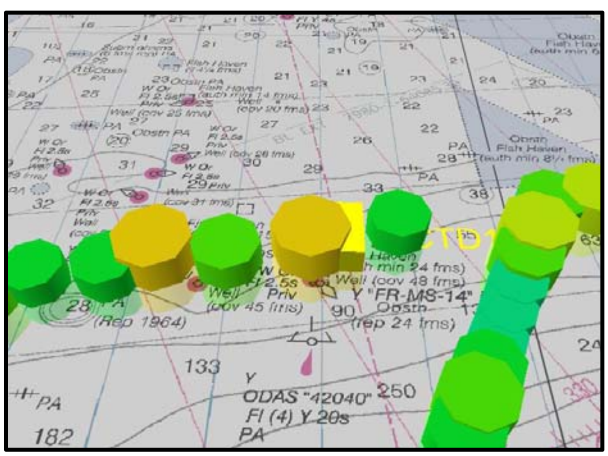


Figure 25. Location of comparison casts.*

*Note: The yellow square indicates the CTD cast location, and cylinders are the MVP locations.

Area 3 –Southwest Pass

The pink MVP cast in figure 26 corresponds to the cast information found in figure 27, which shows a marked peak in the fluorescence at about 20m depth.

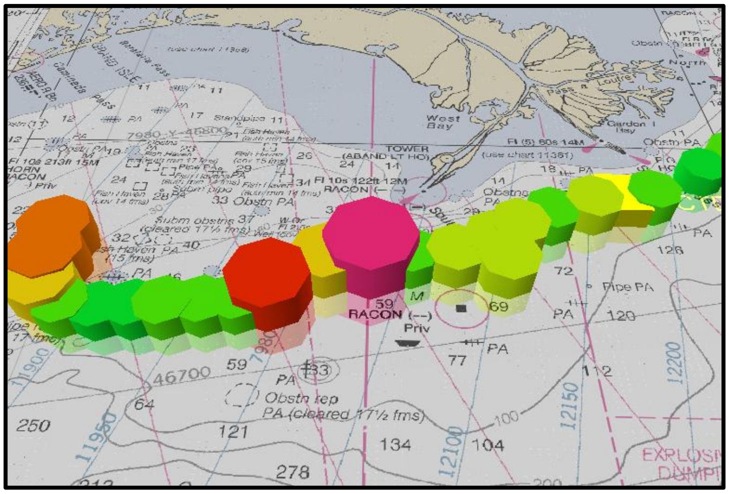


Figure 26. Location of anomaly off SW pass.

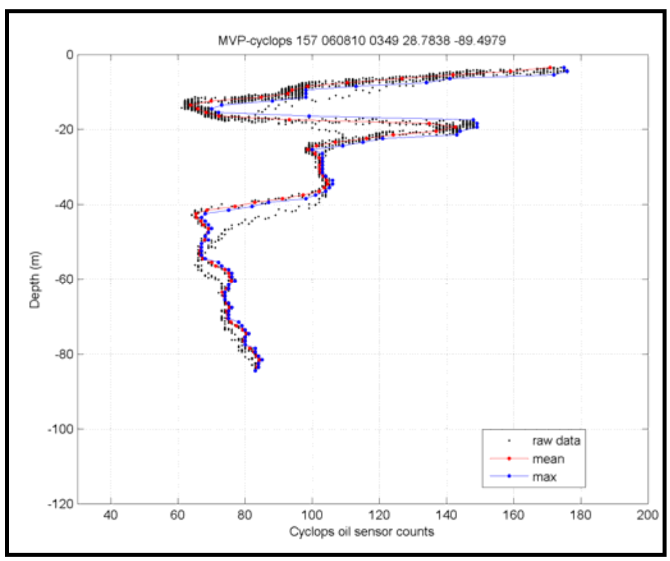


Figure 27. Fluorescence anomaly near SW pass.

Area 4-Furthest West Anomaly

The cast in figure 28 corresponds to the eastern of the two red casts shown in figure 29. This represents the furthest west anomaly observed, due south of the western end of Terrebone Bay.

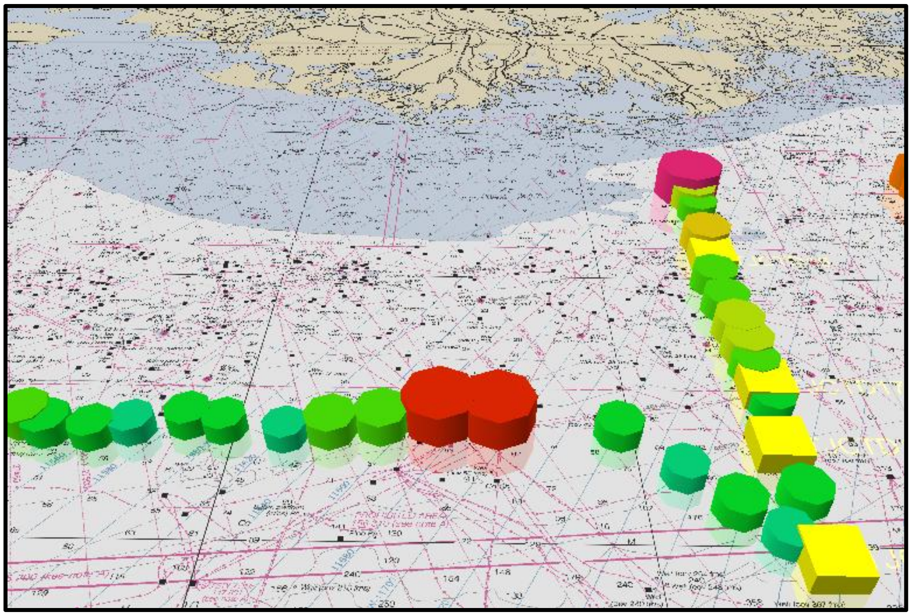


Figure 28. Westernmost Anomaly.

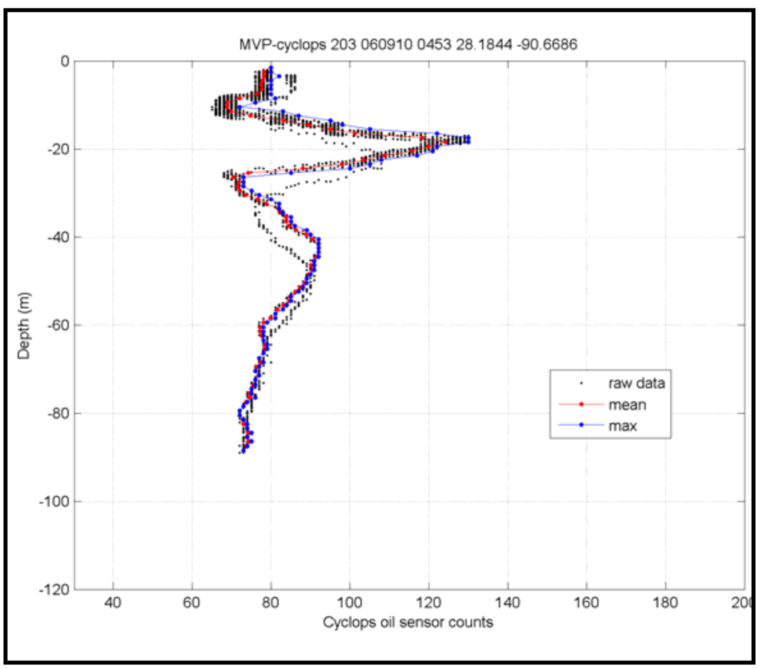


Figure 29. Fluorescence of westernmost anomaly.

Conclusions

CTD casts ~ 5 nmi from the Deepwater Horizon site indicate the presence of a layer at a depth of ~1100 m with high fluorescence, reduced dissolved oxygen anomalies, and high optical backscatter. This layer is extremely variable in space and time on time-scales on the order of days.

These measurements are consistent with reports from other vessels. The source of the layer requires chemical analysis of the water samples collected to confirm the source.

The presence of bottom-following reflectors may provide a mechanism to locate and sample these deep anomalies at the well site using acoustic methods, although this remains to be rigorously tested.

These reflectors may be indicative of the accumulation of dispersed oil or particles at water-mass boundaries and topographic steering of bottom currents.

Onboard data integration and visualization of disparate data, and communication with others on shore played a key role in successful execution of the mission.

The Moving Vessel Profiler allows for very efficient and dense sampling of shallow water (< 100m) and identification of high-fluorescence areas that may indicate the presence of submerged oil.

References

Foote, K.G. , Knudsen, H. P., Vestnes, G., MacLennan, D. N., Simmonds, E. J. 1987. Calibration of acoustic instruments for fish density estimation. A practical guide. ICES cooperative research report 144.

F.E Tichy, H Solli and H Klaveness 2003. Non-linear effects in a 200-kHz sound beam and the consequences for target-strength measurement. ICES Journal of Marine Science. 60(3):571-574.

Turner Designs, 2009 CYCLOPS-7 Submersible Sensors User's Manual. Turner Designs, 845 W. Maude Ave, CA. 20 pp.

Appendix I - Software

Visualization:

Fledermaus Professional 7.2.0 build 347

MVP:

Mvp V 2.351

Matlab R2007B (mvp data processing)

CTD:

Seabird Electronics software suite

Seasave V7

SBEDataProcessing-win32 (processing)

Singlebeam:

Simrad ES60 1.5.2.77 (acquisition)

Fledermaus Midwater 7.20 build 352 (processing)

Echo view 4.90 (processing)

Appendix II - Water Sampling Procedures

The following procedures were developed for crew of the NOAA Ship *Thomas Jefferson* (S222) operating within the Deepwater Horizon spill site.

Sampling Background

The NOAA Ship *Thomas Jefferson* was outfitted with a twelve Niskin bottle water sampling package. Sampling objectives included: (1) determining the concentration of oil compounds in the water column, (2) determining the source via fingerprinting, the degree of weathering, and background levels, (3) documenting exposure of water-column organisms and validating toxicity models, and (4) maintaining the integrity of the samples during sampling, transport and storage. Two independent sample analyses were collected from each Niskin bottle: (1) Volatile Aromatic Hydrocarbons (VAH/VOA/VOC/BTEX) analyzed by SIM GC/MS were collected in duplicate 40 mL preacidified, custody sealed vials and (2) Total Hydrocarbon (THC) by GC/FID were collected 1 in L amber bottles. All analysis of samples will be conducted at the established NRDA lab upon receipt of the shipped samples.

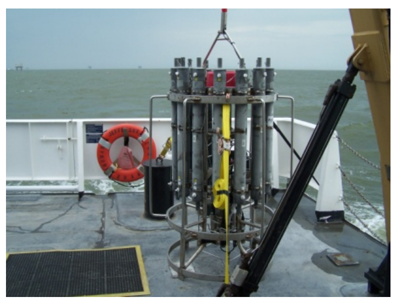


Figure 1. Water sampling package on stern of *Thomas Jefferson*

Sampling Equipment/Containers

VAH samples were collected, wearing clean Nitrile gloves, by pouring directly from the collection device's bottle spout. The spout was depressed and observed for leaks prior to filling the HCl preserved 40 mL septum-capped vials. The collector ensured that there was no headspace (i.e., bubbles) in the vial. THC samples were collected in glass, certified-clean to organic free, solvent rinsed amber 1 L containers. Water samples for THC samples were taken after VAH duplicate samples. Care was taken to leave one inch of headspace for all THC samples.

Figure 2. VAH and VOC sampling bottles

Sample Collection Method

Prior to each cast, Niskin bottles were decontaminated. Bottles were washed with fresh water, soaked with a Dawn/fresh water solution, rinsed with fresh water, rinsed with deionized water, and then soaked with deionized water for a minimum of ten minutes. A blank was drawn from the soaked DI water prior to deployment of the rosette. Stations were either predetermined or were a result of "interesting" data from other monitoring equipment. For each station, samples were drawn from "near surface" (approximately 1 m below the surface), and "near bottom" (approximately 5 m of the bottom). *In situ* monitoring helped to determine other depths of interest. Niskin bottles were lowered through the water column to depth in the open position and tripped closed upon reaching the desired depth on the trip back to surface. Surface slicks were cleared by propulsion from shots ahead on the engine to aid in minimizing contamination. Documentation was made of any presence of slicks, weather, wave conditions, etc., which might suggest mixing of oil during sampling. Other sources of contamination were recorded as well (exhaust fumes, rain, oily surfaces). Clean substrates were utilized for work and care was taken to segregate dirty and clean areas and replace materials frequently to avoid cross contamination.

Figure 3. Water collection

Sample Storage and Transport Method

VAH vials were grouped, placed in a Ziploc bag, secured by bubble wrap and stored at 4°C. THC bottles were sealed with silicon tape, Zip locked, secured by bubble wrap and stored at 4°C. Refrigerator temperatures were monitored throughout the day to ensure a steady and stable temperature. Each refrigerator had two thermometers for monitoring purposes.

Samples were packed on blue ice in large coolers just prior to chain of custody pick-up. Contents in each cooler were inventoried and documented. The coolers were sealed by the authorized custody party. Chain of custody was signed over during pick-up, and all associated paperwork and logs accompanied the samples.

Figure 4. Packaged samples

Appendix III - Decontamination Procedures

The following procedures were developed for crew of the NOAA Ship *Thomas Jefferson* (S222) operating within the Deepwater Horizon spill site.

1) Site Control was established on the fantail of the vessel to contain contamination to areas around operating equipment and minimize unnecessary tracking and exposure. Markings on the deck identified authorized work space restricting movement beyond the allowable area.

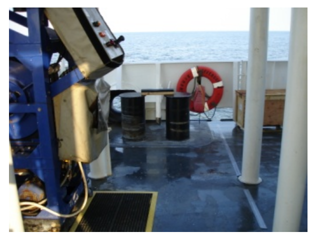


Figure 1 & 2. Isolated work spaces

2) Deck operations were isolated to two outside spaces of the fantail (MVP and CTD deployment and recovery) accessed via one entry and exit location.

3) Only essential, trained personnel in proper PPE were allowed in the operating space.

4) Operations existed in three regions:
    a. Region One: Area of working gear and exposure to elements

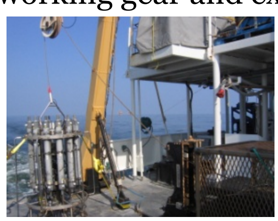


Figure 3. Region one

    b. Region Two: Decontamination station

Figure 4 & 5. Decontamination of gear in region two

- i. Hazmat gear pick up (outside staging):
    1. Gloves
    2. Rain pants
- ii. Oily waste bin for disposable soiled diapers, gloves, gear, etc.
- iii. Wash bin and scrubber for soiled boots, rain pants, gear etc.
- iv. Rinse bin for immediate use following wash
- v. Hanging station for drying washed/rinsed pants, gear etc. with diapers underneath to catch any run-off
- vi. Pressure washer available for aiding in wash down of gear

c. Region Three: Final Decontamination station (inside passageway)

Figure 6. Drying of gear in region three

- i. Bin lined with diapers for indoor drying and storage of washed/rinsed boots, gear, etc.

5) Equipment Operations:

a. Deployment of all equipment was timed such that surface water was clear of any oil. This was achieved by using a shot ahead on the engine to mix the surface water while simultaneously squirting Dawn soap to break up surface oil.
b. Instruments were recovered through a constant fog spray from the sea water fire hose ensuring that the wires were brought up through oil free surface water. As the instruments neared the surface a shot ahead on the engine cleared more of the surface water.

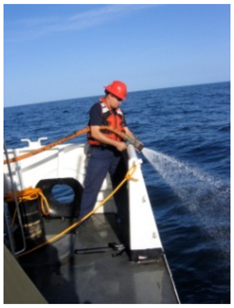


Figure 7. Spraying instrument during recovery

c. Once retrieved on deck, all instruments were decontaminated using soapy fresh water wash downs. The CTD bottles were washed down with fresh water and then filled with a fresh water Dawn soap mixture and allowed to soak until the next CTD. The bottles were drained prior to the next cast, rinsed with fresh water, and a blank water sample obtained from a deionized water procedure.

6) At the end of each day Region One was pressure washed minimizing the retention of liquid contaminants

Appendix IV - Instrument Field Calibrations

Crude oil sensor

The Turner Designs Cyclops crude oil sensor was calibrated using a quinine sulfate standard solution as recommended by the manufacturer (Turner Designs, 2009). The sensor voltage was measured with the sensor placed in standard solutions of 0.5 molar H_2SO_4 with quinine sulfate of 0, 10, 100, 1000 parts per billion (PPB). The sensors exhibited a linear response to the standard, and the MVP and CTD sensors exhibited a similar response (Figure 1).

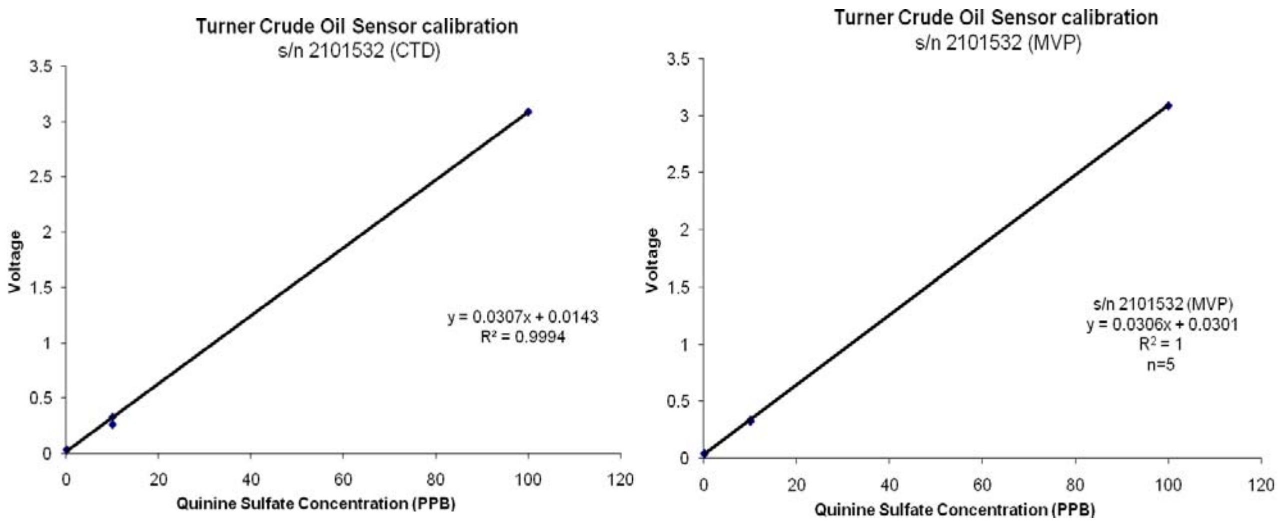


Figure 2. Results of calibration of Turner Designs Cyclops fluorometric crude oil sensor. The upper graph is for sensor used on the CTD, and the lower graph of for the sensor used on the moving vessel profiler (MVP).

ES60 echosounder: The ES60 echosounder was calibrated using the standard sphere technique (Foote, 1987) on June 9th. A 38.1 mm tungsten carbide sphere was used for the 38 and 200 kHz systems, and a 45 mm copper sphere was used at 12 kHz. Calibrations were conducted using the system settings used during data collection. These data could not be analyzed at sea due to time constraints.

Appendix V- Configuration and Collection Procedures Reson Seabat 7125 400kHz Multibeam Echosounder

NOAA Ship *Thomas Jefferson* is equipped with a Reson Seabat 7125 400kHz multibeam echosounder. The primary use for the sonar is to acquire high resolution multibeam bathymetry for nautical charting purposes. The 400 kHz system is designed for use in relatively shallow waters (<75 meters). The system can be configured to acquire 256 soundings per ping (256 beams) or 512 soundings per ping (512 beams). The beams can be configured for equi-angular or equi-distant beam spacing.

Backscatter from the Reson 7125 can be acquired in two different modes: sidescan or snippets. The snippet mode of backscatter focuses on the backscatter observed around the bathymetry solution and ignores any backscatter that is not closely associated with a bottom detection (e.g. fish in the water column). This method prevents noise from the water column from being included in the brightness values of the seafloor. This is important for things like benthic habitat mapping.

On *Thomas Jefferson*, the Reson 7125 data is logged in Hypack Hysweep in .hsx format. Reson 7125 data is converted in CARIS HIPS and SIPS. Navigation data and correctors such as heave, tide, and sound velocity are applied to the converted data during processing in CARIS.

For S-K919-TJ-10, the Reson 7125 was utilized in a completely different manner than the standard operating procedures used aboard *Thomas Jefferson*. Instead of tuning the sonar for bottom detection, the sonar was tuned and configured to log water column data. This was accomplished by selecting an additional message (7008 – Beam Data) in the “Set Filters” window accessed from the “Data Recording” tab in the main sonar display window. The sonar was configured to log “Compressed Mag Only” and “Sidescan”. Snippets were turned off.

The sonar display was set to high contrast and the gates were turned off. Power was set to maximum (220dB). Absorption was set to 110 and the spreading was set to 30. The ping rate was set to match the ping rate of the Simrad ES-60 transducers. Gain and range scale were adjusted periodically when there were large changes in bottom depth.

Data was logged directly on the Reson Transceiver Processing Unit (TPU) using the native Reson .s7k format. Data was logged in 15 second intervals every 15 minutes while the ship was surveying. No Reson 7125 data was logged during CTD/Water sampling casts.

The Reson data was converted in the FM-Midwater add-on tool for IVS3D Fledermaus. The Reson 7125 data does not have navigation information saved directly into the raw sonar data. Therefore, a navigation file in the form of an Smoothed Best Estimate Trajectory (SBET) file must be associated with each Reson 7125 file in order for FM-Midwater to process the sonar data. POSPac data logged from the POS/MV 320 ver4 were converted in POSPac MMS 5.3 to create SBET files.

Several times during acquisition of the Reson 7125 data, the configuration for snippets were observed to be checked when they were supposed to be un-checked. There was no apparent reason for the configuration to change. To mitigate further occurrence, the configuration was checked every 15 minutes prior to logging data.

During conversion in FM-Midwater, each file experienced an error and the program would terminate. IVS3D programmer Maurice “Moe” Doucet has been working closely with Thomas Jefferson personnel to troubleshoot the issue and update the FM-Midwater add-on to handle the problem. Early investigations indicate that the .s7k files have both water column and snippet data logged. This was unexpected by the FM-Midwater tool and caused it to crash. A new version of FM-Midwater is in the works and will be able to handle files that have both water column and snippet data. However, as a result of these setbacks, no Reson 7125 data has been analyzed for Leg 2 of S-K919-TJ-10.