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NOAA Ship Thomas Jefferson Deepwater Horizon Response Mission Report
Interim Project Report-Leg 3, June 15-July 1, 2010

Shepard Smith, Samuel Greenaway, Dennis Apeti, Larry Mayer, Thomas C. Weber, Alex De Robertis, Dan Wright, Mark Blankenship, Jasmine Cousins

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Background

The NOAA Ship *Thomas Jefferson* (TJ) was redirected from standard operations in response to the Deep Water Horizon oil spill. The response efforts included shallow water reconnaissance and deep water investigation for submerged oil. This report documents the initial results from the third leg of response work.

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

- Conduct reconnaissance for indications of submerged oil in the near coastal area.
- Investigate characteristics of submerged oil in the vicinity of the well head.
- Explore mechanisms for entrainment of oil within the water column.

Key Findings

- The acoustic echosounders used in this work did not cause interference with ongoing operations near the well head. Future acoustic work should be coordinated locally.
- Acoustic signatures that can unambiguously be attributed to the main oil plume have been observed close to the well head.
- Interpretation of the MVP mounted fluorometer is complicated by significant background signals, suspected interference from sunlight, and inconsistent detections in heavily oiled areas.

Scientific Staff

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

CDR Shepard Smith, Commanding Officer, Chief Scientist

LT Samuel Greenaway, NOS/UNH, data acquisition and analysis

Dr. Dennis Apeti, NOS/NCCOS, water sampling

Dr. Larry Mayer, Director, UNH/CCOM, off ship data review and analysis

Dr. Thomas Weber, UNH/ CCOM, off ship acoustic data review, analysis, and adaptive mission planning.

Dr. Alex De Robertis, NMFS/AFSC, off ship analysis, bioacoustics, data processing, custom scripting

CST Dan Wright, Chief Survey Tech, TJ

LT Mark Blankenship, Operations Officer, CTD Operations

ENS Jasmine Cousins, water sampling

Capabilities for Water Column Mapping

Fisheries Echosounders-12 kHz, 38 kHz, and 200 kHz-these sounders have a wide dynamic range appropriate for detection of scattering in the water column.

High resolution multibeam echosounder – 400kHz, 256 beam echosounder extends range of acoustic frequencies and allows characterization of small scale features.

Moving Vessel Profiler (MVP) 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.

Standard oceanographic CTD with water sampling rosette. The instrument is equipped with a CTD, Dissolved Oxygen, a CDOM fluorometer, and a turbidity sensor. The rosette contains 12 teflon-lined bottles. The winch has enough cable to cast to 1200m.

Daily Chronology

June 15-Depart Galveston 1500, transit south toward Flower Gardens Banks National Marine Sanctuary

June 16-Conducted four CTDs and water samples for baseline around FGBNMS, begin transect east

June 17-Begin Zig-Zag transects in the coastal zone with the fluorometer on the MVP, CTD casts with water samples every 4 hours

June 18-Zig-Zag coastal transect, Transfer samples ashore via crew boat near Port Fourchon

June 19-Zig-Zag coastal transect

June 20-Zig-Zag coastal transect

June 21-Alongside Pascagoula 1000-1800 for water, supplies, and sample transfer.

June 22-MVP and acoustic transect along 200m depth contour between wellhead and coastal zone

June 23-CTDs in sparsely sampled northern section

June 24-Begin acoustic work in rising plume as close as 1000m from the wellhead, spiraling outward to 3NM

June 25-Repeat 1 NM circular transect, additional acoustic work in and downstream of the rising plume

June 26-Last 1 NM circular transect. Transit to Pascagoula.

June 27-Arrive Pascagoula, MS. Water, supplies, and sample transfer.

June 28 – Depart Pascagoula, MS for Key West, continue alongshore acoustic transect

Configuration and Collection Procedures

Echosounder installation and operation

Simrad ES60

A Simrad ES60 single beam echosounder with hull-mounted transducers operating at 12, 38, and 200 kHz was operated continuously throughout the cruise (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.

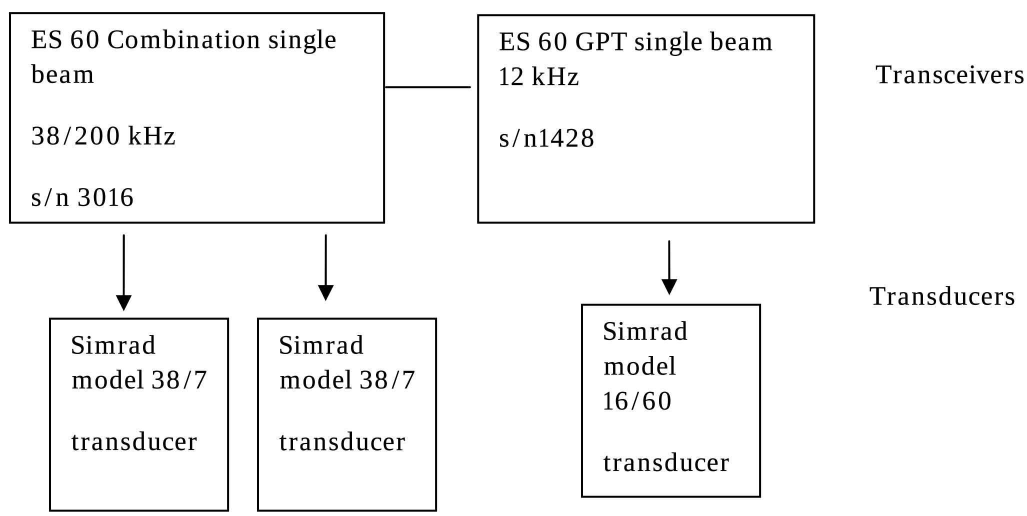

Figure 1: Block diagram of Simrad ES60 installation. Serial numbers for the transducers were not available.

The power values of the ES60 system 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 1-6.2 seconds) were used during data acquisition to reduce multiple returns in the trace. All timestamps were in UTC. Other interfering echosounders were turned off with the exception of the Reson 7125 multibeam sonar discussed below.

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 cruise to 0352 June 25, configuration A was used. This time period includes the first day of sampling in deep water near the Deepwater Horizon site.

Configuration B was used from 0352 June 25 until 1035 June 27 while sampling in deep water near the Deepwater Horizon site until arrival at Pascagoula, MS.

Configuration A was used from June 28 until the end of the cruise. This period was a direct transit from Pascagoula, MS to Key West, FL along a coastal route.

Reson 7125

A Reson 7125 multibeam echosounder was also used for water column backscatter measurements. This system is mounted on the hull of the Thomas Jefferson and operates at a center frequency of 396kHz. This system was operated intermittently throughout this project because of the high data volumes when acquiring water column data. From the beginning of the cruise until June 23, an attempt was made to acquire 15 seconds of data every 15 minutes. Additional data was acquired over regions of acoustic interest.

The system was operated exclusively in the in the 256 beam, equi-angular mode. Efforts to trigger this system off the ES60 were unsuccessful, and some interference between the systems was observed when both systems were operated concurrently. Generally, the ping rate of the 7125 was set to 3 pings per second (pps) while the ping rate of the ES60 was set from 0.16 – 1 pps. Because the 7125 was pinging at a much higher rate than the ES60, the interference from the ES60 transmission, while clearly present in some data records, is not present in most of the 7125 records.

The range scale was set to either just include or to completely exclude the seafloor. Power was generally kept at maximum (220 dB), and the gain at approximately 56 dB. Time varied gain parameters were an absorption setting of 90 and a spreading coefficient of 20. The ship's installed flow-through sound velocity sensor was not operated due to concerns of oil contamination. Sound velocity from the MVP system was periodically monitored and manually input to the 7125 control system. Because of this manually updated procedure, large surface sound velocity errors are likely with some data records. Position, attitude, and time were input into the system from the POS MV via serial cables.

Data was logged in the Reson s7k data format. Sonar settings and positioning information are included in data records within this format.

Because of concerns of acoustic interference from this system on the ES60 in the deep water near the well head, the use of this system was limited. However, two passes directly over the rising plume were recorded with this system.

Data Processing – Echosounder

The ES60 (*.raw files) and 7125 (*.s7k) output files were processed with the Fledermaus midwater tool. The ES60 data were displayed as echograms of volume scatter (S_v), and were examined for relevant features and anomalies. The 7125 data were displayed as echograms of power. Only limited processing of the 7125 data has been achieved as of the submission date of this report.

The acoustic backscatter was examined during acquisition via the ES60 display software and following acquisition through the Fledermaus midwater tool. Real-time acquisition monitoring and on-board processing was done by LT Greenaway and the survey department of the *Thomas Jefferson*. The data was also uploaded to an FTP server in near real time and was analyzed by Dr. Tomas Weber at the University of New Hampshire. The results of this analysis were used to adaptively guide the data acquisition strategy.

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 on the stern, 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 (left), and Multisensor Freefall Fish (right)

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

The SV&P Smart Sensor is one instrument housed on the MVP free fall fish. It is designed to directly measure sound velocity and pressure in water.

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 both depth and sound speed.

Figure 3: 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 band pass emission filter tuned to 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 response time of the Cyclops7 is 300 microseconds. (Turner Designs, 2010)

Figure 4: Turner Cyclops 7 Fluorometer

Data Acquisition Methods

Prior to mounting the Cyclops7 into the MSFFF, a 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 depths between 50 and 200 m while underway at speeds from 5 to 9kts. MVP casts were initiated approximately 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 both the down cast and the up cast.

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.

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 monitoring and review was performed using Velocipy, a program developed by the Hydrographic Systems and Technology Branch of the Coast Survey Development Lab. This program allowed near real time comparison of sensor data with previous casts and geographic display of results. Further analysis was done with a MATLAB script. This script extracted position, depth and fluorescence data from the raw data files. The raw data were averaged into 1m bins for each cast. The data was exported to a Fledermaus-compatible file and viewed as a georeferenced curtain by linearly interpolating between measurements. An example of this display is shown in Figure 5 below.

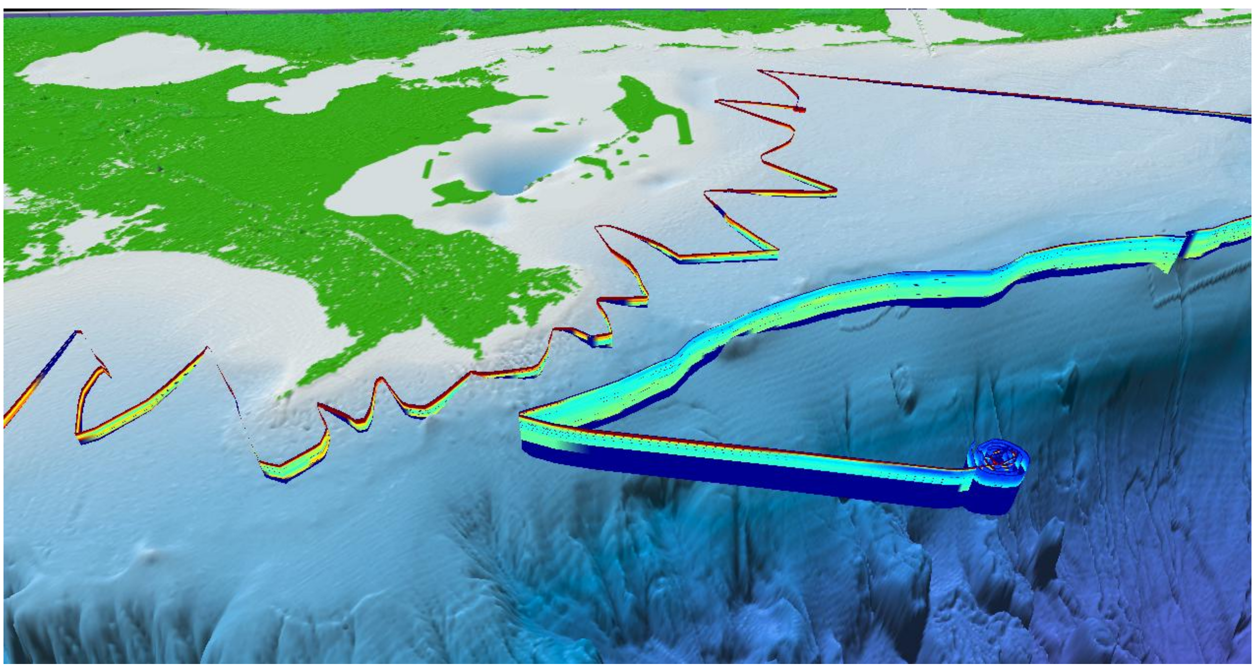

Figure 5: Curtain view of MVP fluorometry data near Mississippi Delta. Vertical scale is exaggerated by a factor of 50. Red colors are high readings, blue are low, deep blue indicates lack of data. Background data is from GeoMapApp.

Moving Vessel Profiler – Significant Data Issues

Two significant issues were discovered with the MVP fluorometer data. One is apparent interference from sunlight and the other is a lack of detection of oil even when the sensor was towed directly through a plume of fresh surfacing oil near the wellhead.

Possible Sunlight Interference

During the up-cast, the vertical velocity of the sensor fish in the upper water column is significantly lower than on the free fall down-cast. This results in a higher vertical data density and a smaller effect from any instrument latencies during the up-cast. A plot of depth against time is shown in Figure 6. Because the speed of the ship through the water was constant during this casts the slope of the curve is directly proportional to the vertical velocity.

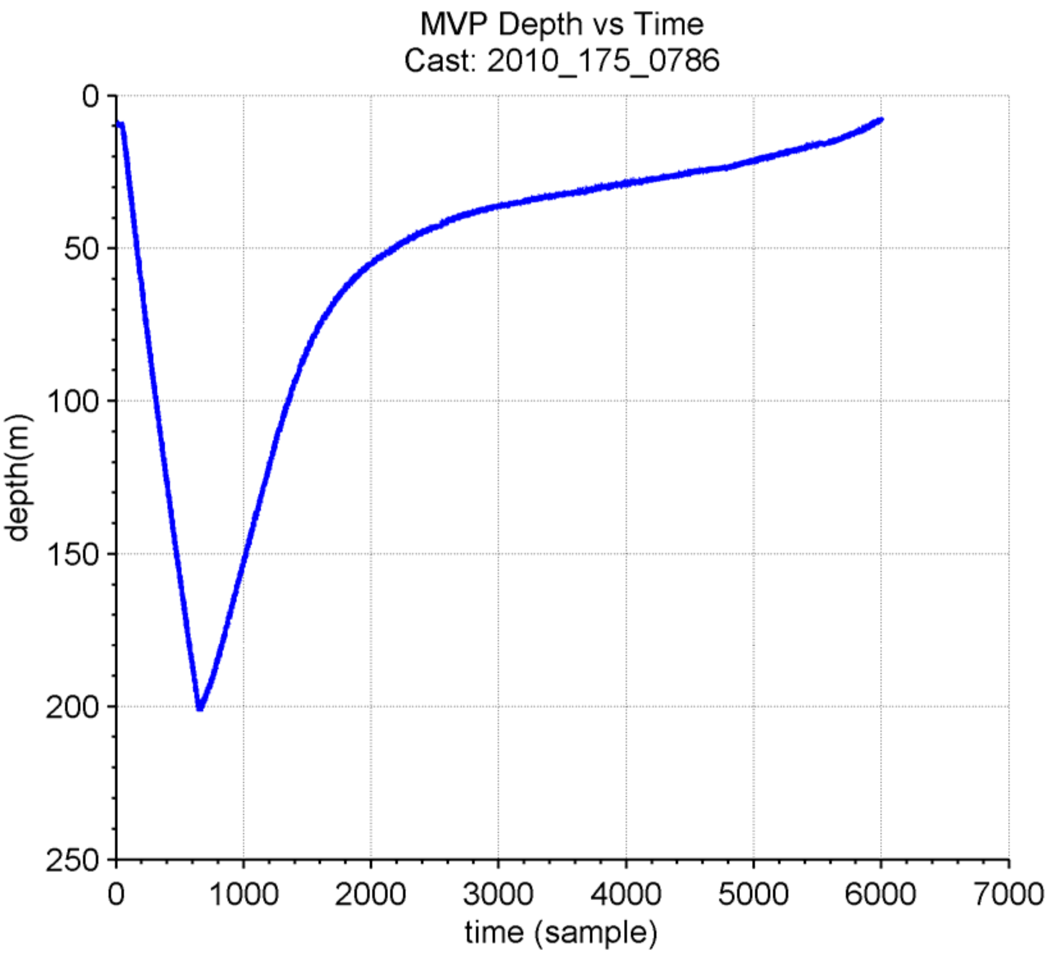

Figure 6 - Depth vs Time for successive MVP casts

In order to take advantage of this higher data density and reduced latency effect in the upper water column, only the up-cast data was initially analyzed. However, anomalous readings were detected on some up cast data that were not present in the down cast data. An example of this anomaly is shown in Figure 7. Fluorescence units as presented are arbitrary because calibration values or system gains have not been applied. This upper water column anomaly in the up-cast is suspected to be due to the interference of sunlight on the UV detector.

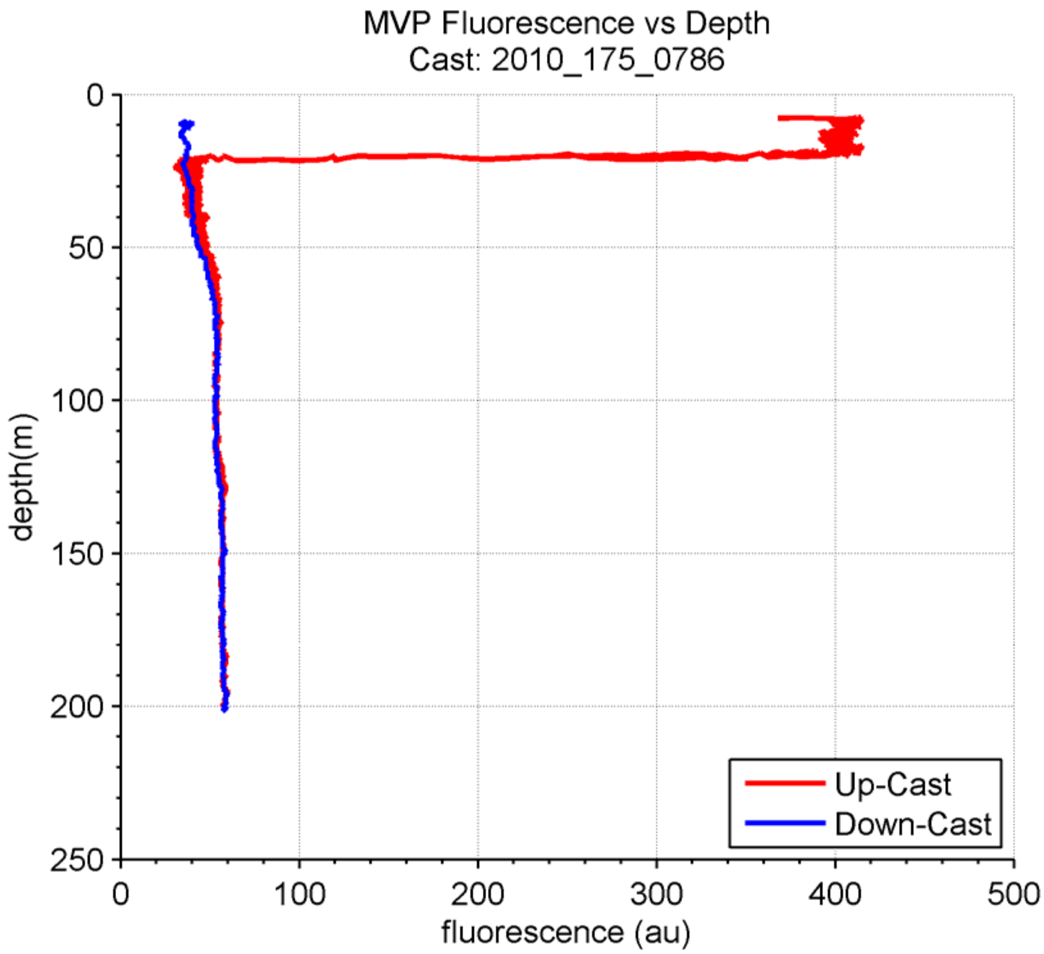

Figure 7: Anomalous reading on up-cast of MVP mounted fluorometer not present in down-cast.

Anomalously high readings were duplicated with the instrument body on deck by pointing the instrument at the sun. This effect was most conspicuous in the clear, offshore waters. An example of the processed up-cast with this artifact is shown in Figure 8. Data acquisition was from 1949 June 24 to 0344 June 25 (UTC). Sunset was at 1054 UTC. The vessel tracks were clockwise, and the inner two circuits were conducted during daylight hours. The outer circuits were done after sunset. The instrument would have been pointed generally towards the setting sun during the up-cast at the southern part of the circuit.

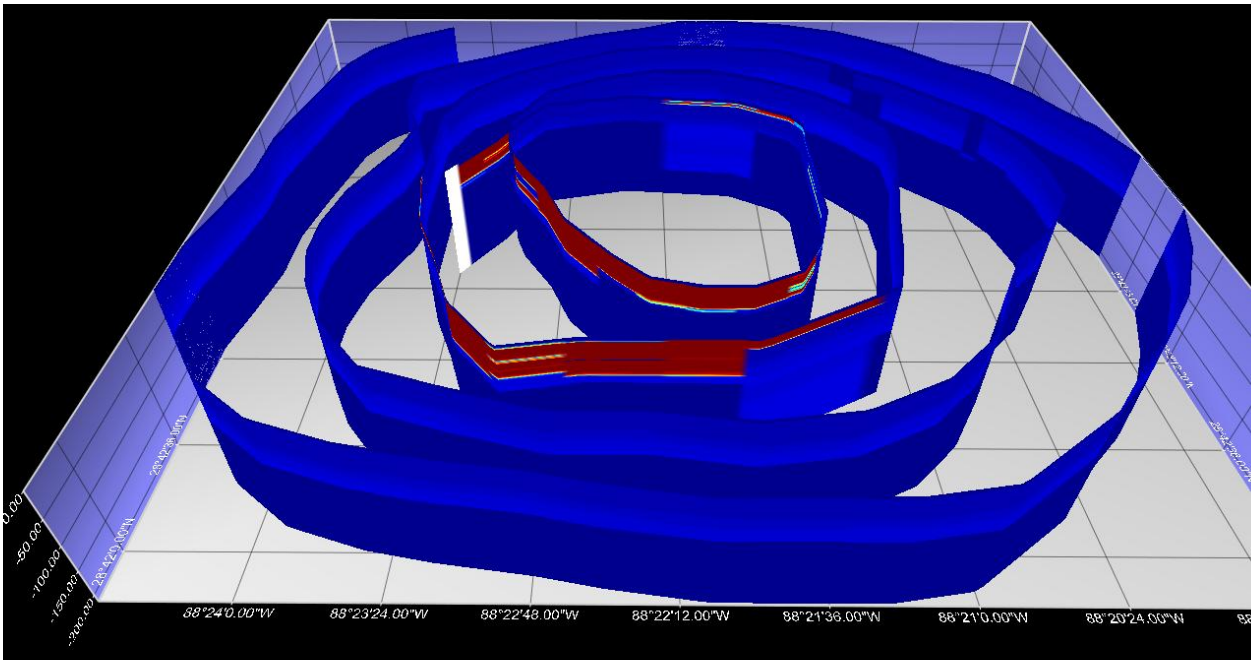

Figure 8: Curtain plot of up cast MVP fluorometry data in vicinity of wellhead. Vie is towards north. Red colors indicate high readings, blue colors indicate low readings. Note large surface anomaly in inner circuits. This is thought to be caused by interference from the sun.

This effect may also have an impact on down-cast data through latency of the instrument. Figure 9 shows the up-cast and down-cast data for a cast that has an anomaly on both the up-cast and down-cast. While the sensor is not pointed toward the sun on the down cast, the high signal in the upper 20m of the down-cast data may be due to the settling time of the instrument. From a cursory analysis of the data, this effect is only seen when the preceding surface values were high.

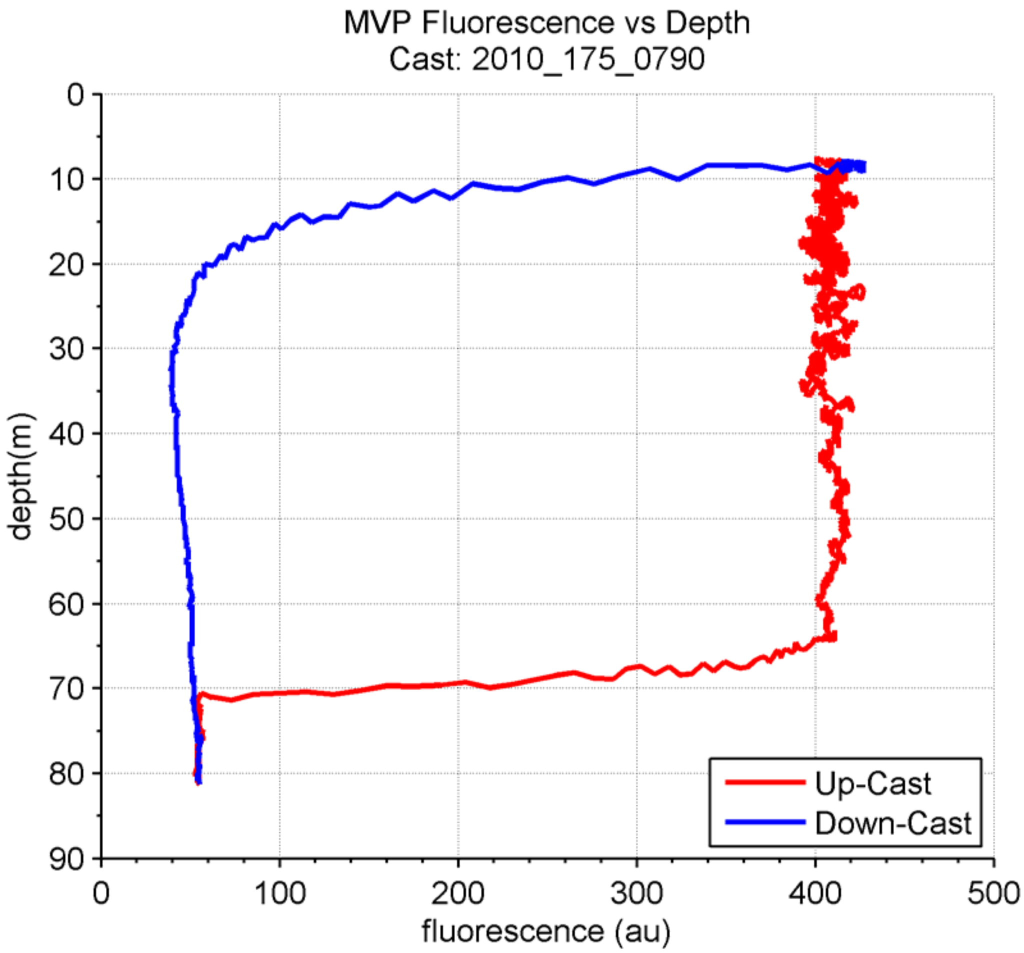

Figure 9: Near surface fluorescence anomalies in both up-cast and down-cast data. Up-cast anomaly is suspected to be due to sunlight. Down-cast anomaly may be due to system latency.

While this reasoning is speculative, all near surface data acquired with this system during daylight hours should be viewed with caution. The processed data shown in Figure 5 was made from downcast data only. In addition, data from the upper 10 meters of the water column was excluded.

Detection of Oil

Another concern with the MVP fluorometer is the apparent lack of response when the instrument was towed through a region of obvious high oil concentration. Figure 10 shows the acoustic detections on the rising oil plume from the 200kHz ES60 over-plotted on the MVP fluorometer curtain display. The MVP mounted fluorometer does not appear to register any increase in signal when towed through the surfacing oil plume.

The high values on the surface on the inner two circuits seem to be associated with the latency related anomaly discussed above.

Following the observation of this effect, the response of the sensor was tested in accordance with the manufacturer's instructions. The instrument was responsive to material placed in front of the lens. The instrument was further tested with an onboard sample of the surface oil. The instrument was responsive to the oil sample when the instrument was pointed at and lowered into the oil and water sample.

An explanation for this result is elusive. There was clearly oil present in the water column. It may not, however, have been dissolved or dispersed enough to register a response on the fluorometer. Alternately, the configuration of the MVP may preclude accurate measurement due to cavitation of the face of the instrument, saturation of the instrument, or some other factor.

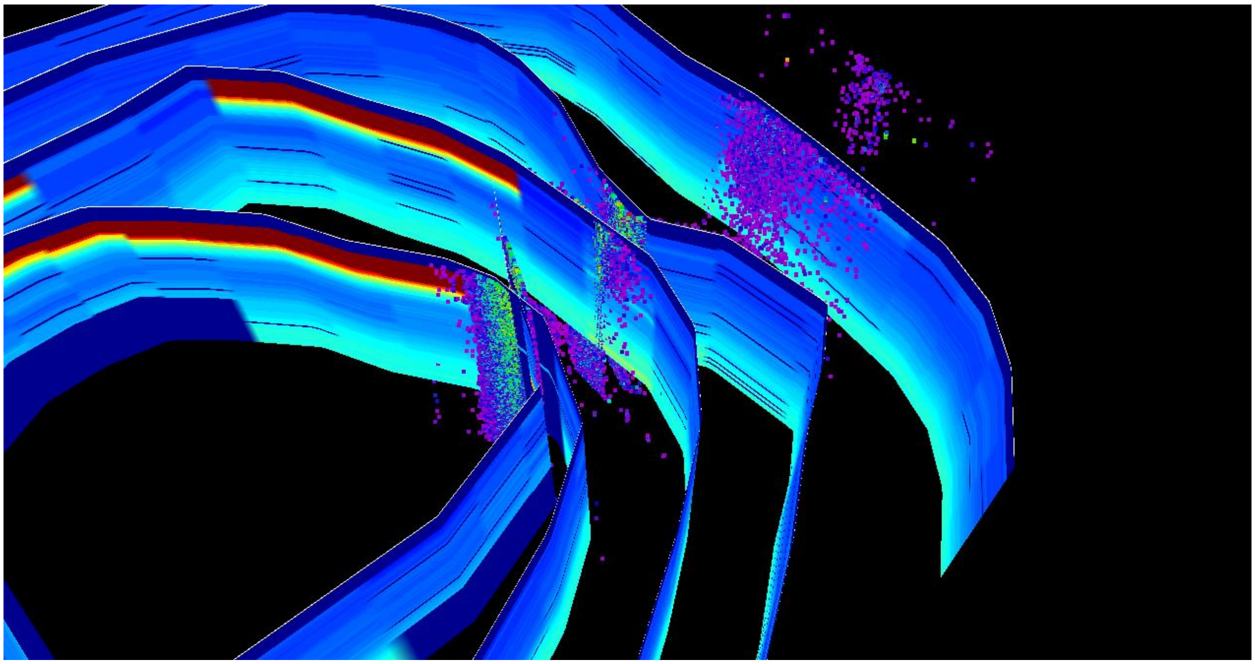

Figure 10: Acoustic oil plume detection over-plotted on concurrent MVP fluorometer data. Acoustic detections are shown by points. View is to the southwest and lines were run in a clockwise fashion. The fluorometer does not appear to register the oil plume.

CTD Operations

The Woods Hole Oceanographic Institution (WHOI) supplied the NOAA ship *Thomas Jefferson* with CTD equipment. WHOI technical personnel operated this instrument during the previous cruise. During this cruise, on board personnel operated this equipment.

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
SBE 11+ Deck Unit
Seabird conductivity sensor (SBE-O4)
Seabird fast response temperature sensor (SBE-03F)
Seabird dissolved oxygen sensor (SBE-43)

Wet Labs CDOM fluorometer (CD2000)-borrowed from AOML
Seapoint Turbidity Sensor
Seabird Model 32 pylon
12 ea. 4 liter Niskin bottles
Altimeter-Benthos PSA9160

A Turner fluorometer was also installed, but no connectivity to this instrument was possible due to a defective voltage channel on the Seabird and the instrument was removed. The CTD transmits real time data through the 3 conductor .322” armored cable to the deck unit. 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 was stopped and a 4 liter Niskin bottle was fired to trap a water sample. This was repeated at various depths up to 12 times. Once back aboard, the water samples were drawn under strict guidelines to preserve 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.

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Table 2 shows the date, time, and location of all the CTD casts. Summary comments regarding the data are also included. Water samples were taken on each cast. Where the maximum depth was less than 200m, samples were generally taken at near bottom depth, 120m, 100m, 80m, 60m, 40m 20m 5m and near surface. In some cases, this sampling interval was modified to capture water samples near anomalies in the fluorescence or dissolved oxygen sensors. Where the maximum depth was greater than 200m, samples were generally taken at near bottom depth, 1000m, 750m 500m, 250m, 100m, 50m, 25m, 7m, and near surface.

Table 2: CTD Cast locations

Station	Date	UTC Time	Latitude (dd mm.mm)	Longitude (ddd mm.mm)	Comments
tj26	16-Jun-10	10:01	27 59.99 N	093 43.04 W	No signal from Fluorometer
tj27	16-Jun-10	12:14	27 55.51 N	093 32.05 W	No signal from Fluorometer
tj28	16-Jun-10	14:25	27 54.55 N	093 41.67 W	
tj29	16-Jun-10	15:46	27 46.60 N	093 40.15 W	
tj30	17-Jun-10	2:07	28 12.02 N	093 00.18 W	
tj31	17-Jun-10	5:39	27 58.13 N	092 43.25 W	
tj32	17-Jun-10	9:29	27 50.72 N	092 16.72 W	
tj33	17-Jun-10	14:08	27 53.61 N	091 37.91 W	
tj34	17-Jun-10	18:03	27 54.93 N	091 12.00 W	
tj35	17-Jun-10	22:26	27 55.17 N	091 18.45 W	
tj36	18-Jun-10	2:12	28 04.71 N	091 05.23 W	
tj37	18-Jun-10	6:06	28 22.69 N	090 50.82 W	
tj38	18-Jun-10	10:14	28 28.90 N	090 29.27 W	
tj39	18-Jun-10	14:19	28 42.90 N	090 16.58 W	
tj40	18-Jun-10	18:33	28 51.73 N	090 09.39 W	
tj41	18-Jun-10	22:17	28 37.98 N	089 57.51 W	
tj42	19-Jun-10	2:27	28 42.62 N	089 12.56 W	NMEA Position not in file
tf43	19-Jun-10	6:51	29 06.49 N	089 50.68 W	NMEA Position not in file
tj44	19-Jun-10	10:00	28 49.75 N	089 44.24 W	NMEA Position not in file
tj45	19-Jun-10	14:22	28 58.11 N	089 44.47 W	
tj46	19-Jun-10	18:01	28 48.43 N	089 40.36 W	
tj47	19-Jun-10	22:14	28 53.34 N	089 30.75 W	
tj48	20-Jun-10	2:04	28 51.93 N	089 21.04 W	
tj49	20-Jun-10	6:13	28 56.16 N	089 09.79 W	
tj50	20-Jun-10	10:12	29 08.25 N	088 55.67 W	
tj51	20-Jun-10	14:20	29 13.97 N	088 46.13 W	
tj52	20-Jun-10	17:36	29 13.83 N	088 37.40 W	
tj52	20-Jun-10	17:58	29 13.86 N	088 37.07 W	
tj53	20-Jun-10	22:39	29 24.24 N	088 41.86 W	
tj54	21-Jun-10	2:10	29 31.93 N	088 29.61 W	
tj55	21-Jun-10	5:59	29 52.59 N	088 37.10 W	
tj56	21-Jun-10	10:15	29 52.13 N	088 27.90 W	
tj57	22-Jun-10	7:16	29 49.16 N	087 31.34 W	
tj58	22-Jun-10	9:44	29 44.01 N	087 13.74 W	Intake blocked- all pumped data bad
tj59	22-Jun-10	14:34	29 33.74 N	087 19.48 W	
tj60	22-Jun-10	19:46	29 21.14 N	087 38.88 W	

tj61	22-Jun-10	22:46	29 16.81 N	087 48.47 W	
tj62	23-Jun-10	2:30	29 15.08 N	088 04.95 W	
tj63	23-Jun-10	6:16	29 10.52 N	088 29.21 W	
tj64	23-Jun-10	10:32	28 57.72 N	088 48.74 W	
tj65	23-Jun-10	14:35	28 49.31 N	089 06.19 W	
tj66	23-Jun-10	23:09	28 46.28 N	088 21.79 W	
tj67	24-Jun-10	5:21	28 48.17 N	088 22.73 W	
tj68	24-Jun-10	10:18	28 49.01 N	088 18.29 W	
tj69	24-Jun-10	14:33	28 49.05 N	088 20.00 W	
tj69	24-Jun-10	17:03	28 49.09 N	088 20.03 W	
tj70	25-Jun-10	8:11	28 49.97 N	088 20.04 W	
tj71	25-Jun-10	23:17	28 43.50 N	088 25.20 W	
tj72	26-Jun-10	8:01	28 42.42 N	088 25.63 W	

Results

Results from Near Shore Areas

CTD and MVP Data

The shallow water area on the shelf is complex. In deeper water, high fluorescence with associated lowered dissolved oxygen has been interpreted as being a possible indicator associated with submerged oil at depth.

In the near coastal area, the usefulness of this indicator is complicated by high background signal. Substantial amounts of fluorescent organic matter are deposited into the northern Gulf of Mexico from the Mississippi, Atchafalaya, and other rivers. Additional fluorescent organic matter is produced from marine sources (Chen and Bada, 1992). Boehme et al. (2004) have shown that the composition as well as the temporal and spatial distribution of this fluorescent material is highly variable throughout the northern Gulf of Mexico.

Dissolved oxygen has also been studied in relation to hypoxia and the associated Gulf of Mexico “Dead Zone”. Rabalais et al. (2002) have shown that the variability of dissolved oxygen is also complex and variable in space and time.

This report does not seek to address fluorescent organic matter in the water column or hypoxia except to caution against interpretation of either fluorescence or dissolved oxygen anomalies as being conclusively indicative of submerged oil. As an example, two plots of fluorescence and dissolved oxygen as a function of depth are shown in Figure 11. Both are from an area roughly east of the Mississippi river delta and were taken within 30 nm of each other. One of the casts was taken from in 2009, before the Deepwater Horizon incident. The other was taken during this cruise.

It is clear that anomalous looking spikes in fluorescence and significant signals in dissolved oxygen have been seen in this area prior to the Deepwater Horizon incident. This does not mean that any anomalous results are not the result of submerged oil, but it does indicate that careful analysis will be required to separate effects.

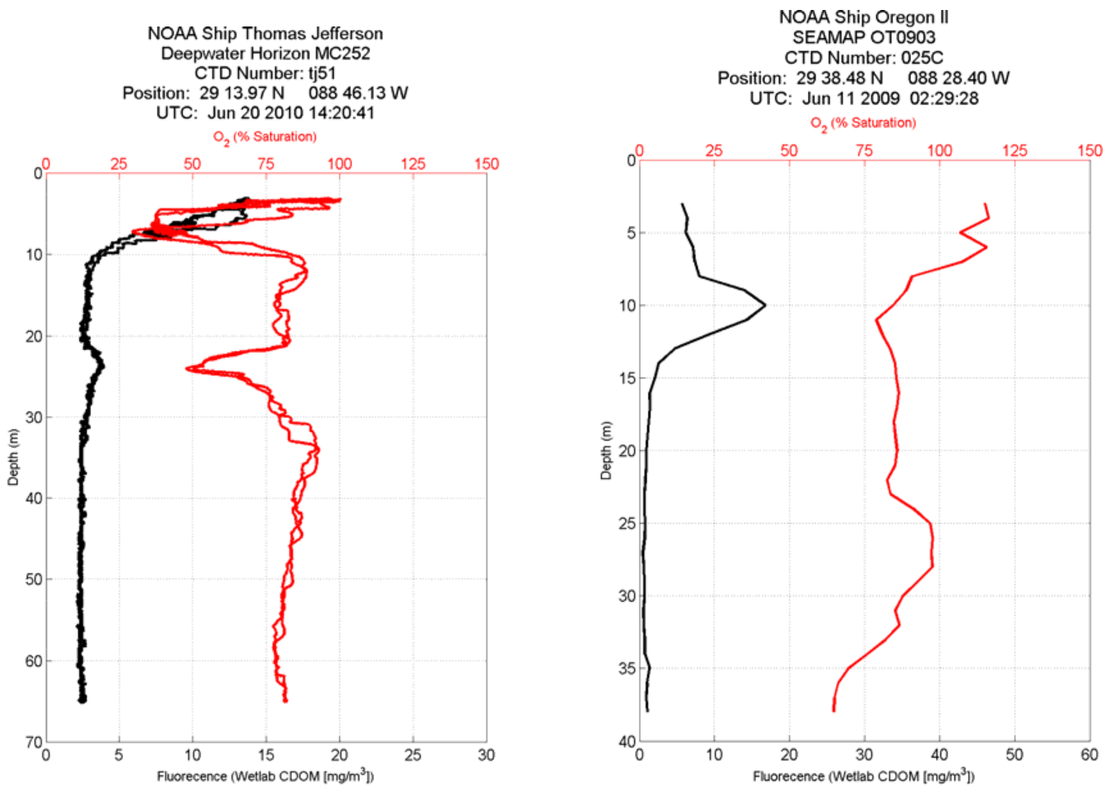

Figure 11: Two casts taken east of the Mississippi river delta. The data on left is from this project. The data on the right was acquired in 2009. The casts are within 30nm of each other. Fluorescence and dissolved oxygen signals have been measured in this area that are not related to the Deepwater Horizon incident.

Acoustic Results

As with the CTD and MVP data, the acoustic signals in the near shore area are complex. There is significant structure in the near shore area, much of which likely due to biology. The biological signal is likely highly variable in both space and time.

In one area west of the Mississippi Delta there may be a connection between the acoustic return and a possible hypoxic area. Under the assumptions that the acoustics return from the water column is largely due to scattering from biological organisms (Urick, 1983) and many organisms avoid hypoxic areas (Rabalais et al., 2002) it is reasonable to expect that hypoxic areas may exhibit a reduction in acoustic scattering. Figure 12 shows the location of the CTD and acoustic data and Figure 13 shows the dissolved oxygen data plotted against the acoustic signal. The data are suggestive that the low acoustic scattering and reduced oxygen levels may be related.

Similar use of acoustics to delineate oxygen deficient areas has recently been demonstrated by Bertrand et al (2010) off the coast of Peru.

This reasoning is speculative and the data sparse. In addition, the intent of this cruise was certainly not to investigate hypoxia and the instruments and methods are likely not optimized for this task.

While the connection between acoustic scattering and possible hypoxia is intriguing, it is brought up here primarily as an example of the complexity of the near shore area.

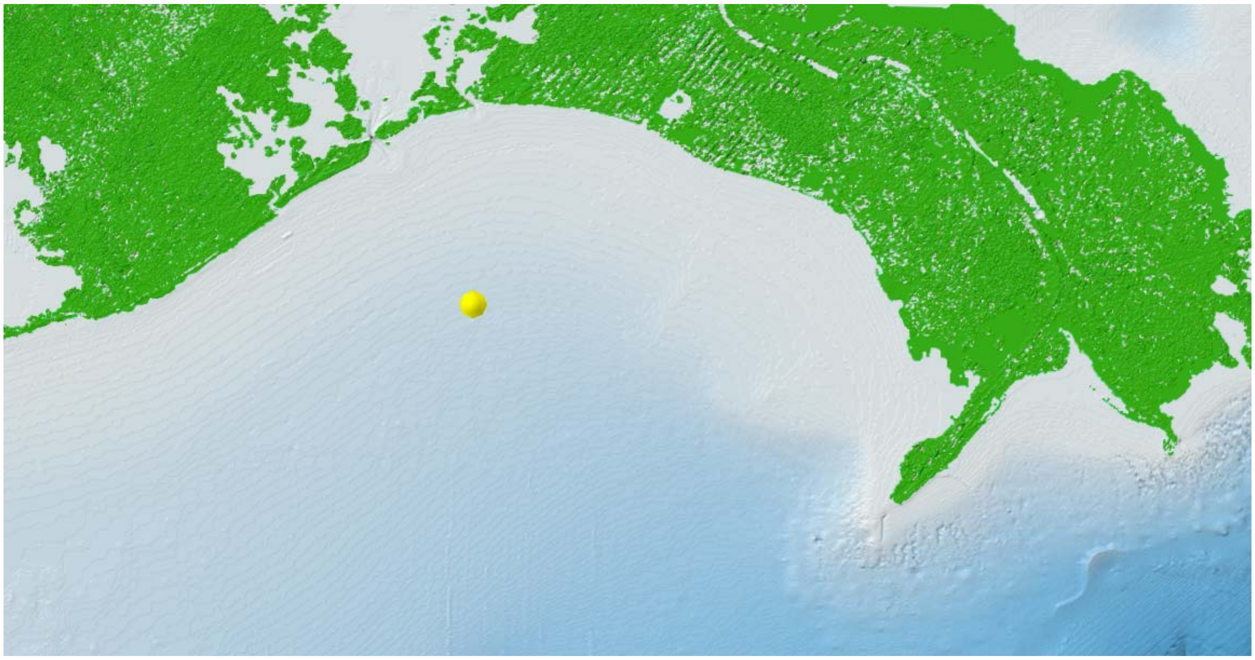

Figure 12: Location of TJ CTD station 43.

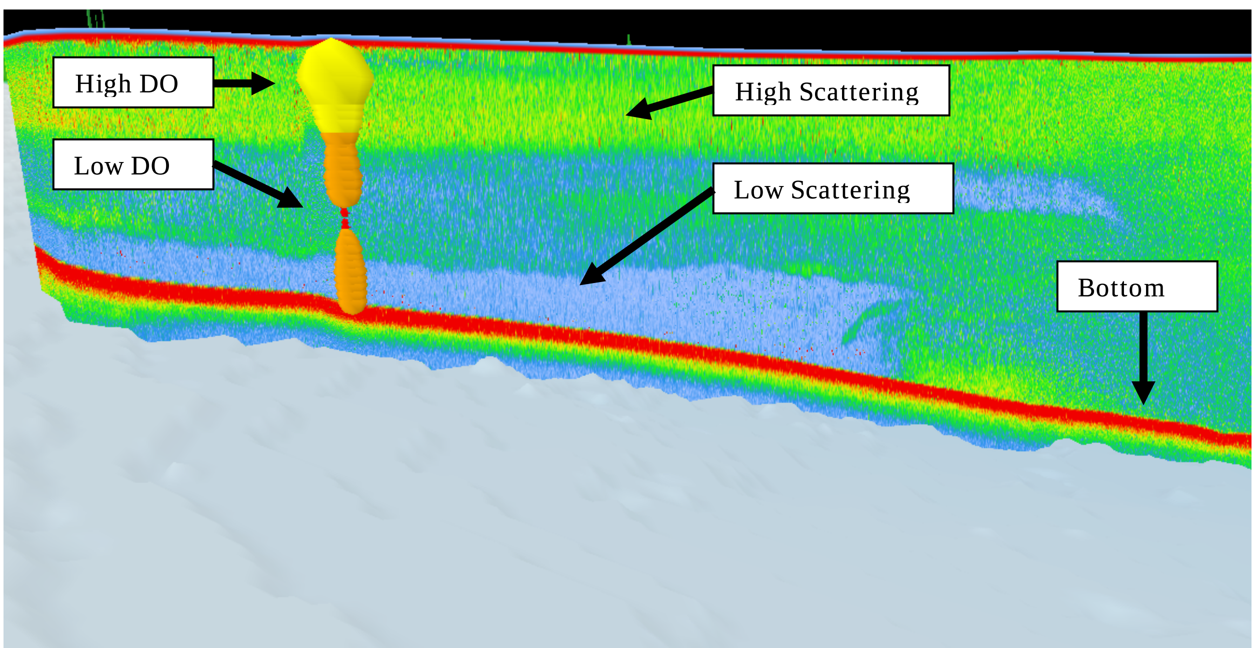

Figure 13: Dissolved oxygen from TJ CTD station 43 plotted against 200kHz volume scattering. Size and color of points corresponds to dissolved oxygen (DO). Low DO is small and red.

There are many other acoustic signals in the near shore area, but the most plausible explanation for these signals following cursory analysis is likely biology.

Results from Near Well Head

CTD and MVP Data

The data issues with the MVP mounted fluorometer have been discussed previously. These issues, apparent sunlight interference and apparent lack of detection of surfacing oil, were not discovered until the vessel was near the well head. The water near the well head was generally much clearer than that further inshore. This may have exacerbated any sunlight interference. The apparent lack of detection of surfacing oil was only apparent when the sensor was deployed in surfacing oil near the well head.

Acoustic Data

The acoustic data in the vicinity of the wellhead is significantly different from earlier *Thomas Jefferson* and *Gordon Gunter* missions in that the ship was allowed much closer to the incident location. The closest pass was approximately 2 km from the well head. This access allowed direct acoustic measurement of the rising plume of surfacing oil as well as acoustic measurements of deeper of deeper waters that had interacted with the rising plume.

Acoustic based measurements had been restricted from the area near the well head due to concerns of acoustic interference with ongoing operations at and near the well head. During this mission, direct communications between the *Thomas Jefferson* and the on-scene operations coordinator (SIMOPS) and the platforms operating remotely operated vehicles (ROV) was established. Plans were put in place to immediately cease acoustic operations on board *Thomas Jefferson* if any interference were detected. Following discussion of system specifications with SIMOPS, no interference was expected by either party. During operations, no interference by the *Thomas Jefferson* on operations was noted at any time.

The surfacing plume of oil was observed in the 200kHz ES60 record. Figure 14 shows both the acoustic trace and a track-line plot. The surfacing plume is clearly visible in the acoustic record and corresponded to visual observations of fresh, surfacing oil near the ship. This surfacing plume was not apparent in the 38 kHz or 12 kHz records.

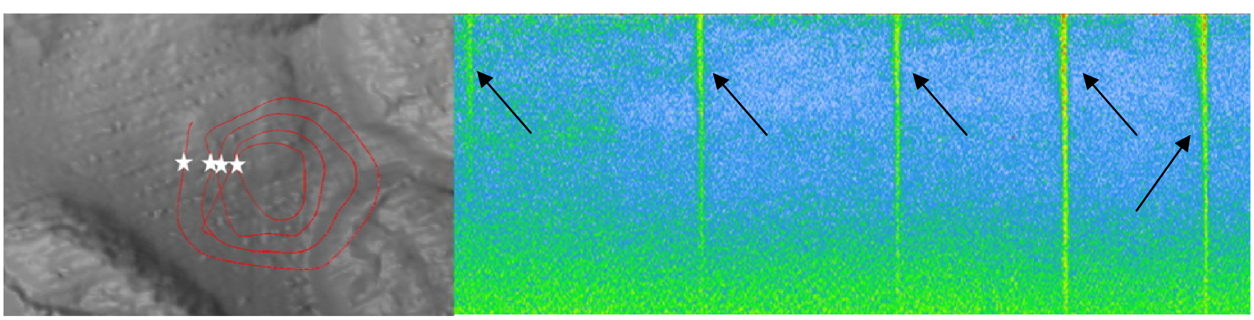

Figure 14: 200kHz record over surfacing oil plume during spiral transect. Image on left shown track around incident location; stars indicate plume location. Image on right shows 200kHz volume scattering strength. Horizontal axis is time, vertical axis is depth. The vertical features are the top of the rising plume, on the spiral transect. The plume crossing closest to the wellhead it to the right, the furthest out is to the left.

The volume scattering strength extracted from the data directly in the surfacing plume is shown in Figure 15. The scattering was generally observed to decrease away from the well head. If we assume that the composition of the surfacing oil is constant across these samples, this result could be explained by the concentration of oil droplets decreasing with distance, the size of the oil droplets decreasing with distance, or both.

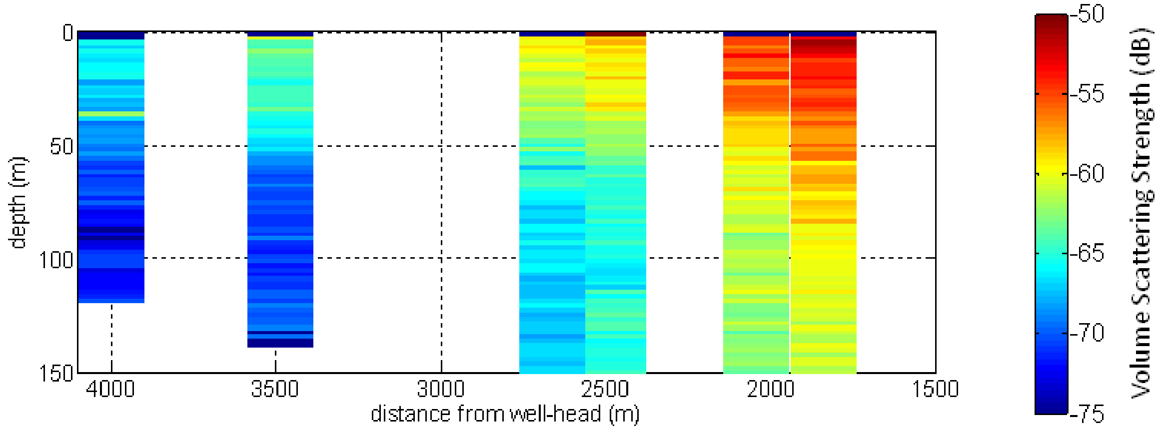

Figure 15: 200kHz volume scattering strength of the surfacing oil plume.

Under the assumption that the size of the oil droplet is small compared to the wavelength of sound (Rayleigh scattering approximation) the differential scattering cross section of a droplet is proportional to the fourth power of the acoustic frequency and the sixth power of the droplet radius (Medwin and Clay, 1998).

$$\Delta\sigma \propto f^4 a^6$$

Because of this strong frequency dependence, the target strength of a given droplet at a lower frequency will be substantially less than target strength at a higher frequency. Target strength is defined as the logarithm of the differential scattering cross section.

$$TS = 10\log_{10}\Delta\,\sigma$$

Taking a calculated 200kHz volume scattering strength of -55dB from one of the upper, inner passes, we would expect the volume scattering strength to be approximately -84dB at 38kHz and -104 dB at 12kHz. These values are close to if not below the noise floor of the lower frequency systems on the *Thomas Jefferson*, so the lack of detections at 38kHz and 12kHz is not unexpected.

The rising plume of oil also was very evident in the 396kHz Reson 7125 multibeam data. Following cursory analysis, there was no small scale structure apparent in the plume at scales of less than 100m.

Significantly, if the size distributions of the surfacing oil droplets were known, the volume fraction and thus the total volume of surfacing oil could be independently estimated from these measurements.

Though the lower frequency acoustic systems were unable to resolve the surfacing oil plume, they did reveal substantial structure throughout the water column that are suspected to be related to the oil plume. An image of this signal is shown in Figure 17.

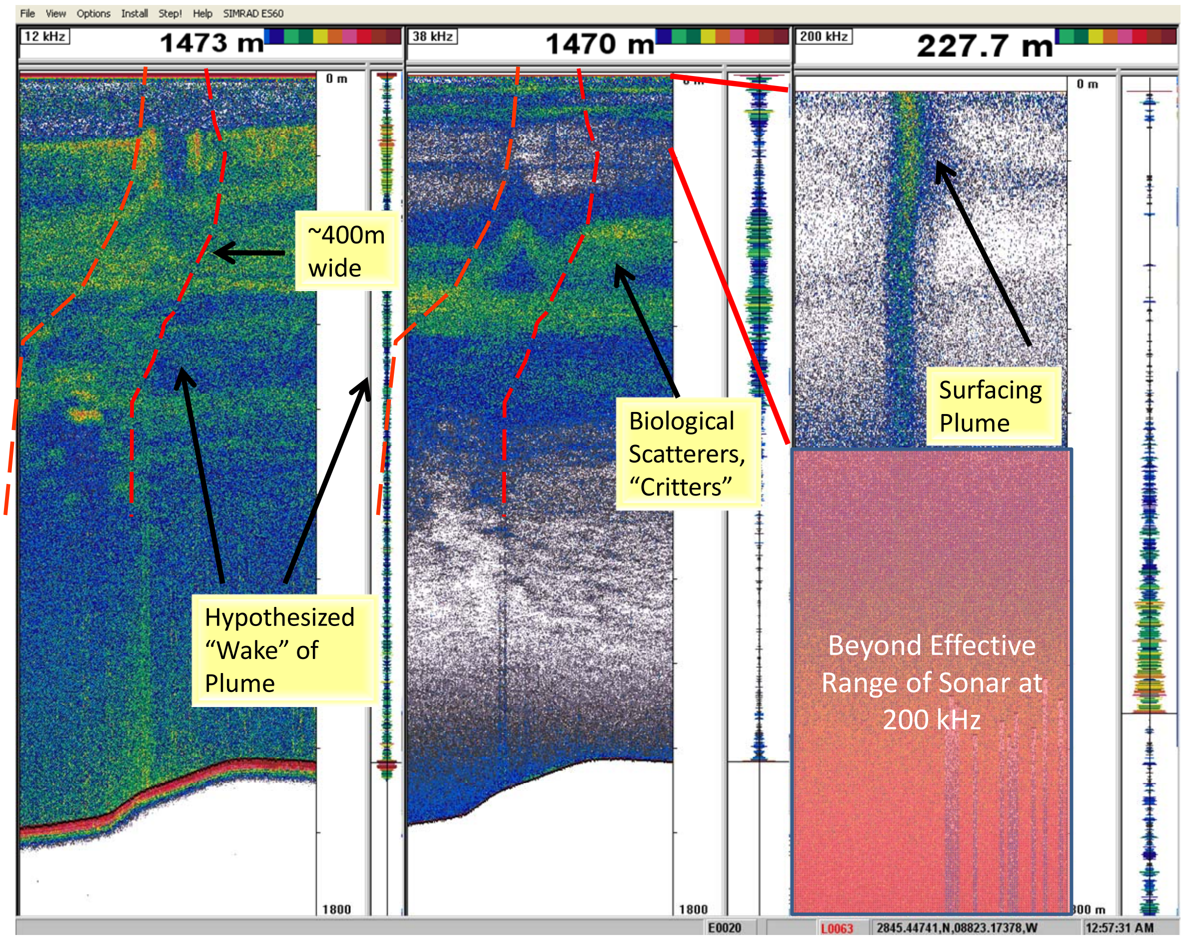

Figure 16: Acoustic transect across surfacing plume and possible disruption to biological scatterers downstream of the plume. The panel on the left is from the 12kHz system, the center panel is 38kHz, and the right panel is 200kHz. The horizontal scales of each panel are time, the vertical scales are depth. Note that the vertical scale of the right panel is six times the scale of the other panels.

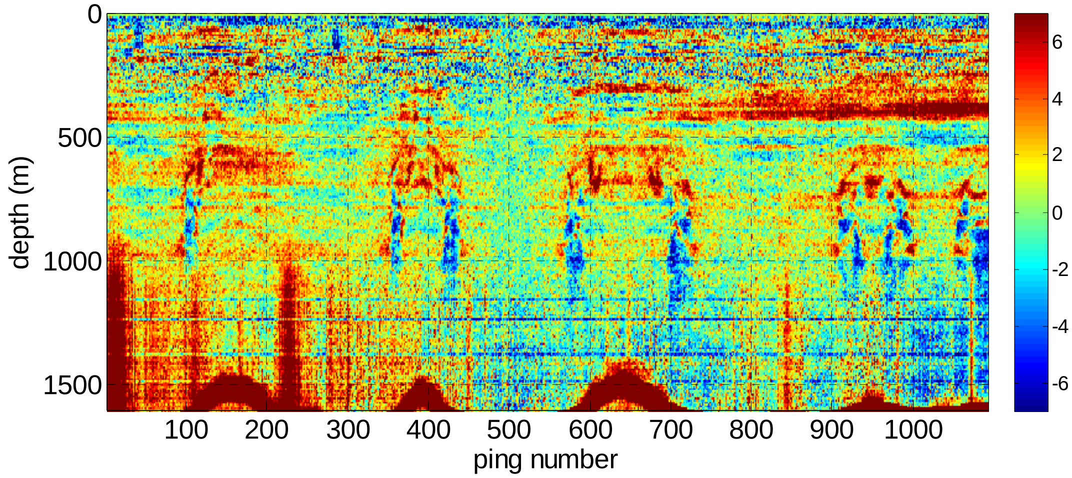

Figure 17: 12kHz anomaly west of well head. Background has been removed. Data is series of passes orthogonal to current direction, moving away from well. Units are scattering volume strength change from background.

Figure 18 shows portions of the same data presented in a geographically registered fashion. In these presentations, we are looking east towards the well head. The current at the time was flowing generally to the west.

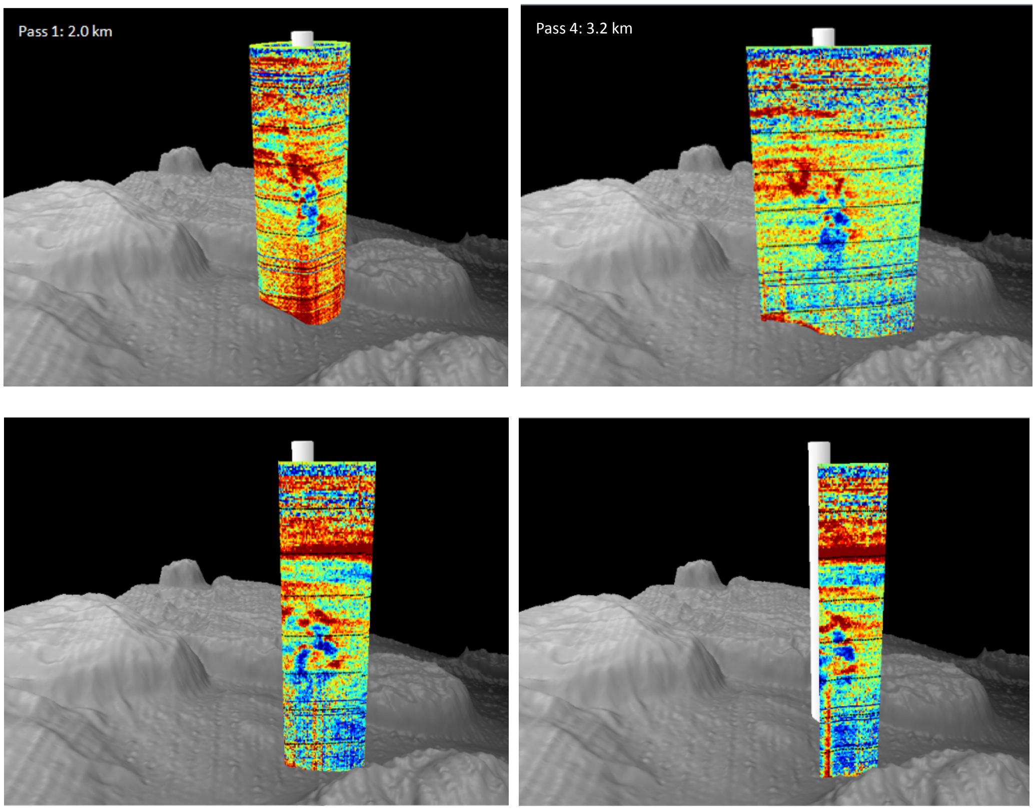

Figure 18: 12kHz anomaly west of well head viewed geographically registered. The well head is represented by the white cylinder. Distances from well head are (clockwise from upper left): 2.0 km, 3.2 km, 4.8 km, 5.8 km.

A CTD cast was taken through the center of this anomaly at a distance of approximately 5.8 km from the well head. A standard plot of the CDOM fluorescence and dissolved oxygen is shown in Figure 19. There is a fluorescence anomaly at 1100m. This cast is shown plotted against the 12kHz acoustic data in Figure 20.

The fluorescence anomaly is located at the base of the acoustic anomaly, but there does not appear to be elevated fluorescence throughout the acoustic anomaly. This suggests that the acoustic anomaly is not comprised of oil, but may be indicative of the passage of oil through the water column. As the surfacing plume passes through the layers of biology it may disturb the layers through turbulence, active avoidance, vertical advection, or a combination of effects. If this anomaly can be thus viewed as a wake of the main plume of oil going to the surface, it then marks the area in the water column that has interacted with this rising oil. If any oil is stabilizing at depth or otherwise leaving the main plume, it should then be located within or near this acoustic disturbance.

If this interpretation is correct, this suggests that similar acoustic results may allow much more precise targeting of sampling activities than current methods.

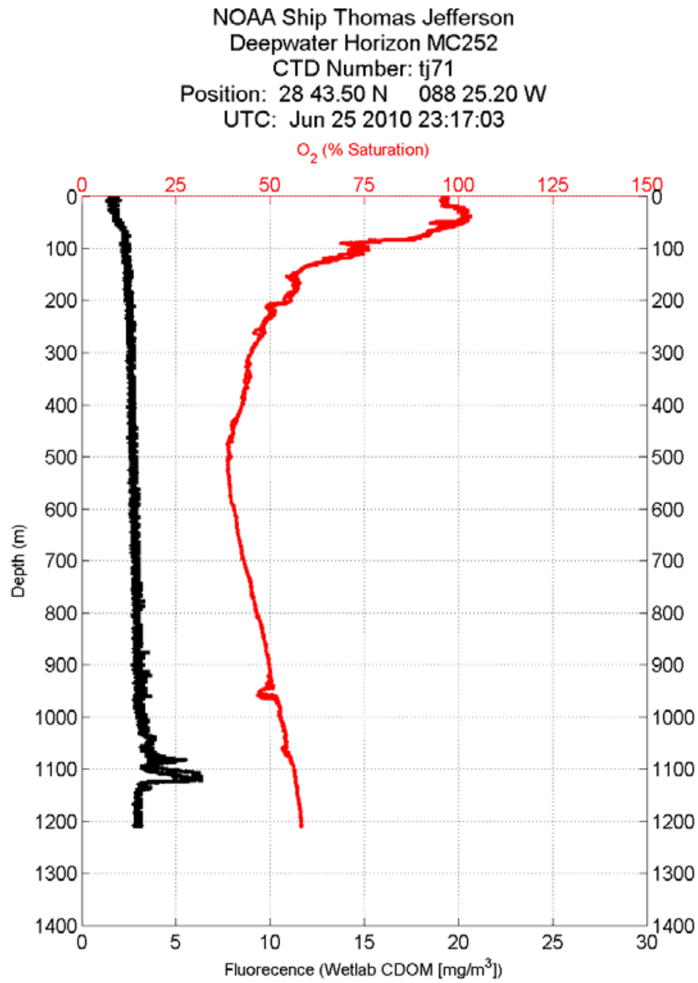

Figure 19: CTD cast TJ71 taken through base of acoustic anomaly.

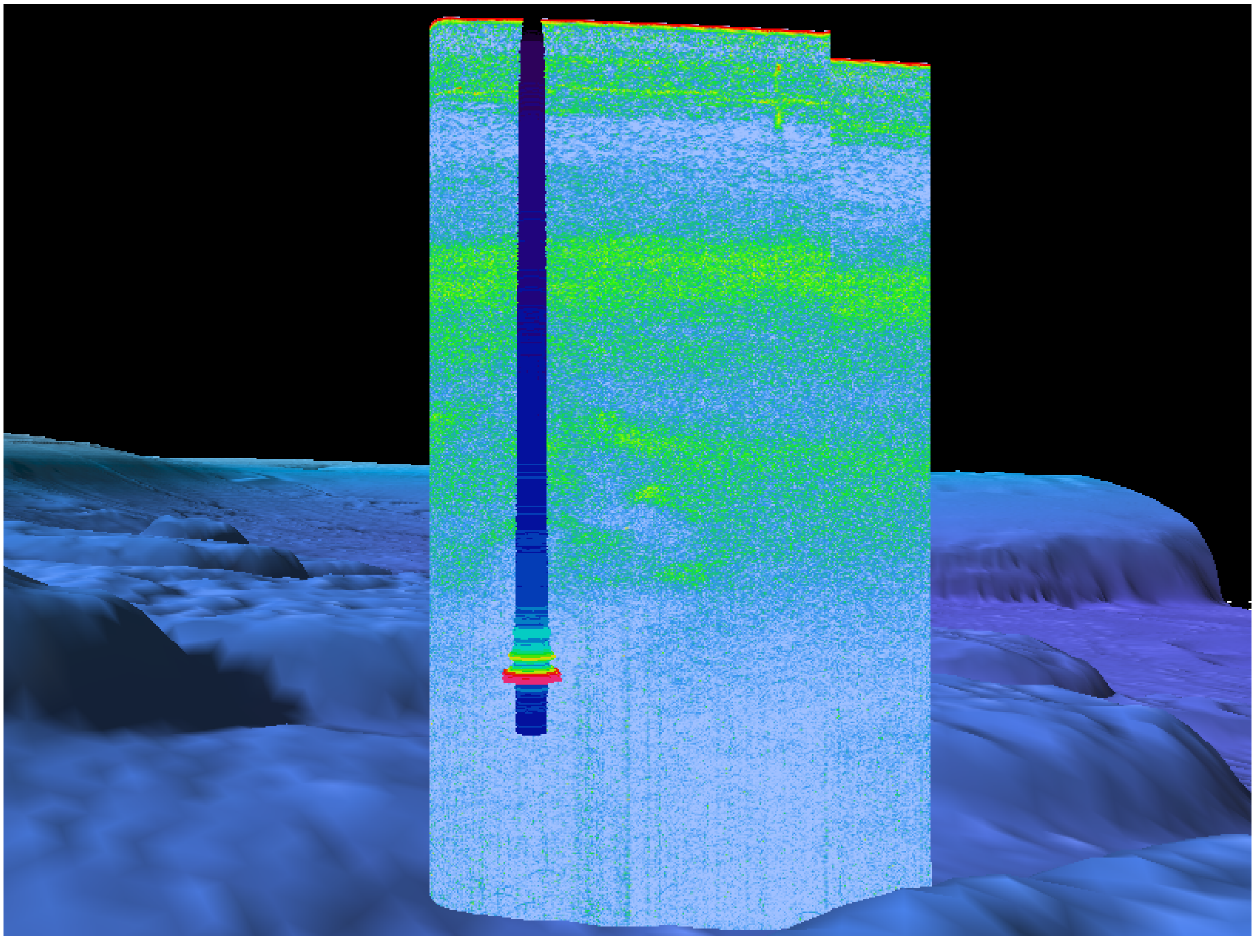

Figure 20: TJ71 CTD data plotted on 12kHz acoustic data. Larger radius and red colors indicate higher fluorescence. Smaller circles and blue colors indicate low fluorescence. CTD data and acoustic data were acquired within a two hours of each other.

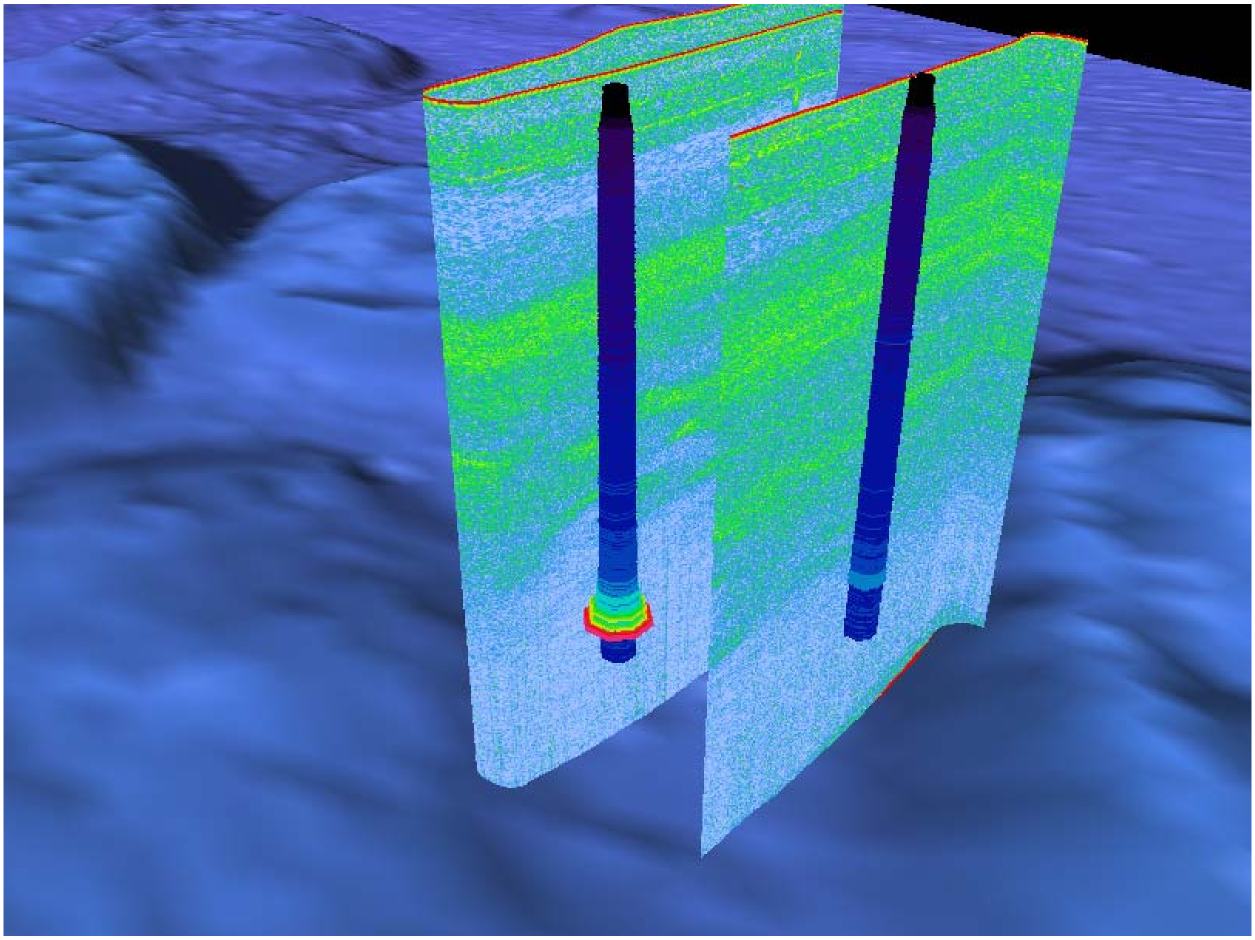

Figure 21: CTD 71 and CTD72 plotted against concurrent 12kHz acoustic data. View is towards south east. CTD72 is further to the west (right in this plot) and was taken approximately 9 hours afterCTD71. The acoustic anomaly is not present in the acoustic data associated with CTD72 and the fluorescence anomaly is much weaker.

Conclusions

Acoustic instruments of the kind used in this study do not interfere with ongoing operations at the well head.

The MVP mounted fluorometer requires careful evaluation to determine efficacy at finding submerged oil.

Acoustic measurements at high frequencies with concurrent droplet size analysis may allow independent estimate of oil flow volume to the surface.

Acoustic measurements at lower frequencies may be an effective method for identifying water masses that have interacted with the rising plume of oil.

Recommendations for Additional Work

Because high fluorescence (even at crude oil frequencies) and reduced DO are common properties of coastal water masses, additional instruments are needed to develop a methodology for finding and characterizing subsurface oil in the coastal zone.

More sensitive acoustics, combined with a lower noise floor and additional frequencies between 38 kHz and 200 kHz may yield important additional insights into the nature of the main rising plume of oil, and guide more directed sampling and *in situ* measurements.

Full depth casts and water sampling further from the well head (15 miles) could be used to estimate the rate of microbial metabolism of the 1100m water mass, and to begin to understand the fate of subsurface oil.

It should be noted that the NOAA Ship *Thomas Jefferson* is limited in her capabilities, and may not be the most appropriate platform for this additional work. In particular, the somewhat high noise floor of the acoustics, the limit of 1200m on the CTD, and the lack of a wet lab constrain the possibilities for future TJ tasking.

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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 used by 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 in 1 L amber bottles. All analysis of samples will be conducted at the established NRDA lab upon receipt of the shipped samples. As a collaborative project with USGS NOAA Ship *Thomas Jefferson* collected water samples for dispersant analysis in plastic 1 L pre-sterilized bottles.

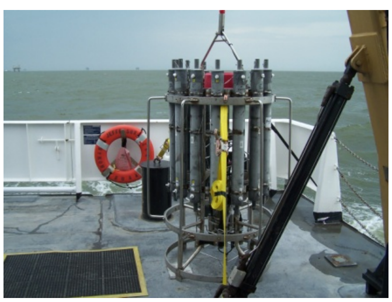


Figure 1. Water sampling package on stern of *Thomas Jefferson*

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. Dispersant samples were collected from designated Niskin bottles as well as from a pre-cleaned surface bucket that had been skimmed across the surface of the water on station.

Figure 2 and 3. THC, VAH and Dispersant 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 4. 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. Dispersant samples were sealed with silicon tape, clear packing tape, Zip locked and then stored in a freezer.

VAH and THC 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. Dispersant samples were packed with dry ice and shipped frozen.

Figure 5. 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.

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.

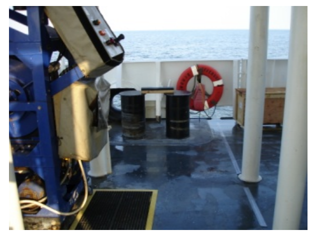


Figure 1 & 2. Isolated work spaces

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

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

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

Figure 3. Region one

Region Two: Decontamination station

Figure 4 & 5. Decontamination of gear in region two

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

Region Three: Final Decontamination station (inside passageway)

Figure 6. Drying of gear in region three

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

Equipment Operations:
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.

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.

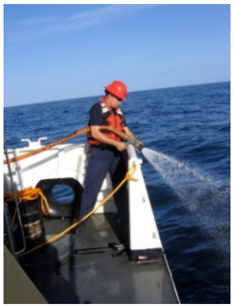


Figure 7. Spraying instrument during recovery

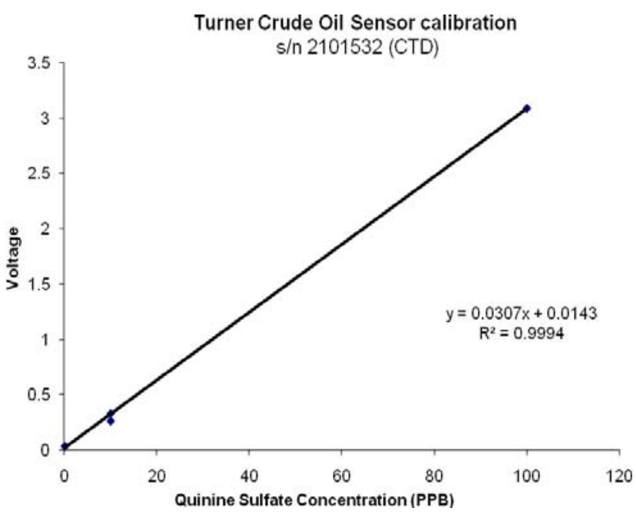
Once retrieved on deck, all instruments were decontaminated using soapy fresh water wash downs. The CTD bottles were washed down with fresh water and then filled with a fresh water Dawn soap mixture and allowed to soak until the next CTD. The bottles were drained prior to the next cast, rinsed with fresh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

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).



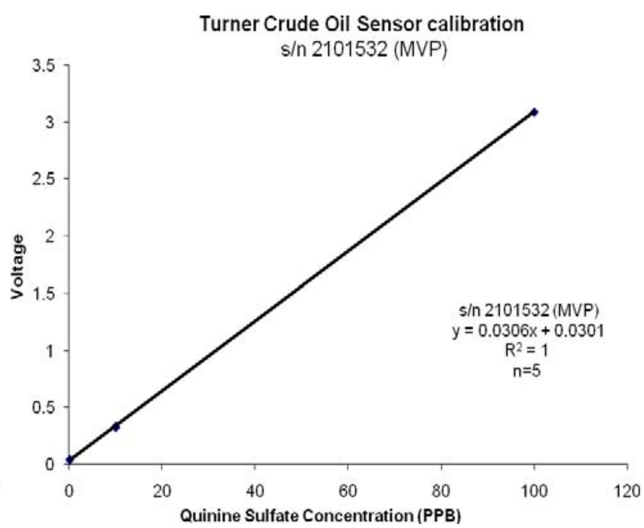


Figure 2. Results of calibration of Turner Designs Cyclops fluorometric crude oil sensor. The upper graph is for sensor used on the CTD, and the lower graph of for the sensor used on the moving vessel profiler (MVP).

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 have not been completely analyzed.