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The tarballs on Texas beaches following the 2014 Texas City "Y" Spill: Modeling, chemical, and microbiological studies

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ABSTRACT

We modeled the transport of oil, source-fingerprinted 44 tarball samples from Galveston Island (GV) and Mustang Island (MT), and determined the hydrocarbon and bacterial community composition of these tarballs following the 2014 Texas City "Y" Oil Spill (TCY). Transport modeling indicated that the tarballs arrived in MT before the samples were collected. Source-fingerprinting confirmed that the tarballs collected from GV and MT, 6 d and 11 d after the TCY, respectively, originated from the spill. Tarballs from GV showed 21% depletion of alkanes, mainly C_9–C_{17}, and 55% depletion of PAHs mainly naphthalenes, and dominated by alkane-degrading *Alcanivorax* and *Psychrobacter*. Samples from MT were depleted of 24% alkanes and 63% PAHs, and contained mainly of PAH-degrading *Pseudoalteromonas*. To the best of our knowledge, this is the first study to relate oil transport, tarball source-fingerprinting, chemistry, and microbiology, which provides insights on the fate of oil in the northern Gulf of Mexico.

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1. Introduction

The Texas City "Y" (TCY) Oil Spill occurred on March 22, 2014 when the inbound cargo ship MV Summer Wind collided with the oil tank-barge Kirby in Galveston Bay near Texas City, Texas. The collision resulted in the release of approximately 168,000 gal of RMG 380 (Marine Fuel Oil/Special Bunker) oil into the Galveston Bay. Initially, strong southerly winds blew much of the oil offshore but by March 31, most of the oil had come ashore (NOAA, 2014a). Tar residues were washed up along the shorelines of Galveston and Matagorda Islands, and within several days they were found as far south as Mustang and Padre Islands, >300 km southwest of the incident site.

These residual oil mixtures which may consist of 70 to 95% sand by weight have been recently classified as submerged oil mats (SOMs) and surface residual balls (SRBs) commonly referred to as tarballs — a term to be used throughout this manuscript to refer to SRBs (OSAT-2, 2011; OSAT-3, 2013). SOMs are large mats of sedimented oil, sand, and shell that are deposited in the sandy bottom surface, while SRBs are smaller and mobile pieces distributed on the shores (Michel et al., 2013). Most SRBs are generally secondary deposits resulting from weathering of larger deposits, but some can form during initial oiling (OSAT-3, 2013). The formation of tarballs is the ultimate fate of much oil spilled in the environment (Dietrich et al., 2014); hence, the transport of oil spilled in a dynamic marine system is worth investigating. Since RMG 380 contains high levels of polycyclic aromatic hydrocarbons (PAHs), tarballs formed from it could pose long-term environmental risk to the marine ecosystem (Kiruri et al., 2013; Suneel et al., 2014; Warnock et al., 2015; Yin et al., 2015a). The tarballs also have negative economic effects for nearby communities by impacting recreational and tourism activities (Warnock et al., 2015).

Tarballs are formed through the weathering of oil at the sea surface. The weathering processes include evaporation, emulsification, dissolution, sedimentation, dispersion, spreading, photooxidation, and biodegradation, leaving behind oil components that are heavier and more viscous (NAS, 2003; Warnock et al., 2015). Tarballs also grow in size due to aggregation of smaller flakes of weathered oil that adhere to each other after agitation by winds and waves (Payne, 1982). Water-in-oil emulsions are the main precursors of tarballs, and heavier oil with high viscosities such as the RMG 380 form emulsions faster than low-density oils (Payne, 1982). Depending on the type of spilled oil, the time required to form a tarball may vary from a few days to months and is affected by the intensity of waves, currents, and winds during the transport of the oil in seawater (Clark et al., 1997; Woodham, 2010; Suneel et al., 2014). In the northern Gulf of Mexico (nGoM), evaporation is believed to be the primary weathering mechanism for light hydrocarbons when oil is floating in the ocean, but photodegradation and other physico-chemical processes also contribute to the weathering process (Patton et al., 1981; Liu et al., 2012; Bacosa et al., 2015a; Yin et al., 2015a).

Although tarballs scattered along the shorelines undergo various weathering processes, biodegradation is mainly responsible for their

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eventual elimination from the environment (Warnock et al., 2015). However, the small surface area to volume ratio of tarballs hinders biodegradation by limiting the ability of bacteria to access the hydrocarbons (Atlas, 1981; Leahy and Colwell, 1990). The rate of biodegradation also depends on the source oil, types of microbes, and environmental conditions. Biodegradation occurs at a faster rate in warmer climates such as the Gulf of Mexico as these environments are more conducive to microbial activities (Warnock et al., 2015; Bacosa et al., 2015a). Microorganisms isolated from tarballs have varying growth profiles, and efficient consumers such as *Chromobacterium* can degrade tarballs (Itah and Essien, 2005). Tarballs also can act as reservoir for pathogenic bacteria such as *Vibrio*, which may not directly consume hydrocarbons in tarballs but benefit from by-products of hydrocarbon degradation (Tao et al., 2011; Liu and Liu, 2013). However, the hydrocarbon-degrading bacterial community associated with oil residues varies considerably with hydrocarbon composition (Bacosa et al., 2010; Bacosa et al., 2012; Bacosa et al., 2015a; Bacosa et al., 2015b), and those associated with tarballs are not well understood.

The beaches in the nGoM, particularly those of Texas barrier islands are frequently impacted by tarballs at different times of the year (Macko et al., 1981; Warnock et al., 2015; Bellinger, 2015). Numerous studies have just focused on chemical methods for analyzing tarballs, but fingerprinting alone is not sufficient to trace the sources and determine the fate of tarballs (Zakaria et al., 2001; Suneel et al., 2013; Mulabagal et al., 2013; Warnock et al., 2015). A few publications include numerical experiments involving tarball transport (Dalyander et al., 2014), and only the work of Suneel et al. (2014) applied both fingerprinting and modeling techniques (Warnock et al., 2015). Here, we describe the results of an integrated approach using oil transport modeling, source fingerprinting, hydrocarbon composition, and bacterial community analysis. All of these components are important for understanding the fate of tarballs in the marine environment, considering that the weathering and transport processes are intertwined.

The 2010 Deepwater Horizon (DWH) Oil Spill and the 2014 Texas City "Y" Spill are two major recent spills in the nGoM (Yin et al., 2015b). While the weathering patterns and microbiology of the oil residues from the DWH have been extensively studied for about 5 years, the fate of remnant oil from the TCY Spill is yet to be studied. To date only the work of Yin et al. (2015b) reported on TCY Spill, and they found that the oil residue collected close to the spill site experienced little weathering, but they only collected one sample and did not examine temporal and spatial changes in hydrocarbon and bacteria composition. In this study, we modeled the transport of oil from the TCY Spill site in Galveston Bay to Mustang Island, fingerprinted and characterized the tarballs from TCY Spill deposited on Galveston and Mustang Islands, and determined the associated bacterial community that may play a role in hydrocarbon degradation. Results from this study are important in understanding the dynamics and fate of oil residue along the Gulf coast, considering the extensive oil-related activities in the nGoM and the predominant sources of PAHs in the water column is of petroleum origin (Adhikari et al., 2015).

2. Materials and methods

2.1. Numerical modeling

Numerical drifters were run offline using saved output from a high-resolution model of the Texas and Louisiana shelves. The circulation model was run using ROMS and has been previously found to capture the shelf currents, sea level and temperature, and spatial structure of the salinity field reasonably well (Zhang et al., 2012a; Zhang et al., 2012b). The drifters were simulated using the TracPy wrapper of the TRACMASS trajectory model, which runs natively on the staggered Arakawa C grid using in ROMS to step drifters forward with the highest accuracy possible for given output (Döös et al., 2013; Thyng and Hetland, 2014). More details of the combined model system are available in Thyng and Hetland (in revision). A velocity correction of −0.3 m/s in the along-shore direction was used to better align the model velocity during this particular time period with that from a Texas Automated Buoy System (TABS) buoy (D, near San Jose Island, between Mustang and Matagorda Islands) (http://tabs.gerg.tamu.edu/). About 8000 drifters were initialized 100 m apart over 2 simulations and run forward for 10 d starting from the approximate spill time until 6 h later, to account for oil that may have continued to leak out of the barge. Drifters were located vertically at the surface of the ocean and advected by a combination of the surface currents and direct wind drift that changed in time over the simulation. The current was combined with 3% of the wind at a 7° deflection angle to the right (due to the Coriolis Effect, Dietrich et al., 2012) for the first 3 d – while the oil was in a slick – and linearly decreased to zero over the 4th day to represent the oil breaking down into tarballs which do not feel the wind directly. These times were chosen to align with the appearance of the oil as seen in the photographs taken by spill responders (NOAA, 2014b).

2.2. Sample collection

A total of 44 tarball samples were collected from Galveston Island (GV) and Mustang Island (MT) at five different times after the TCY Spill (Table 1). Tarballs from GV were collected 6 d (8 tarballs) and 11 mo (6 tarballs) after the spill, while those from MT were obtained 11 d (8 tarballs), 3 mo (6 tarballs), and 13 mo (16 tarballs) after the spill. These samples were collected from the same location in the beaches of GV and MT at different times one year after the TCY Spill to account for long-term weathering of the surface tarballs. The tarballs were collected aseptically using a stainless steel spoon, placed in pre-combusted sterile glass jars, transported to the laboratory on ice, and stored in the freezer (−20 °C) until analysis. The sand in the periphery of selected tarballs was also sampled similarly to account for background bacterial community.

2.3. Hydrocarbon analysis

The tarballs were freeze-dried for 24 h prior to further analysis. Before extraction, each sample was spiked with deuterated surrogate standards — hexadecane-d_{34}, acenaphthene-d_{10}, phenanthrene-d_{10}, and perylene-d_{12}. About 2 g from each sample was extracted by sonication using 20 mL dichloromethane. The total solvent-extractable materials (TSEM, expressed in mg/g) as defined by Wang et al. (2004), was determined by transferring an aliquot of the extract (5 mL) to a pre-weighed glass container, filtering through a column with glass wool, and evaporating the solvent gently with a nitrogen stream (Liu et al., 2012). For hydrocarbon analysis, sample clean-up and fractionation were conducted according to Liu et al. (2012) and Wang et al. (2004). Briefly, 1 mL of

Table 1
Tarballs collected from Galveston and Mustang Islands.

Sampling site	Date of sampling	Time after spill	No. of samples	Sample label
Galveston Island	3/28/2014	6 d	8	Gv1–Gv8
Mustang Island	4/02/2014	11 d	8	Mt1–Mt8
Mustang Island	6/20/2014	3 mo	6	Mt9–Mt14
Galveston Island	2/20/2015	11 mo	6	Gv9–Gv14
Mustang Island	4/19/2015	13 mo	16	Mt15–Mt30

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