Long-Term Transport of Oil from T/B DBL-152: Lessons Learned for Oils Heavier than Seawater

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Abstract

The T/B DBL-152 spill (70,000 bbls, API 4.0, viscosity = 1,500 cSt at 21˚C (70˚F)) was unusual in that the oil sank to the bottom. Long-period wave energy events may have mobilized the sunken oil when above a threshold value. The long-term circulation of the Louisiana Texas shelf suggests the oil would move downcoast and offshore when mobilized by long-period wave events, eventually settling at a depth where the bottom wave energy is too low to remobilize the oil. Previous spills of relatively heavy oils are compared to the T/B DBL-152 Spill: Barge Bouchard 155, IXTOC 1 exploratory well, Morris Berman Barge, T/B MCN-5, T/V Alvenus, T/V Berge Banker, T/V Mobiloil, T/V Sansinena. These case studies lead to four guidelines for heavy oil spills.

1. Tarmats occur when floating oil moves into the surf zone, collects sediment and sinks.
2. With enough energy, tarmats on the bottom generally break up into smaller pieces of oil that spread out over a large area. Otherwise, the tarmats remain stationary and intact.
3. Oils denser than the local waters have not impacted shorelines unless the oil was spilled in the surf zone or moved into relatively denser water so the oil became buoyant.
4. Oils denser than the local waters break up into smaller pieces as they move and spread out in the environment.

1 Introduction

On November 11, 2005, the tank barge DBL-152 allided with a drilling rig that sank during the recent hurricane Rita (Figure 1). As a result, the barge spilled an estimated 70,000 bbls (close to 3 million gallons) of "slurry oil," an oil with an unusual combination of properties (high density, low viscosity) compared with oils more commonly encountered in spills. A large portion of the released oil sank to the seafloor to form large discrete mats in many areas and smaller globules in others. Observational data suggest that oil remained in two areas of heavier concentration until a series of storms apparently redistributed the oil. The NOAA Scientific Support Team for the T/B DBL-152 Federal On-Scene Coordinator was requested to look at the long-term transport mechanisms of the Louisiana-Texas shelf as they relate to this spill and any potential shoreline or environmental impacts on coastal beaches or the Flower Garden Banks National Marine Sanctuary.

Figure 1. Incident location. This figure shows where the accident occurred and where the finally barge came to rest relative to the Louisiana and Texas coastlines.

To understand the difference between a spill on the water's surface and one on the bottom of the ocean, we must consider the difference in how the laws of physics manifest in these two cases. (1) With an oil slightly less dense than seawater, the oil spreads thinly over the water's surface and covers a larger area. With an oil slightly more dense than seawater, the oil does not spread thinly over the bottom. Observations in this spill indicate oil thickness of about 6.5 cm (2.5 inches). The oil may be broken up and spread out over a large area, but as small pieces rather than as a thin coating. (2) Taking observations at the surface is easier than beneath the surface. Visualizing the large-scale distribution of oil on the bottom is difficult as the only means (e.g. VSORS, ROVS) of "seeing" the oil show a very small area at a single time. Thus the accuracy of assessments is very limited in time and space. Though we were looking for more than 1 million gallons of oil from this spill, we could observe only at a very small portion of the ocean's bottom at any one time.

1.1 Facts

1. The slurry oil[*] from T/B DBL-152 has a density of 1.04 g/cm^3 and a viscosity of 1,500 cSt at 21˚C (70˚F) (NOAA, 2005). Though these are normal ranges for oil properties, this is an unusual combination of high density and low viscosity.

[*] A slurry oil is a low API gravity, low viscosity oil created by mixing different slurry oils "in line" to meet a product API gravity specification. The destination tank is filled from the bottom and the lightest oil in the mixture is added last to aid in mixing. (NOAA, 2005)

2. The oil sinks in quiescent seawater.
3. The oil will behave similarly to local sediments in terms of episodes of burial and re-exposure and mobilization into the water column.
4. The oil will remain stationary on the bottom until an event occurs with enough energy to stir it up into the water column. Average current conditions will not be sufficient to move the oil continuously.
5. Outside the inner shelf (where coastal current jets form), long-period waves will be the only source of turbulent energy at the bottom other than large storms strong enough to mix the entire water column. Data from the LATEX study (DiMarco et al., 1997) indicate the vessel is located in an area influenced by coastal jets.
6. Long-period surface gravity waves are more energetic at the bottom in shallower water than in deeper water.
7. Overall circulation (Cochrane and Kelly, 1986; Cho et al., 1998) and long-term sediment transport on the Texas-Louisiana shelf is downcoast (Louisiana → Texas) and offshore.

1.2 Hypotheses

1. We do not expect globules of this oil on the bottom to coalesce into a larger slick at some later time.
2. We expect that once the oil sinks to the bottom, it will move "with the water" only when disturbed, until the turbulent energy in the water column decreases enough that the oil can settle out again.
3. When mobilized into the water column, we expect the oil to break up into smaller and smaller pieces and be deposited downcoast and offshore of the initial location over the long-term.
4. We expect the oil to be dispersed farther and farther horizontally over time primarily by long-period wave events.
5. We do not expect the oil from T/B DBL-152 to result in beach impacts above background on any time scale.

1.3 Things We Don't Know

1. Long-term sediment/oil interactions for this type of oil
2. Long-term chemical weathering of this oil in seawater.

<u>Terms of Reference</u>
Upcoast – Direction along the coastline from Texas to Louisiana.
Downcoast – Direction along the coastline from Louisiana to Texas.
Onshore – Direction more directly toward the coast.
Offshore – Direction most directly away from the coast.

2 Oil Property Considerations

The difference in density between seawater and the T/B DBL-152 oil is 0.005-0.015 g/cm^3 (NOAA, 2005), which is much less than the difference between vegetable oil and water (0.074-0.090 g/cm^3). Since the gravitational restoring force of a fluid interface is proportional to the difference in density between the two fluids, we expect the oil to sink to the bottom and move "with the water" when sufficiently disturbed. The viscosity of the T/B DBL-152 oil is relatively low compared to other heavy oils, so we expect the spilled oil to be easier to "break up" than most heavy viscous oils*. Divers report that the oil was easy to break up with the movement of their hands (NOAA, 2005). When discussing small amounts of the oil, we are using the term "globule" rather than "tarball"**.

3 Long-Term Persistence

This slurry oil has an unusual combination of oil properties, but these individual properties are within the normal range for oils. Thus, we expect the long-term chemical and biological degradation of this oil to be similar to other oils. In this section, we discuss the minimum size limit for globules that could potentially be transported long distances above the ocean floor in suspension.

3.1 Globule Sizes

Observations over time (NOAA, 2005) indicate that the T/B DBL-152 oil moved away from areas where it was previously visualized related to storm events (e.g. long-period waves). We also know that the oil appears to be relatively easy to break up into smaller globules from field observations and bench-scale laboratory tests. Unfortunately, the existing methods for determining particle size distribution of oil are empirical formulas derived from oil on the water's surface, where the energy from breaking waves breaks up the oil. In this case, however, the oil is on the bottom and turbulence at the bottom would be the only mechanism to break up the oil. We know of no way to translate the energy from the "percent whitecapping" in the empirical formulae to the energy generated by long-period surface waves to the bottom.

However, the most important question is not how to determine the particle size distribution, or even the volume of oil broken up into small particles. Rather, if a substantial amount of the oil is broken up into small particles, the critical question is: Where will it go? More specifically: Will it result in substantial impacts to the shoreline or other region of concern? These questions can be addressed without knowing the details of the globule forming process.

The local existing sediments provide some information about how bottom turbulent energy in the region of the spill translates into suspension and transport of particles. The sediments on the bottom in this region are a mixture of coarse silt and fine sand. This indicates that sediments of that size are suspended by the larger wave events, and settle out under quieter conditions. Finer sediments than those found in the area remain in suspension under normal conditions.

The ability of a particle to remain in suspension is a function of its fall velocity, *i.e.* the velocity at which the particle will fall in still water. Fall velocity is a function of the density, shape and size of the object, and the viscosity of the water. The fall velocity of a particle with a given set of properties can be estimated with the Gibbs (1971) formula:

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* In order to make quantitative estimates of how easily the oil would break up, we would need more information, such as the oil's surface tension. We think a qualitative discussion will serve our purposes.

** Typically the term "tarball" is used to describe a surface-weathered heavy oil with a more solid exterior and soft interior.

$$w_0 = \frac{-3\nu + \sqrt{9\nu^2 + gd^2(s-1)(0.003869 + 0.02480d)}}{0.011607 + 0.07440d}$$

where w_0 is the fall velocity, measured in cm/s; ν is the viscosity of the water in cm^2/s; s is the specific gravity and d is the diameter in cm of the particle. This formula is applicable to spherical particles of from 0.0063cm to 1.0 cm. While the existing natural sediments are not likely to be spherical, this is accurate enough for an approximation.

An oil globule with the same fall velocity as the bottom sediments will behave similarly to the sediments. By estimating the size of an oil globule with the same fall velocity as the bottom sediments, we can determine the size of oil globule that will remain in suspension in that environment. We expect this to be an "order of magnitude estimate" because of all the assumptions.

Assumptions about sediment particles

- Particles are spherical.
- Particle diameter is about 100 microns (0.01 cm, between coarse silt and fine sand).
- Particles have a specific gravity of 3 (approx. value for quartz).

Assumptions about oil globules

- Globules are spherical.
- API is 4.5 (Specific gravity = 1.04).

Water viscosity is taken to be 0.01 cm^2/s (1.05 cSt). Using the Gibbs formula, the fall velocity of the sediment is 0.88 cm/s. Also using the Gibbs formula, the diameter of a particle with the same fall velocity as sediment is approximately 1.5 mm, a relatively small globule of oil. These assumptions result in a maximum estimate for the globule size. Non-spherical, flocculated, or less dense particles would all result in a lower fall velocity, and a smaller equivalent oil globule size.

This indicates that only very small oil particles are able to remain in suspension for a long time. These particles will be widely dispersed before reaching the shoreline. Larger particles will be moved along the bottom, mostly during larger wave events, and will not travel nearly as fast or as far as the suspended particles. The sediments in the spill area may be different than "normal" due to the recent hurricane events, but the overall conclusions that only small globules of oil remain in suspension to be transported by the currents remain valid.

3.2 Bottom Wave Energy

Observations from the T/B DBL-152 spill has given us useful insight into how waves affect the T/B DBL-152 oil on the bottom. Observations on November 20th indicated a couple of large pools of oil on the bottom, including oil in the trench scoured by the barge after the accident (NOAA, 2005). Observations on November 30th indicated that much of the oil had either moved or dissipated (NOAA, 2005).

Surface gravity wave energy decreases with depth, and longer period waves (thus longer wavelength waves) affect the water to a greater depth, generally about 1/2 the wavelength (Dean and Dalrymple, 1991). Thus the wave energy at the bottom is somewhat different than the energy at the surface. Long-period waves will have a substantial effect at the bottom, but short-period waves will not. In the location of interest, the water depth is about 15 m (~50 feet), so only waves with a period greater than about 5 seconds will be felt on the bottom. NOAA National Data Buoy Center (NDBC, www.ndbc.noaa.gov) wave buoys report the wave energy spectrum at the surface. These data indicate how much energy is in the waves for each period band at a given time, are available in real time, and have been archived for a number of years.

Analysis of these data from NDBC wave buoys in the region indicates that there were two substantial wave events between the grounding of the vessel and November 30th: November 14-19th and November 26-29th. The November 29th incident was the larger of the two. As the oil was in place on November 20th, but had moved or dissipated substantially by November 30th, we conclude that the wave energy during the earlier event was not enough to mobilize the oil, and the energy in the later event exceeded the threshold for mobilizing the oil.

To assess the wave energy at the bottom, the surface spectrum is transformed by scaling each frequency according to how it decays with depth, and then adding up the individual energy totals to obtain the total wave energy at the bottom. Using linear wave theory (Dean and Dalrymple, 1991, as well and any wave dynamics text) the horizontal velocity under a wave is given by:

$$u(x,z,t) = a\omega \frac{\cosh(k(h+z))}{\sinh(kh)} \cos(kx - \omega t)$$

where ω is the wave frequency ($2\pi/T$), k is the wave number ($2\pi/L$), h is the water depth, and a is the wave amplitude. At the bottom, $h = -z$, so amplitude of the horizontal velocity scales with $1/\sinh(kh)$. The kinetic energy scales with the square of the amplitude of the oscillation, so energy at the bottom is:

$$E_b = \frac{E_s}{\sinh(kh)^2}$$

where E_b is the energy at the bottom, and E_s is the energy at the surface. E_s is provided for each wave period band by the NDBC wave spectrum data. By scaling the energy in each wave period bin in a spectrum according to the appropriate wave number for that period and the water depth, and summing the results, we get an estimate for the total wave kinetic energy at the bottom.

This analysis was done for the month of November 2005 and for the archived data from 2004. These data are from the most representative buoy available, NDBC buoy 42035, just south of Galveston Bay. That buoy is about 30 miles west of the incident site, and 15 miles closer to shore, in about 14 m (45 feet) of water. We expect the wave conditions there to be similar, though it may report less wave energy from north winds. As the North winds have smaller fetch, they tend to result in less energy at longer periods, and thus have less effect at the bottom.

A plot of the wave energy at the bottom in 15 m (50 feet) of water is given in Figure 2. The two wave events are clear, one between November 14th and 19th, and a second one between November 26th and 29th. This indicates that a bottom energy of 2 m^2/Hz (square meters per hertz)* was not enough to mobilize the oil, but an energy between 2 and 12 m^2/Hz was enough to mobilize the oil. The exact required energy is unknown, but from the plot we have estimated that 6 m^2/Hz was exceeded for a

* m^2/Hz is a unit used for wave spectral energy density; it is proportional to kinetic energy in the waves

substantial period of time and may be a reasonable estimate for the energy level required to break up and mobilize the oil.

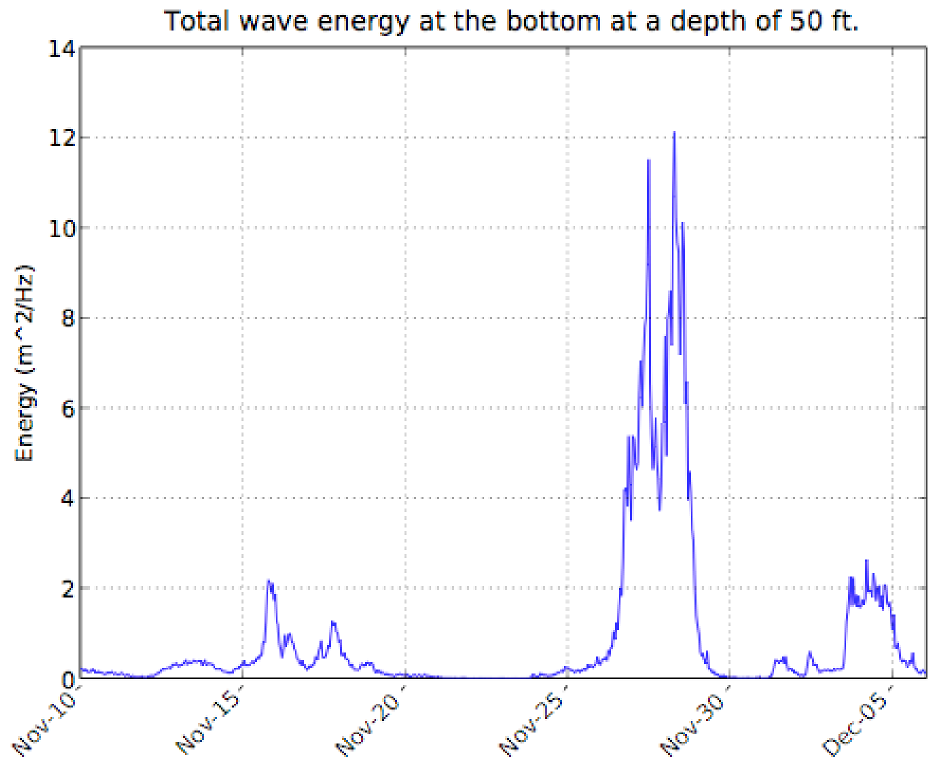


Figure 2. Bottom wave energy based on NDBC Buoy 42035 for November 2005 transformed to the depth of grounded vessel (50 ft).

- The bottom energy for the entire year 2004 can be seen in Figure 3. Clearly energy levels above 6 m^2/Hz are quite common. (The large energy spike in September is Hurricane Ivan.) Lastly, Figure 3 is the 2004 data scaled to see the lower energy events better. This plot clearly indicates periods of bottom wave energy level exceeding 6 m^2/Hz (or even 12 m^2/Hz) are very common. In 2004, the energy level was above 6 m^2/Hz for a total of 240 hours (about 3% of the time). This analysis indicates that over the course of the next year there are likely to be many wave events large enough to mobilize and distribute the oil on the bottom.

3.3 Long-Term Oil Fate

We do not expect the smaller globules of oil to coalesce into a larger slick at some later time. Convergence zones, such as found on the water's surface, are not found at depth, so we do not expect a mechanism for bringing globules of oil together. The smaller the globules of oil become, the more available the oil is to local biodegradation.

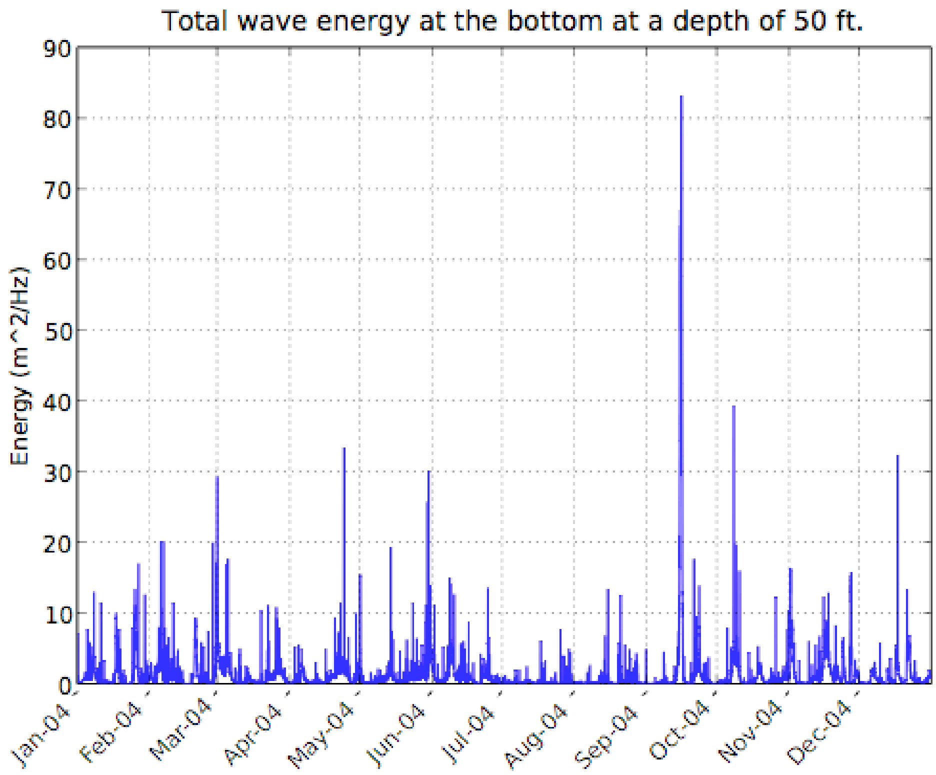


Figure 3. Bottom wave energy based on NDBC Buoy 42035 transformed to depth of grounded vessel (50 ft).

4 Long-Term Transport – Timescale of Months to Years

In order to discuss the long-term (1-100 years, 1-100 km) transport of the oil from T/B DBL-152, we look to long-term sediment transport studies on continental shelves because the oil is denser than the local seawater and we expect it to behave like lighter sediments. River sediments provide the best example because these sediments can be uniquely identified among the moving shelf sediments. Studies of river sediments in different areas (Sternberg and Nowell, 1999) show that a river's sediments end up offshore and to the "right" (in the northern hemisphere) out to the depth where surface gravity wave influences decrease (depths of 61 m (200 feet) or more).

Sufficiently energetic events are more likely to be caused by long-period waves than by the local bottom currents. For particular sediment transport events, distance moved along the shelf is greater than the distance moved across the shelf. We expect the Louisiana-Texas shelf would show (similar to Sternberg and Nowell, 1999) more frequent events mixing sediments up into the water column occurring closer to shore and very few events further offshore. The increasing depth of the shelf in the offshore direction causes less wave energy to reach the bottom. Hence, sediments (and oil denser than the local water) will be stirred up and moved less and less frequently over time as it is deposited farther and farther offshore over time. We expect most of the heavy oil from the T/B DBL-152 to be deposited downcoast and offshore of the present location over the long-term.

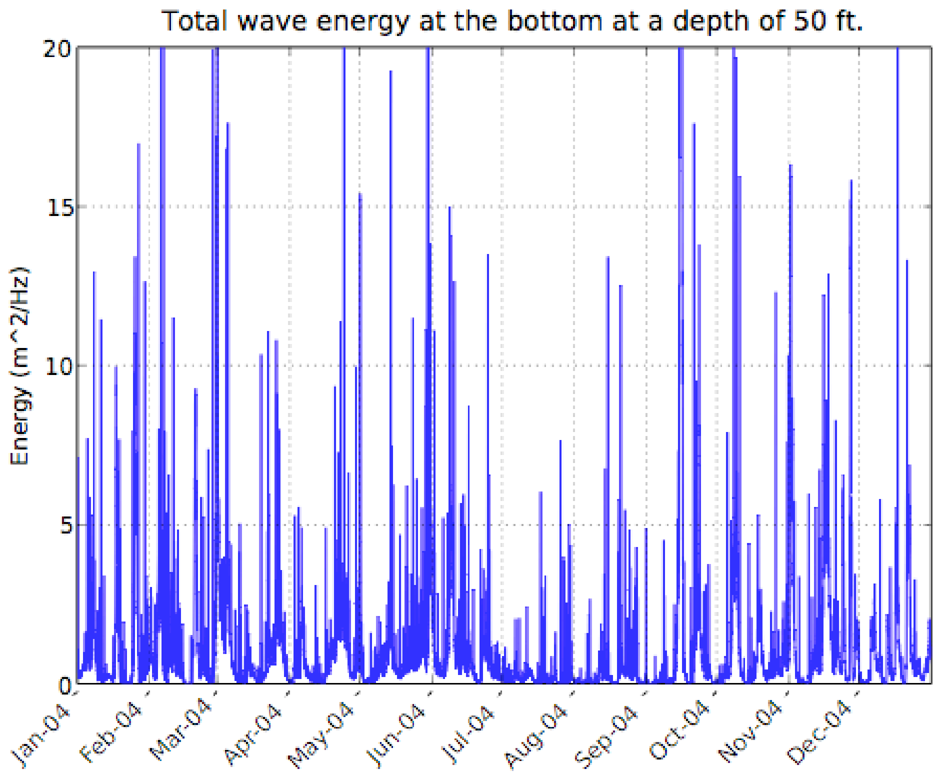


Figure 4. Bottom wave energy based on NDBC Buoy 42035 transformed to depth of grounded vessel (50 ft). This is a close-up of the lower energy levels in Figure 3.

Gravity-induced flow would also tend to make the oil flow offshore toward deeper water. Any locally dense waters flowing along the bottom would be likely to carry the oil downhill to deeper water.

The mobilized oil globules could collect in relatively low-lying areas until a storm event sufficient to remobilize the oil occurred. "Field laboratory" experiments indicated that the globules did not have a tendency to stick or join together, even over a period of days. In the ocean, it is difficult to imagine a mechanism that would bring the globules together with enough energy to merge.

4.1 Could the Oil Get onto a Beach?

Over a long time, we expect mobilized oil to settle on the seafloor with a general distribution of smaller oil globules farther downcoast and offshore. Storms could remobilize oil to locations shallow enough to feel surface gravity waves, but this mobilized oil is expected to be smaller than the original globules visualized at the spill. We have never seen any oils denser than the local water impact the shoreline unless the source of the oil was within the surf zone (see historical incident comparison in Section 5). This section addresses concerns about the potential for shoreline impacts from the T/B DBL-152 spill in the event that our estimates of oil fate and behavior are significantly inaccurate.

Under upwelling conditions, the local surface water moves offshore, with a compensating movement of the water at the bottom in the onshore direction. In this case, winds directed upcoast can create upwelling favorable conditions. The maximum wind-driven onshore bottom current is probably 5 cm/s (Dr. Robert Hetland, TAMU, personal communication). Steady strong winds would have to blow for almost 12 days in order to create a 5 cm/s onshore bottom current to move the oil 28 nm (the most direct distance to shore), which is unlikely to occur. If the currents were able to move the oil into the nearshore area, these same currents would turn to run parallel to the shoreline boundary (conservation of mass) and would not move up onto the beach. Since the currents will not run into the shore, a wind event that would mobilize offshore sediments (and oil) onshore would then be needed. Any oil moved up onto the beach from the surf zone is likely to be below background in size and amount. The winter season is predominantly downwelling favorable on this portion of the Louisiana-Texas shelf. This implies that the near-bottom flow is more likely to have a small offshore component, as well as a larger, downcoast (westward) flow at the incident location.

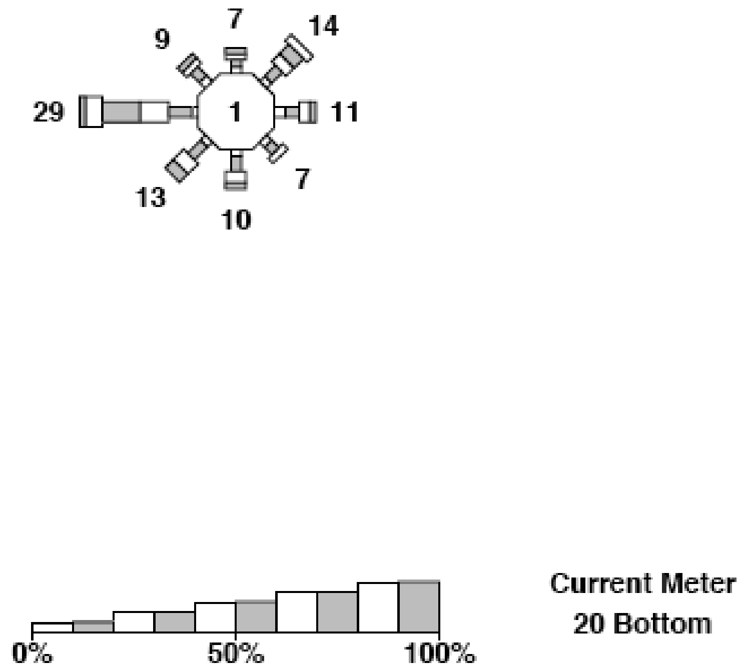
The LATEX Data Report (DiMarco et al., 1997) summarizes extensive current meter data from 33 moorings throughout the Louisiana-Texas shelf from April 1992-December 1994. These data are summarized in objectively mapped circulation patterns in Cho et al. (1998). From the LATEX data, the winter bottom currents (December 13, 1993 to February 12, 1994) from current meter 20 (29.261ºN, 094.064ºW) are summarized in Figure 5. These data show the dominance of the "non-summer" downcoast circulation pattern. Chu et al. (2005) statistically analyzed the LATEX and Surface Current and Lagrangian Drift Program (SCULP-1, Sturges et al., 2001) data and found that current reversals in the Fall-Winter season occur on average every 12 days on the Louisiana-Texas shelf due primarily to synoptic winds.

From examination of the NOAA nautical charts, the Louisiana-Texas shelf decreases in shelf width and increases in steepness in the downcoast direction from the area of the spill. Surface oil traveling downcoast with the coastal currents would approach the shore and could more easily be blown by the wind onto the shoreline, but the oil from T/B DBL-152 is too dense to move at the sea surface. We envision the T/B DBL-152 oil breaking up into smaller pieces and dispersing horizontally as it moves downcoast. The mobilized oil should have a higher probability of moving offshore based on the statistics of the currents. Waves generated during storm events could remobilize the oil, but we expect these same storm events to also further break up any oil remobilized.

If the oil gets near the beach and into the surf zone, the large amount of energy from breaking waves within the surf zone is likely to break the oil up into even smaller pieces. Because of the low viscosity of the oil, we do not expect it to form tarballs, but rather soft globules that would be beaten up in the surf.

4.2 Is the Flower Garden Banks National Marine Sanctuary in Danger?

The Flower Garden Banks are three locally shallow areas composed of sensitive coral reefs: Stetson Bank, West Flower Garden and East Flower Garden. These reefs are located 105-110 nm offshore (near the shelf break) of the Texas-Louisiana border and are found between the latitudes of 28˚ 12'N and 27˚ 50'N and longitudes 94˚ 18'W and 93˚ 32'W, which is approximately 90 nm SSW of this incident. These reefs are perched on two salt domes that rise above the local sea floor, and the reefs themselves have locally steep boundaries (Figure 6). The reefs extend to within 15-30 m (50-100 feet) of the surface, with the surrounding bottom depths 91 m (300 feet) or deeper.



Dir	Current Speed Range (cm·s^{-1})											Avg. Speed
	1-5	5-10	10-15	15-25	25-35	35-45	45-55	55-65	65-75	>75	Total	
N	1.7	1.7	1.3	1.6	0.2	0.0	0.0	0.0	0.0	0.0	6.6	11.2
NE	1.9	3.7	2.9	3.1	2.1	0.5	0.1	0.0	0.0	0.0	14.3	15.4
E	2.7	3.3	2.8	1.5	0.1	0.2	0.0	0.0	0.0	0.0	10.6	10.0
SE	1.8	2.5	1.8	0.4	0.0	0.0	0.0	0.0	0.0	0.0	6.5	8.3
S	1.6	3.7	2.8	1.5	0.1	0.0	0.0	0.0	0.0	0.0	9.7	10.2
SW	1.8	4.4	3.7	2.9	0.2	0.0	0.0	0.0	0.0	0.0	13.0	11.2
W	1.5	5.4	7.4	9.2	4.1	1.4	0.3	0.0	0.0	0.0	29.3	17.2
NW	2.1	3.0	1.7	1.5	0.5	0.1	0.0	0.0	0.0	0.0	9.0	10.9
Total	15.2	27.8	24.3	21.7	7.5	2.3	0.4	0.0	0.0	0.0	99.1	13.1
Calm											0.9	

Figure 5. This is Figure 20b3123r from DiMarco et al. (1997) showing the current rose and joint distribution of bottom currents from current meter 20 from December 13, 1993 to February 12, 1994. The table indicates the percentage of time the currents fall within indicated ranges of speed and direction, with values of 1 cm/s or less assigned to “calm”. The current rose indicates the percentage of time (darker area in box) that the currents are within the same speed ranges as in the table.

We do not expect the Flower Garden Banks to be within the long-term trajectory of this spill. With bottom depths in excess of 91 m (300 feet), long-period wave energy is unlikely to move small globules of this oil out to this depth on the shelf. Large-scale ocean circulation physics makes it difficult for a column of water to significantly change latitude or depth. Both laboratory studies (Boyer and Davies, 2000) and numerical simulations (Beckman and Haidvogel, 1997) show that the overall circulation flows around submerged seamounts, rather than over the top of them. If the oil were moving in the area of the Flower Garden Banks, it would be moving similarly to the water along the bottom, so the oil would move around the salt domes where the Flower Garden Banks National Marine Sanctuary resides.

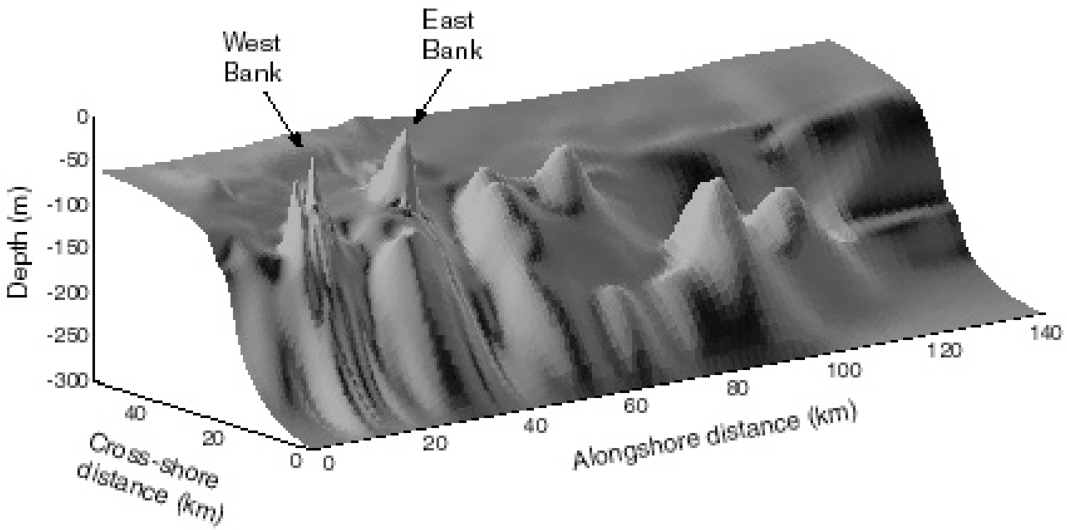


Figure 6. 3-D representation of the local bathymetry in the vicinity of the Flower Garden Banks National Marine Sanctuary, courtesy of Simone Francis (Francis, 2005).

5 Historical Spills for Comparison

Representatives of ITOPF requested that we compare this spill with two other spills that occurred in this region: the IXTOC 1 exploratory well blowout in 1979 and the T/V Berge Banker in 1995. Both these spills were of oil lighter than the surrounding water, even the heavy fuel oil of the T/V Berge Banker, so the transport of oil from these spills was dominated by surface processes rather than bottom processes. Representatives from the State of Texas have requested that we compare this incident with other spills of oil that sank. We have included the T/V Alvenus, Morris Berman Barge, T/V Sansinena, Barge Bouchard 155, T/V Mobiloil and T/B MCN-5. These spills are all archived in the HAZMAT Historical Spills Database and personal observations from HAZMAT Scientific Support Team members on-scene when available. The T/V Sansinena spill predates the formation of NOAA/HAZMAT, but the U.S. Coast Guard report is included in our Historical Spills Database.

These historical comparisons have several themes that relate to the T/B DBL-152.

- Tarmats occur when floating oil moves into the surf zone, collects sediment and sinks.

- With enough energy, tarmats on the bottom generally break up into smaller pieces of oil that spread out over a large area. Otherwise the tarmats remain stationary and intact.
- Oils denser than the local waters have not impacted shorelines unless the oil spilled in the surf zone or moved into relatively denser water so the oil became buoyant.
- Oils denser than the local waters break up into smaller pieces as they move and spread out in the environment.

5.1 Case 1 – IXTOC I exploratory well

Scenario: The IXTOC I exploratory well blew out on June 3, 1979 in the Bay of Campeche off Ciudad del Carmen, Mexico. By the time the well was brought under control in 1980, an estimated 140 million gallons of oil had spilled into the bay. (The IXTOC I is currently #2 on the all-time list of largest oil spills, eclipsed only by the deliberate release of oil from many different sources during the 1991 Gulf War.) The IXTOC 1 well blowout resulted in emulsified crude oil impacting much of the Texas shoreline in the form of tarballs and relatively fluid floating oil between early August and mid-September, 1979. In mid-September a significant storm event removed much of the remaining oil stranded on the beaches (not yet cleaned). Over the next few years, large storm events brought tarmats composed of the IXTOC 1 oil mixed with significant amounts of sediment onto the beaches. The hypothesis was (is) that the oil was mixed vigorously with the sediments by the storm wave action and moved offshore behind the first or second sandbar. The tarmats were heavy enough that they remained relatively immobile offshore until a storm of sufficient energy could bring them onshore. Subsequent storms were able to move this heavier oil back onto the beaches in the form of tarmats or very sandy tarballs.

Conclusions for T/B DBL-152: The oil from the IXTOC 1 exploratory well was lighter than the local seawater and more cohesive after emulsifying than the oil carried by T/B DBL-152. We do not expect the mechanisms that created shoreline impacts during the IXTOC 1 spill to apply to the T/B DBL-152 spill. The IXTOC I oil became heavy tarmats through oil stranded on the beach being mixed with sand during a storm event, and became a new source of oil within the surf zone. We do not expect the oil from T/B DBL-152 to move into the surf zone or be viscous enough to create heavy tarmats.

5.2 Case 2: T/V Berge Banker

Scenario: On February 5, 1995, the T/V Berge Banker carrying Arabian Light Crude collided with the T/V Skaubay in the Galveston Lightering Area, 50-60 nautical miles south of Galveston Bay, Texas in the Gulf of Mexico. Reports indicate that the two vessels collided while maneuvering during lightering operations. Based on tank soundings, the Berge Banker released 900 barrels [37,000 gallons] of Bunker C oil into the water. On February 16, tarballs from this spill began coming ashore on the beaches of Matagorda Island near Corpus Christi, Texas, 259 km [140 nautical miles] away. Tarballs continued to impact beaches until March 3 when small tarballs were reported on Port Isabel city beaches.

Bunker C is a persistent oil that does not readily disperse or evaporate. Bunker C sheens less than a crude or lighter fuel oils when it is spilled, thus making it less visible from the air. However, like other oils, Bunker C does break into smaller particles due to wave action. This oil became tarballs initially located around the lightering area, although they were easily overwashed by waves. Once they were dispersed horizontally on the water surface, they were extremely difficult to see from aircraft. So, to the airborne observer, the oil seemed to have disappeared. The slick was lost from sight for several days. Tarballs from a persistent oil can travel hundreds of miles virtually unobserved. Transported by winds and currents, they may be overwashed by waves and actually spend some fraction of the time under water (typically in the upper few metres of the water column). Should the oil reach a natural collection area such as a convergence line or a beach, the tarballs can recoalesce into a contiguous slick. On February 16, tarballs began contacting the beach on the Gulf side of Matagorda Island and continued to impact beaches until March 3 when small tarballs were reported on Port Isabel city beaches. Scenarios such as this often result in reports that the oil sank, moved along the bottom and then resurfaced to create beach impacts, but these reports are not true.

Conclusions for T/B DBL-152: The Bunker C oil from the T/V Berge Banker was less dense than the local seawater and more viscous after weathering than the oil from the T/B DBL-152. The movement of floating Bunker C tarballs under the influence of surface currents and winds is quite different than the movement of the heavy oil sitting on the bottom under the influence of the weaker bottom currents that could not bring oil up onto the shoreline.

5.3 Case 3: T/V Alvenus

Scenario: On July 30, 1984, the T/V Alvenus grounded in the Calcasieu River Bar Channel 11 miles southeast of Cameron, Louisiana. Approximately 65,500 bbls [2,751,000 gallons] of crude oil was lost from the vessel. The oil floated and eventually ended up impacting areas along the Bolivar Peninsula and areas inside of Galveston Bay, Texas. An estimated 7,400 to 11,100 bbls [310,800-466,200 gallons] of oil adsorbed onto suspended sediment nearshore and sank in the surf zone, forming tarmat blankets up to 4 inches thick. Some of the subsurface oil formed cylindrical shaped rolls that moved up and down the beach with wave action. Unless mixed with sand, the oil dispersed easily into the water with gentle action.

Conclusions for T/B DBL-152: The oil from the T/V Alvenus was lighter than the local seawater and floated into the nearshore environment, picked up sediment and sank. This phenomena has occurred numerous times along the Texas coast, but we do not expect this to happen with the oil from T/B DBL-152 because (1) this oil is heavier than seawater, (2) there is no mechanism to move significant amounts of this oil along the bottom and into the surf zone intact, and (3) the oil from the T/V Alvenus that was not loaded with sediment was easily dispersed into smaller particles as is the oil from the T/B DBL-152. Energy sufficient to move the T/B DBL-152 oil should break it up in smaller globules.

5.4 Case 4: Morris Berman Barge

Scenario: On January 7, 1994, the Morris Berman Barge ran aground in the fringing reef offshore of San Juan, Puerto Rico, releasing approximately 18,000 bbls [756,000 gallons] of API 9.5 oil [density=1.0035 g/cm^3]. Much of the oil floated but some of the oil was found on the bottom in both offshore areas and on the landward side of nearshore reefs. Most of the sunken oil was located within 2 km of the vessel grounding site. Laboratory tests later determined that the oil that sank contained a few percent sand. The oil on the bottom was observed resembling lava lamps as the oil separated from the sand and began to refloat, presumably because the warm tropical waters allowed the sand to sink through the oil, and the oil to flow up around the sand. This buoyant oil released from the submerged sediment and oil became available to contaminate the shoreline.

Conclusions for T/B DBL-152: The Morris Berman grounded nearshore, in the surf zone of the fringing reef. The oil sank because of sediment accumulated within the oil in the surf zone, and the oil only mobilized to the shore after separating from the sand in the warm water. The dense, sediment-laden oil tended to remain in place on the bottom. This example demonstrates how even the energy of the surf zone is often not powerful enough to move heavy oil significant distances along the bottom. The T/B DBL-152 oil spilled is located in an area with episodic high energy events, and has no mechanism for decreasing density as with the Morris Berman Barge spill.

5.5 Case 5: T/V Sansinena

Scenario: On December 17, 1976, an explosion resulted in a spill of more than 33,000 bbls [1,386,000 gallons] of fuel oil with API values between 7.9-8.8 [density=1.0151-1.0086 g/cm^3], in Los Angeles Harbor, California. An estimated 200 bbls [8,400 gallons] of oil floated. The remainder sank and pooled on the bottom of the harbor. The floating oil was boomed and a portion of the surface oil did impact the local shorelines. However, there is no documentation of any of the sunken oil ever refloating or remobilizing and as a result impacting any shoreline. Over the next 16 months, nearly all the oil was recovered from the bottom in this low-energy environment.

Conclusions for T/B DBL-152**:** No documented shoreline contact occurred from the portion of the T/V Sansinena oil that sank to the bottom of the harbor. In the low-energy environment of the Los Angeles Harbor where the spill occurred, the oil remained on the bottom, close to where it was lost. Note that this spill predates HAZMAT, so we do not have any direct knowledge of this spill. We expect the oil from the T/B DBL-152 to only move during long-period wave events of sufficient energy, and to remain denser than the local seawater.

5.6 Case 6: Barge Bouchard 155

Scenario: On August 10, 1993 at 0545 hours, a collision between the freighter Balsa 37, the barge Ocean 255, and the barge Bouchard 155 occurred in Tampa Bay, Florida. Approximately 8,000 bbls [336,000 gallons] of #6 fuel oil was lost from the Bouchard 155. In the shallow, low-energy areas along the mangrove islands and at a few locations in the surf zones, a small fraction of the total oil spilled mixed with beach sand and shallow sediments to form subsurface tarmats. Several tarmats in water depths between 2 and 3 m (6 and 20 feet) maintained their cohesiveness and were eventually cleaned up or buried by sand.

Conclusions for T/B DBL-152: The floating oil did not sink until it picked up sediment in the nearshore areas. During the incident, the winds were light and dominated by sea breeze effects, and the seas were light with minimal currents. This low-energy environment allowed the tarmats to remain cohesive and eventually become buried. In the case of the T/B DBL-152, high-energy storm events will break up the oil and not allow large mats to persist.

5.7 Case 7: T/V Mobiloil

Scenario: On March 19, 1984, a steering failure at 0005 hours resulted in the T/V Mobiloil grounding in the Columbia River, about 10 miles downstream of Portland, Oregon, and discharging about 4,000 bbls [168,000 gallons] of residual and fuel oils that ranged from API 7 to 14 [density=1.0217-0.9725 g/cm^3]. The floating oil impacted shoreline areas downstream. The subsurface oil was very difficult to locate and no shoreline impacts from the subsurface oil were ever reported. Some of the oil that traveled at mid-water depths started to float near the mouth of the river as the salinity and water density increased. As a consequence, there were some shoreline impacts on the outer Washington Coast from scattered tarballs.

Conclusions for T/B DBL-152: The subsurface oil from the T/V Mobiloil that impacted the outer coast of Washington floated to the surface as it exited the Columbia River into the denser seawater near the coast. Beach impacts occurred from onshore winds affecting this newly floating oil. No other beach impacts from the sunken portion of the oil were reported. Based on examination of the Levitus Climatological Atlas of the World Ocean, the seawater of the Louisiana-Texas shelf never reaches a high enough density to cause the oil from the T/B DBL-152 to become buoyant (Levitus, 1982).

5.8 Case 8: T/B MCN-5

Scenario: On January 31, 1988, the T/B MCN-5 turned onto her port side near Anacortes, Washington and lost approximately 2200 bbls [92,400 gallons] of Heavy Cycle Gas Oil (HCGO) with a density of 1.086 g/cm^3 along with various diesel and IFO fuels. The oil sank and traveled out of the Guemes Channel area due to the strong tidal currents. No shoreline impacts were reported. Small quantities of this oil were found in deeper pocket areas (5-6 nm from the spills) outside the main channel in Rosario Straits.

Conclusions for T/B DBL-152: The Heavy Cycle Gas Oil (HCGO) from the T/B MCN-5 sank because it was denser than the local seawater. No shoreline impacts occurred from the oil that sank. Some of the diesel and IFO fuel spilled did come ashore, but none of the HCGO. Once the heavy oil mobilized, it was broken up and collected only in deep pockets and collection areas with relatively low energy. Only small concentrations of HCGO were found. No large tarmats of HCGO were reported and are presumed not to have formed. This spill demonstrates that once an oil denser than the local seawater breaks up and spreads, it is difficult to collect even in "collection" zones. The areas of Guemes channel and Rosario Strait in Washington State have much higher tidal energy than the Louisiana-Texas shelf. We expect the oil from the T/B DBL-152 to behave similarly with episodic long-period wave events breaking up and distributing the oil.

6 Conclusions

The heavy slurry oil from T/B DBL-152 behaves very differently than oils more commonly encountered during oil spills. The oil is expected to remain stationary on the bottom until bottom wave energy (generated by storms) causes the oil to break up and mix the oil into the water column. The oil would then move with the local currents as it slowly sinks down to the bottom again, and then comes to rest. Net transport on the Louisiana-Texas shelf is downcoast (from Louisiana to Texas) and offshore. Once deep enough on the shelf to be infrequently disturbed by storm-induced waves (generally greater than 200 ft), the oil could remain for a significant amount of time. We do not expect shoreline contacts above background from this spill.

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