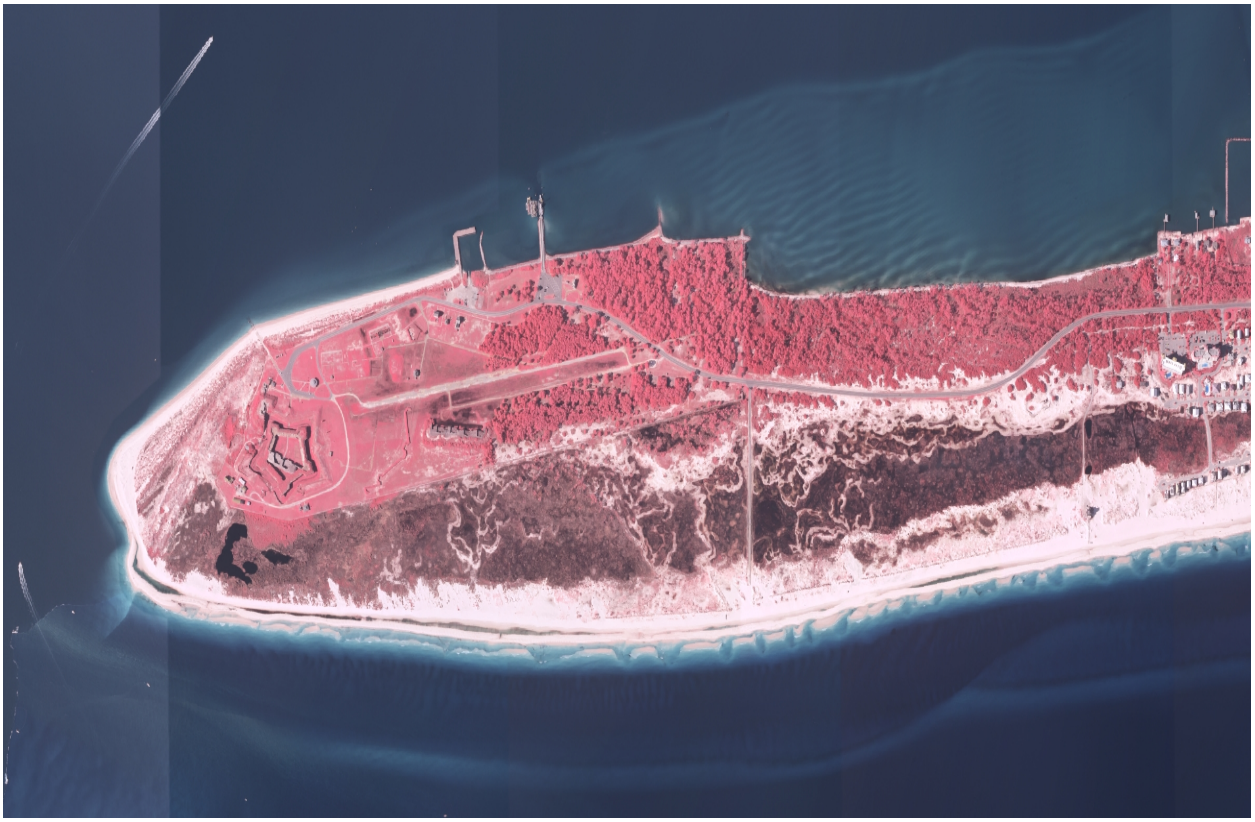
OPERATIONAL SCIENCE ADVISORY TEAM (OSAT-3)
Unified Command

Investigation of Recurring Residual Oil in Discrete Shoreline Areas in the Eastern Area of Responsibility



Prepared for

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Deepwater Horizon MC252

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Executive Summary

Extensive field investigations and response activities have been conducted in the past three years along the Eastern states of the Gulf of Mexico (Mississippi, Alabama, and Florida) following the Deepwater Horizon MC252 Spill of National Significance (MC252 spill). These activities have resulted in many locations meeting endpoint criteria defined in the Deepwater Horizon Shoreline Clean-up Completion Plan (SCCP) (2011). However there are some remaining discrete areas of shoreline that have experienced periodic remobilization of weathered oil ("re-oiling") which has prevented or delayed these segments from reaching the endpoint criteria. The program outlined in this document was initiated to integrate the various types of data collected during the Response and utilize these data, aerial photographs, and output from hydrodynamic models to provide the Federal On-Scene Coordinator (FOSC) with information on the likely source(s) of residual oil and the mechanism(s) whereby re-oiling may be occurring in these specific shoreline locations.

The third Operational Science Advisory Team (OSAT-3) was chartered to provide a science-based review of data collected during the MC252 spill response; to conduct directed studies and sampling as necessary to evaluate source(s), transport, and deposition of weathered residual oil from the MC252 spill; and to recommend additional operational activities to more effectively recover this material. The decision on whether or not this oil is amenable to removal actions[1] under the provisions of the *Clean Water Act,* the *Oil Pollution Act of 1990,* and the *National Oil and Hazardous Substances Pollution Contingency Plan* lies with the FOSC. The OSAT-3 charter outlined five tasks:

> **Task 1**. Evaluate the trends observed in frequency, rate and potential for remobilization of oil on segments.
>
> **Task 2**. Determine and record the locations and typical shoreline profiles and morphology for likely source(s) of residual oil or origin of the surface residual balls (SRBs).
>
> **Task 3**. Define or determine the mechanisms whereby re-oiling phenomena may be occurring.

[1] The Oil Pollution Act of 1990 (OPA 90) defines a removal action as "containment and removal of oil or a hazardous substance from water and shorelines or the taking of other actions as may be necessary to minimize or mitigate damage to the public health or welfare, including, but not limited to, fish, shellfish, wildlife, and public and private property, shorelines and beaches."

Task 4. Investigate the potential for mitigating actions that may be taken to reduce these potential occurrences and, to the extent mechanisms are identified, evaluate their feasibility, and the net environmental benefit of employing such methods.

Task 5. Recommend a path forward in order to reach SCCP guidelines or appropriately manage identified areas through alternative methods.

The OSAT-3 team used a three-pronged approach to define the sources and mechanisms of shoreline re-oiling associated with segments failing to meet SCCP endpoint criteria:

- Evaluation of existing observation and material collection data to validate and characterize re-oiling conditions across the varied shoreline types in the Area of Responsibility (AOR) over time.
- Development of hydrodynamic models to assess the mobility, transport, and deposition of residual oil and native sediment.
- Evaluation of the potential for formation and persistence of weathered oil deposits by mapping changes in beach morphology since initial shoreline oiling.

Integrated assessments of these data (both spatial and temporal) were conducted during multiple review sessions with coastal experts and participating state and federal response and natural resource agency groups from February through August 2013. These sessions addressed shoreline segments that did not meet SCCP endpoint criteria as of June 1, 2012 (634 of the 3,007 segments in the Eastern states AOR), as determined by the Gulf Coast Incident Management Team (GCIMT), as well as segments that did meet endpoint criteria, but were of continuing concern to the state and federal response and natural resource agencies as identified during the review sessions.

Based on the initial integrated assessment, the OSAT-3 team determined that sufficient data and Geographic Information System (GIS) capabilities were available to evaluate the formation and persistence of weathered oil deposits across the AOR. The FOSC concurred with a recommendation made by the National Oceanic and Atmospheric Administration (NOAA) Scientific Support Coordinator (SSC) and directed that Tasks 4 and 5 be separated from OSAT-3 and integrated into an operational project called the Buried Oil Project (BOP), which was executed in parallel. The intent of the BOP was to expedite delineation and recovery activities, where feasible, in areas identified as more likely to contain buried oil deposits. The BOP team regularly received data and guidance from the OSAT-3 team, and provided additional information on current field conditions. This report presents the results of OSAT-3 activities and notes where results were forwarded for further evaluation under the BOP. The results of the BOP are summarized in a report included in Appendix G.

Summary of Key Findings

- The potential for the formation and persistence of weathered oil deposits is a function of initial oiling coupled with coastal hydrodynamics and geomorphology over time (erosion and accretion). All evidence supports the hypothesis that buried oil deposits formed landward of the first sand bar on Gulf-facing beaches. Buried oil deposits are also found in protected areas and near inlets and are often associated with anchored boom, marsh vegetation, or peat platforms.

- Since initial oiling, the majority of shoreline and nearshore areas have undergone sufficient erosion (vertically and laterally) to result in breakup and/or redistribution (and cleanup) of the initial sand/oil deposits. In addition to these natural processes, buried oil deposits were excavated by Response teams once they were revealed by erosion or delineated during field activities.

- There are isolated and identifiable areas where submerged or buried oil deposits may remain, due to insufficient erosion since formation. Locations where these deposits might have persisted (assuming they formed) since the time of initial oiling were documented and provided to the BOP team for further evaluation.

- Re-oiling patterns and dominant mechanisms vary across shoreline segment types and can vary within a segment depending on conditions. Increases in material collections/observed shoreline re-oiling are not a definitive indication of potential concentrated sources of material at that location. Conversely, periods of low re-oiling observations may not indicate an absence of source material, as concentrated deposits do not break up and remobilize if covered by sand.

- Four major mechanisms of weathered oil remobilization were identified:
  (1) Cross-shore (perpendicular to the shoreline) transport of material broken off of submerged oil mats (SOMs) in the intertidal zone in close proximity to the stranding;

(2) Cross-shore transport and/or uncovering of diffuse material referred to as surface residual balls (SRBs) or patties (depending on size), in the intertidal and nearshore subtidal zones;

(3) Longshore (parallel to shore) transport and deposition of SRBs from diffuse sources; and

(4) Simple uncovering of material of all sizes (buried since initial oiling and/or residual oil from cleanup operations) across tidal zones.

- In Gulf-facing segments, most residual oil remobilization is caused by the burial, uncovering, and/or cross-shore transport of small, diffuse material nearshore. Because this material is less mobile than the surrounding sand, it is likely to become buried and exposed under normal sand transport processes, thereby lengthening the time it may take to move onshore.

- Differences in initial oiling (less oil and more patchy distribution) and lower wave energy along the protected areas (those areas that are not exposed to wave action from the Gulf of Mexico, such as mainland beaches and marshes of Mississippi and the back side of Mississippi barrier islands) compared to Gulf-facing beaches results in sand/oil mixtures with different characteristics in these environments.

- Hydrodynamic modeling results indicate that, with the exception of tidal inlets, larger SRBs and patties (>2.5 cm in diameter) are redistributed to distant down-current locations only during storm conditions (offshore waves greater than 2 meters). This modeling also indicates that some regions are more conducive to accumulation of smaller residual material than others.

- Not all buried oil has been removed from this AOR due to a combination of ecological, operational and safety considerations. Most of the re-oiling in this AOR is from diffuse secondary sources being reworked by coastal processes, and that pattern is likely to continue. Further residual oil remobilization of some segments in the AOR may occur, but the conditions needed to remobilize (and the locations of these re-oiling occurrences) are generally predictable.

1.0 Introduction

The purpose of this report from the third Operational Science Advisory Team (OSAT-3) is to provide the Federal On-Scene Coordinator (FOSC) for the Deepwater Horizon MC252 Spill of National Significance (MC252 spill) with information on the likely source(s) of residual oil and the mechanism(s) whereby remobilization of residual oil ("re-oiling") may be occurring in specific shoreline locations along the Eastern states of the Gulf of Mexico (Mississippi, Alabama, and Florida) affected by the MC252 spill (Appendix A). This information is intended to inform the FOSC decision-making on potential operational actions that can be taken to identify, delineate, and recover this residual material more effectively from targeted shoreline segments that have been delayed in endpoint criteria defined in the *Deepwater Horizon Shoreline Clean-up Completion Plan* (Unified Command, 2011) (*http://www.restorethegulf.gov/sites/default/files/u306/Signed%20SCCP1.pdf*). The OSAT-3 Charter will be closed out after completion of Tasks 1-3 (Appendix A) and release of final reports for the Eastern States and Louisiana AORs.

The coastline was divided into segments by the Shoreline Cleanup Assessment Technique (SCAT) teams during the MC252 spill response in order to provide (1) a reference system for the location of oiled areas, and (2) a detailed documentation of the shore zone. A total of 3,007 segments were defined by SCAT in the Eastern AOR (Table 1.1) and varied in length from 10 to 8,588 meters, with an average of 580 meters. Segments were numbered based on a prefix (ALBA = Alabama Baldwin County) followed by a number based on an alongshore sequence (ALBA1-044).

State	Total # of Segments[a]		# of Segments that Failed SCCP Criteria[b] (as of 6/1/2012)	
	Federal Land	State Land	Federal Land	State Land
Alabama	114	718	16	199
Florida	145	1275	65	107
Mississippi	194	567	115	132
Subtotal by state	453	2560	196	438
Total for AOR	3007		634	

[a]Segments defined by SCAT during response activities; 6 segments (3 in Florida, 3 in Mississippi) have dual federal and state jurisdiction;
[b]SCCP Criteria for Eastern States AOR Shoreline Segments (Unified Command 2011)

Table 1.1 MC252 spill response shoreline segments in the Eastern states AOR.

Shoreline segments that failed to meet the *Shoreline Clean-up Completion Plan* (SCCP) endpoint criteria as of June 1, 2012 (634 segments, Figure 1.1[2]) and shoreline segments that met endpoint criteria but remained a continuing concern to the state and federal response and natural resource agencies were evaluated in the OSAT-3 process.

These segments span a wide range of:

- Environmental settings (e.g. sediment type[s], wave energy, tidal range, currents, vegetation, and erosion/deposition patterns)
- Shoreline activities not associated with the MC252 spill response (e.g. beach renourishment, dredging, jetties, and culverts)
- Oiling histories (e.g. frequency, degree, and consistency of initial oiling)
- MC252 spill response activities (e.g. nearshore booming and oil removal operations).

Figures 1.2 through 1.7 are aerial images of segments illustrating the shoreline types investigated in the AOR.

[2] Larger versions of each of the figures presented in this document are available in Appendix F. Additionally, all maps and associated data can be viewed at http://www.restorethegulf.gov/

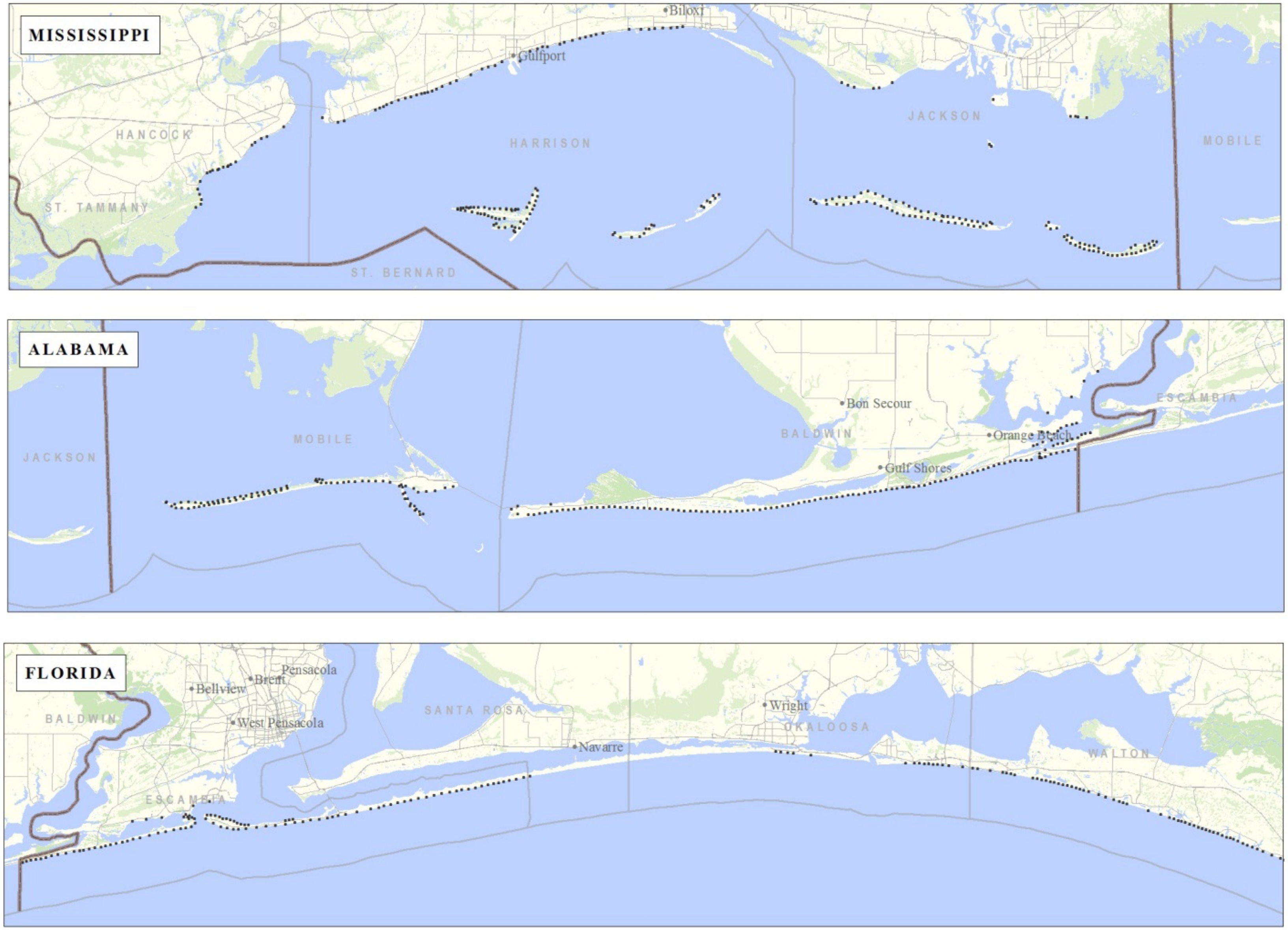

Figure 1.1 Overview of segments in the Eastern states AOR that failed to meet *Shoreline Clean-up Completion Plan* (SCCP) endpoint criteria as of June 1, 2012.

Figure 1.2 Aerial image showing segments along Mississippi mainland coast.
Segments MSHA1-031 / 032 are native marshes with some sand (white) and are in a sheltered location with low wave energy. Segment MSHA1-036 is in a similar wave energy environment, but receives periodic sand additions (artificial renourishment).

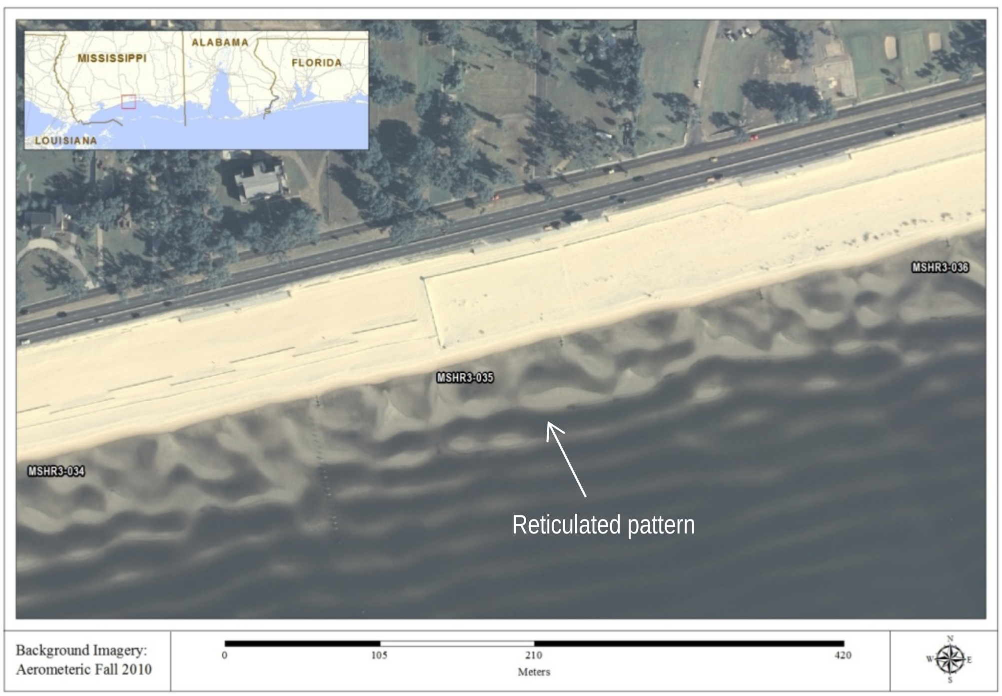

Figure 1.3 Aerial image of amenity beach area along Mississippi mainland.
The beach shown in segments MSHR3-034 to MSHR-036 is maintained by artificial renourishment of sand to provide recreational value. Note the "reticulated" patterns in the shallow nearshore area. These areas are amenable to formation and persistence of patty-sized deposits.

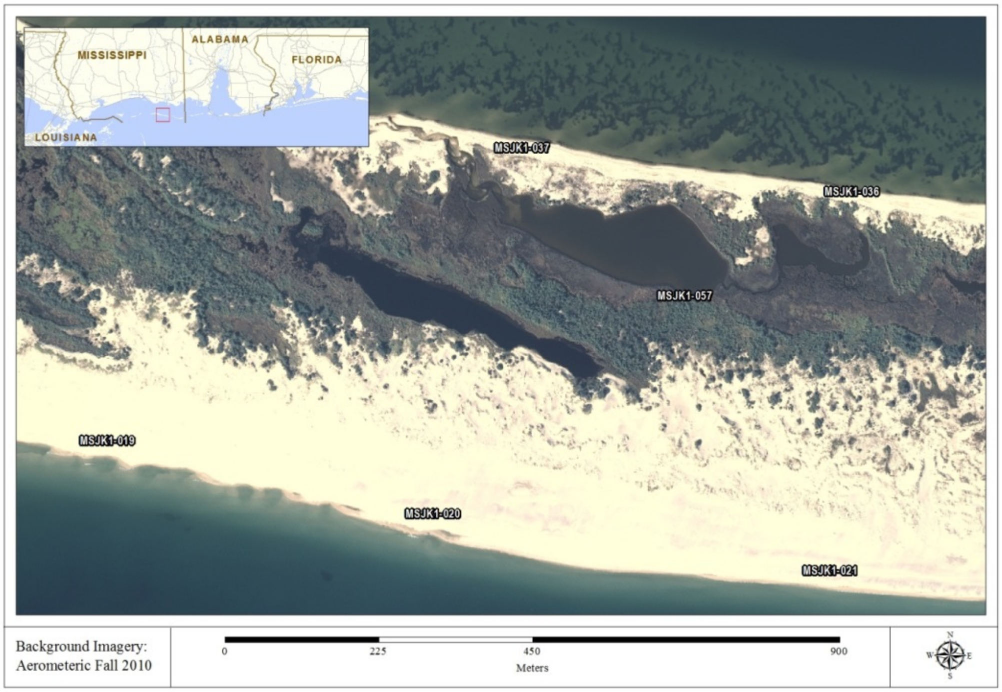

Figure 1.4 Aerial image of segments along Horn Island Mississippi, part of Gulf Islands National Seashore. Segment MSJK1-037 is on the back side of the barrier island and is not subject to high energy waves from the Gulf of Mexico. The shallow reticulated sand along these areas support submerged aquatic vegetation and provide valuable wildlife habitat. Segment MSJK1-020 is a sandy beach and faces the Gulf of Mexico.

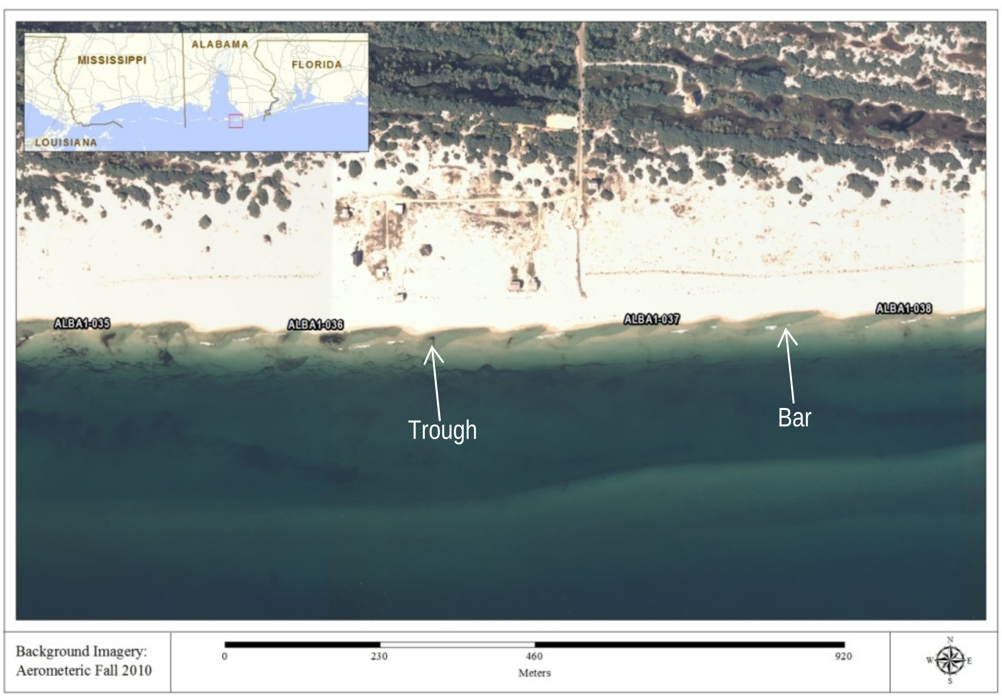

Figure 1.5 Aerial image of segments along Gulf-facing beaches in Bon Secour National Wildlife Refuge, AL. Longshore bars (a) and troughs (b) are evident in segment ALBA1-037. These features are the result of natural geomorphic processes (waves, current).

Figure 1.6 Aerial image of segment ALBA2-011 along Gulf-facing beach in Alabama.
The inlet shown is maintained by dredging to allow water exchange between Little Lagoon and the Gulf of Mexico. Extensive SOMs were removed by Operations in this area during the MC252 spill response.

Figure 1.7 Aerial image of Pensacola Pass, Florida.
Strong tidal currents move through the Pass which is maintained by dredging. Extensive SOMs were removed in segment FLES1-043 by Operations during the MC252 spill response formed by a combination of heavy initial oiling, beach morphology, wave energy, and booming.

For the purposes of this report, three forms of residual oil/sand mixtures were identified in the sandy intertidal and shallow surf-zone along the Eastern States AOR:

(1) **Submerged oil mats (SOMs).** SOMs are primary deposits (undisturbed since initial stranding, amalgamation, and burial) in the subtidal and intertidal zones with a surface area greater than 1 square meter. They formed under two scenarios: 1) when weathered oil at the water surface at the time of initial oiling reached either a shallow environment with sufficient energy to facilitate entrainment of sand by the oil, and therefore settle, or 2) when surface oil arriving near coastlines was stranded and seeped into the sand at low tide. Later, these primary deposits may have been covered by sand. SOMs observed during the MC252 spill response were generally meters in cross-shore width, meters to tens of meters in alongshore length, and up to tens of centimeters thick (Figure 1.8).

Figure 1.8 Submerged oil mats (arrow) and other deposits in a) segment ALBA1-040 (photo taken 8/23/2010), b) segment ALBA2-008 (photo taken 8/7/2010).

(2) **Patties**. Patties can be found across all tidal zones and have a diameter ranging from 10 centimeters to 1 meter, and can be primary or secondary deposits (fragments of primary deposits transported from initial depositional location). Primary patty deposits are commonly found in lower energy environments, such as the back side of barrier islands or along mainland beaches and marshes (with sand) although they have been documented on Gulf-facing beaches (Figure 1.9).

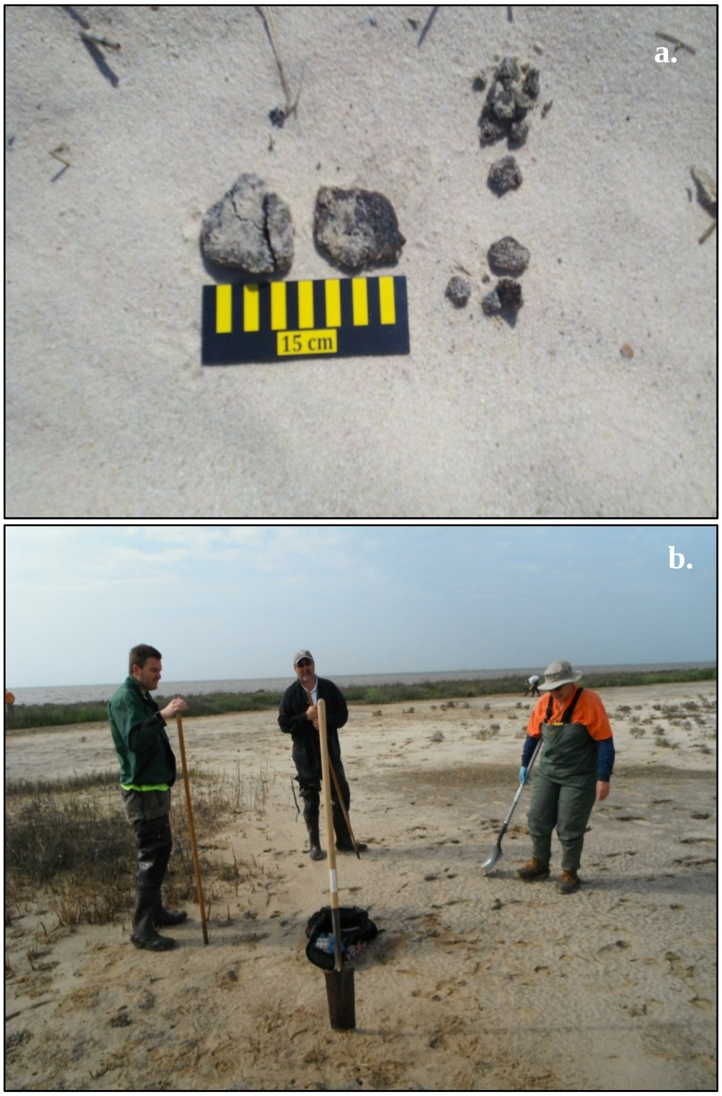

Figure 1.9 Patty-sized deposits observed in a) in segment MSHA1-049 (photo taken 11/2/2012), b) in segment MSJK4-019 (photo taken 3/7/2012).
Both deposits were described by SCAT as having “gooey” texture, indicative of low wave energy during initial stranding and lack of repeated wave action/exposure post formation.

(3) **Surface residual balls (SRBs)**. SRBs can be found across all tidal zones and have a diameter of less than 10 centimeters. In general, most SRBs are secondary deposits resulting from weathering of larger deposits, but it is possible some formed during initial oiling (Figure 1.10).

Figure 1.10 SRB in intertidal zone of amenity beach on segment ALBA1-037 (photo taken 5/8/2011).

Oil was deposited along the shoreline in three zones: the subtidal, intertidal, and supratidal (see Figure 1.11). Residual oil in the subtidal zone is usually in the form of SOMs and oil in the supratidal zone is usually oil that was buried during storm events. SRBs may be found in all three zones, but are generally restricted to the subtidal and intertidal zones.

As of June 1, 2012, remobilized residual oil on the shorelines across this AOR is primarily SRBs. SRBs are a mixture of mainly sand and 4-20 percent weathered oil. There are some areas in the AOR with little sand, where weathered oil mixed with or was stranded on finer grained, organic sediments, such as marshes and relic peat platforms on the back sides of the barrier islands. Chemical testing as part of the OSAT-2 study (2011) showed that the chemicals of concern from a human health and an ecotoxicity standpoint have largely been depleted due to the extensive weathering that the oil has undergone since its release (see *http://www.restorethegulf.gov/release/2011/03/01/osat-2-fate-and-effects-oil-beaches*).

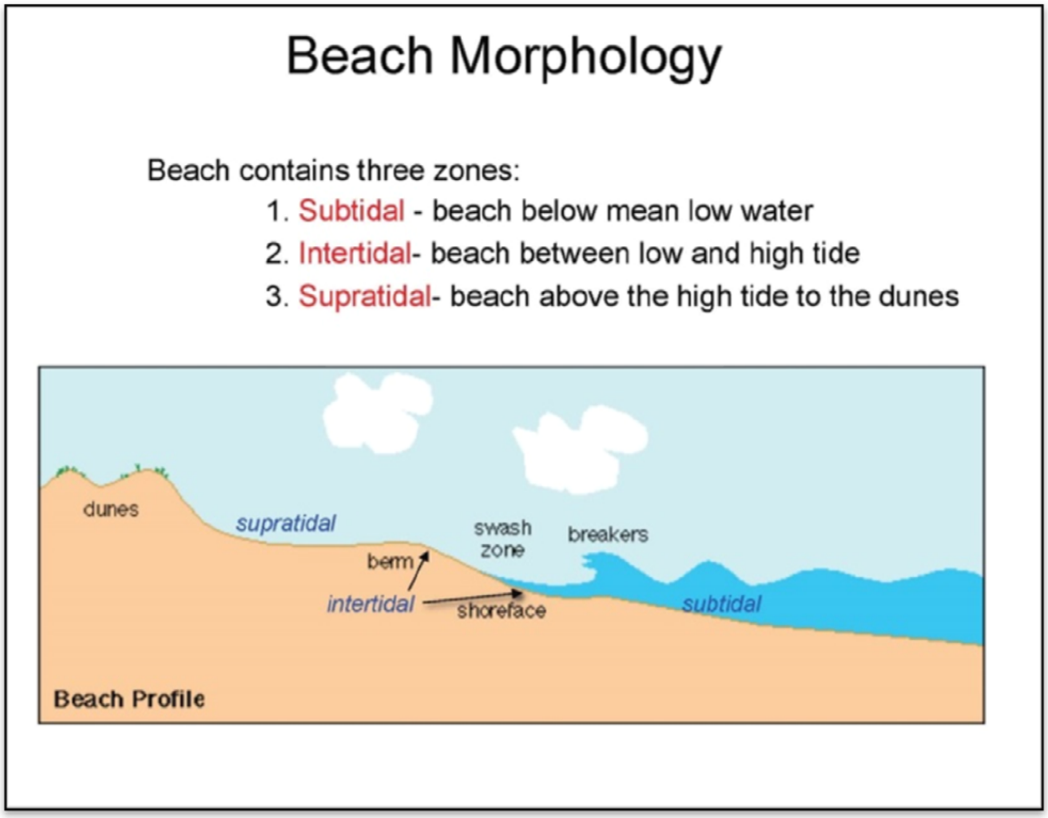

Figure 1.11 Shoreline zones. From OSAT-2 (2011).

The OSAT-3 team used the following process to define the source and mechanisms of re-oiling associated with shoreline segments that failed to meet SCCP endpoint criteria:

- Characterized shoreline conditions at the time of oiling through review of detailed aerial images, georectified photographs, and information derived from the SCAT teams.
- Applied hydrodynamic models developed specific to the AOR to refine understanding of formation, mobilization, transport and deposition of sand/oil mixtures associated with re-oiling.
- Used time-sequential aerial imagery to examine shoreline erosion and accretion since initial oiling in evaluation of the potential for concentrated buried oil deposits as a source of re-oiling.
- Based on this evaluation, coupled with an extensive assessment of available SCAT and operational data, sources and mechanisms for re-oiling were defined and areas with a higher potential for contribution by concentrated sources of buried oil were identified for subsequent evaluation by the BOP team.

The final products of OSAT-3 are (1) a segment-by-segment characterization of re-oiling, including spatial databases of all data evaluated, and (2) identification of specific areas within shoreline segments that may contain SOMs in the intertidal and nearshore area. This information was provided by the OSAT-3 team to the BOP team as the foundation for developing plans for delineation and removal of potential deposits of residual oil. The areas investigated by the BOP team are discussed in Appendix G.

2.0 Methods

At the beginning of the OSAT-3 project, the state response and natural resource representatives submitted a preliminary list of the highest priority segments that had not met SCCP endpoint criteria as of June 1, 2012. The OSAT-3 science team conducted an initial review of SCAT and Operations data for the identified segments. The data demonstrated a general decreasing trend in material collections as well as a decrease in the degree of re-oiling.

A number of factors not related to sources of residual oil can influence daily material collections and observations including tide level, time since last survey, debris on beach obscuring SRBs and periodic access restrictions due to environmental and/or cultural resource issues. Periods of low re-oiling observations could not be used as a definitive diagnostic for the absence of a concentrated source, such as a SOM, as SOMs have been located in some segments in the AOR after extended periods of low material recoveries. Conversely, increases in re-oiling within a segment may also not be indicative of the presence of SOMs. Increased collections of SRBs and patties along some segments were directly related to SCAT surveys being conducted at extreme low tides when material typically underwater was exposed (Figure 2.1).

Re-oiling sufficient to cause some segments to not meet SCCP endpoint criteria is due to the interaction among multiple sources and varied mechanisms. Therefore, examination of re-oiling patterns alone would not be sufficient to fully determine sources and mechanisms of re-oiling across the AOR. During the initial evaluation, two main issues emerged as essential to understanding residual oil remobilization and potentially identifying source deposits included: 1) longshore transport and deposition of sand/oil mixtures and 2) formation and persistence of SOMs. Specifically:

- Can SRBs move long distances alongshore (from one segment to another)?
- If so, how do differences in the clean-up methods influence the time it will take for segments to return to baseline conditions?
- Are there unknown SOMs in deeper offshore areas or in shallow bays that could be a source of continued shoreline re-oiling?
- Are there additional data/methods available to reduce uncertainty related to the persistence of SOMs?

Figure 2.1 SRBs and patties collected along Mississippi amenity beaches (MSHR3-035 and MSHR3-036). Deposits were collected on 1/22/2012 in the nearshore during an extreme low tide event. The material collected along these segments (Panels c through f) were collected well Gulf-ward of the wrack line (Panels a and b) in areas typically submerged. A similar pattern of increased collections during extreme low tide events was observed along many segments evaluated by the OSAT-3 team.

Additional studies were conducted to address information gaps related to longshore transport of SRBs and the formation/persistence of SOMs. Under the direction of the OSAT-3 Science team, coastal experts developed modeled estimates of the mobility and transport of native sediment and SRBs based on wave conditions across the AOR since initial oiling. Results of these models provided boundaries on remobilization, transport, and deposition processes associated with re-oiling. In addition, potential SOMs persistence through time was evaluated by mapping changes in shoreline morphology since initial oiling using high-resolution aerial images collected just prior to and through the MC252 spill response.

The OSAT-3 team included a wide range of specialists, including information technologists, GIS analysts, and subject matter experts. The team developed an infrastructure for effective data management, visualization and analysis. The concurrent acquisition, processing and integrated analysis of multiple data sets was necessary for the development of timely, fit-for-purpose products. No individual component used in the analysis was considered determinative. A weight-of-evidence process that accounted for the strengths and weaknesses of different lines of evidence was utilized to arrive at a consensus on the relevant sources and mechanisms for re-oiling of individual segments across the varying shoreline types in the AOR.

2.1 Overview of Integrated Assessment

The OSAT-3 team integrated information and data from these main areas:

- Operations and SCAT data, which provided information on re-oiling.
- Hydrodynamic models to assess the mobility, transport, and deposition of residual oil and native sediment.
- Evaluation of the potential for formation and persistence of SOMs by mapping changes in beach morphology since initial shoreline oiling in areas amenable to the formation of SOMs.

The data evaluated by OSAT-3 included output from hydrodynamic models for sediment and SRB mobilization and transport, wave energy and sediment suspension processes associated with SOM formation, interpretation of aerial images to understand shoreline morphology during initial oiling and changes over time, oiling history (SCAT data), data associated with removal of material from segments (Operations), and important ancillary information (wind, waves, and tides).

The aerial imaging and GIS system utilized by OSAT-3 facilitated spatial and temporal integration of an unprecedented amount of oil spill response data. For example, the GIS system allows immediate access to orthoimagery (Figures 1.2 through 1.7, 2.2); oiling history; more than 1 million georeferenced, time-stamped photographs (Figure 2.2); and SCAT subsurface oiling records (Figure 2.3). In addition to data access, the system allows spatial and temporal examination of multiple data sets.

Integrated assessments of the data and information (both spatial and temporal) were conducted during multiple review sessions with coastal experts and participating state and federal response and natural resource agency groups from February through August 2013. Based on the available data, the OSAT-3 team determined that local diffuse sources are responsible for most but not all of the re-oiling observed in the segments that do not meet the SCCP endpoint criteria. In addition to these local sources, review of the SCAT data provided evidence of longshore transport and deposition of small SRBs along segments near tidal inlets. The potential for distant sources to contribute to re-oiling across the AOR due to longshore transport and deposition was evaluated based on the output of the hydrodynamic models.

The contributions, mechanisms, and locations of more concentrated deposits (SOMs and other buried material) were evaluated by first examining the potential for their formation utilizing oiling history and nearshore morphology at the time of initial oiling. Next, the OSAT-3 team evaluated the persistence of these areas through time by mapping changes in shoreline morphology utilizing high-resolution imagery.

An integrated assessment of the contributions of local diffuse, concentrated, and more distant sources provided a more thorough understanding of the complexity of the sources and mechanisms associated with shoreline re-oiling in this AOR.

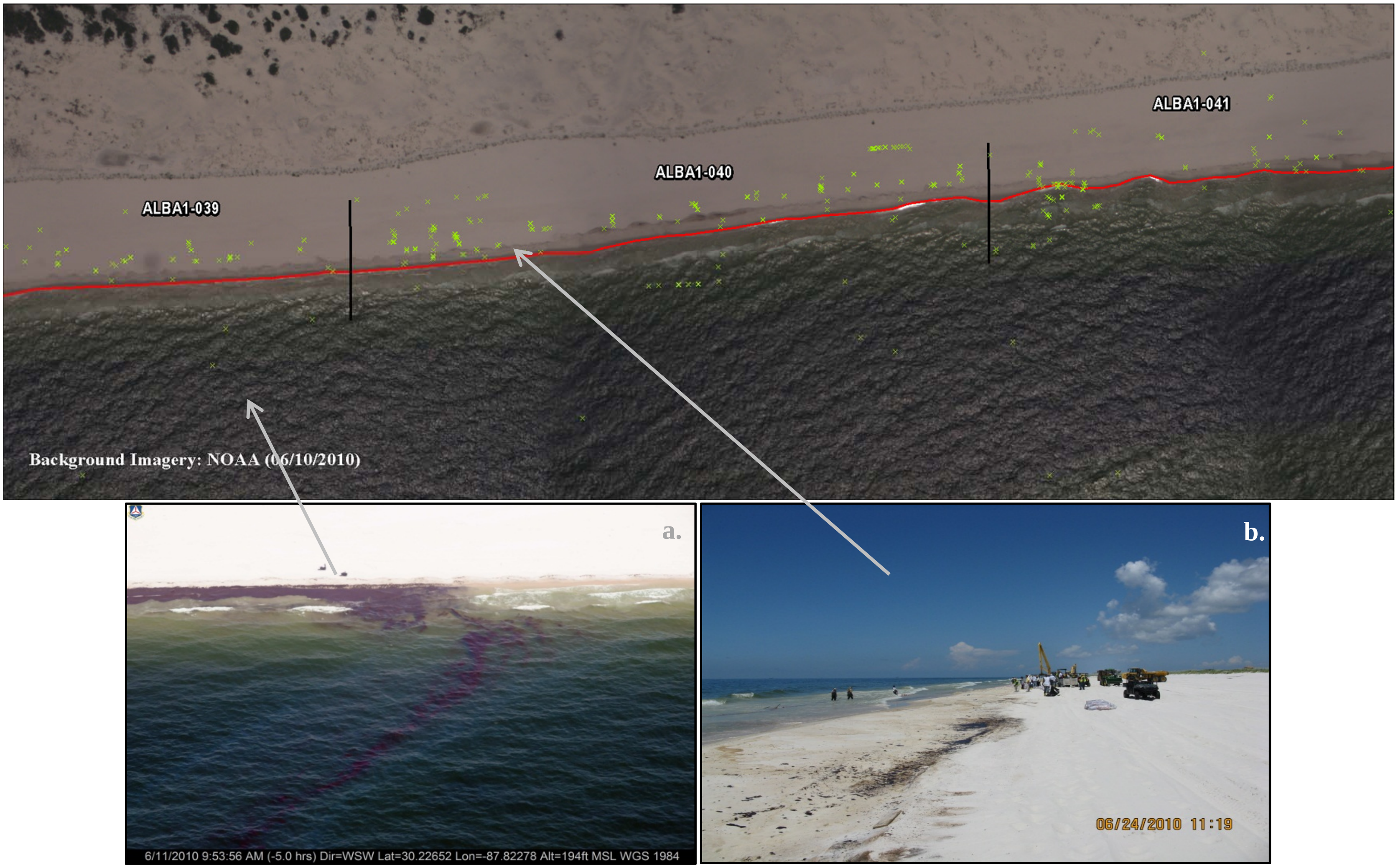

Figure 2.2 **Location and examples of georeferenced photographs in areas around ALBA1-040.** Each green symbol designates the location of a georeferenced photograph. Panel a) is an aerial photograph taken on 6/11/2010, a day that SCAT observed heavy oiling along the segment. Panel b) is a photograph showing operational removal activities on 6/24/2010.

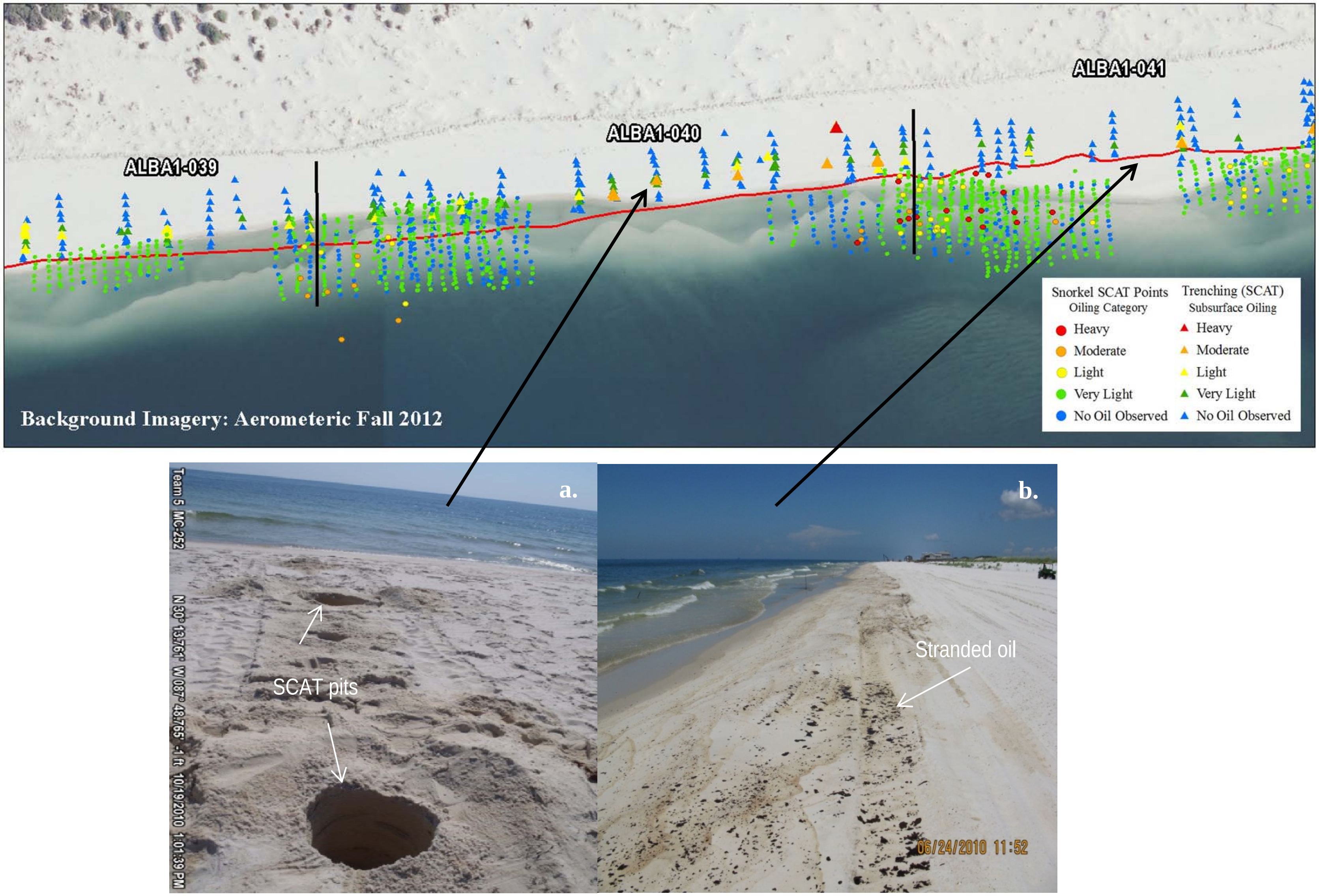

Figure 2.3 Location of SCAT (triangles) and snorkel SCAT (circles) coded by oiling condition.
Panel a) documents SCAT subsurface assessments (photo taken 10/19/2010). The pit nearest the shore had no observable oil and the adjacent pit had moderated oiling. Panel b) shows heavy surface oiling with a range of material sizes (photo taken 6/24/2010). Symbols denote location and oiling condition observed during Response activities.

2.2 Evaluation of Field Data to Determine Characteristics of Segment Re-Oiling

The primary data sources used to evaluate re-oiling in the segments of interest were provided by the MC252 spill response SCAT and Operations teams. The Operations data included a daily record of material collections by segment in the AOR. Material collections data included recovery location, the amount of material collected (in pounds), the method of material recovery (i.e., manual or mechanical), the angularity of the material collected, and in some cases, the size of the material collected (Appendix F). Operations activities focused on specific locations provided additional data on the location of surface or sub-surface oiled material (including SOMs, SRBs, and stained sand) observed in beach areas in specific portions of the AOR. SCAT survey data used in the evaluation included surface and subsurface assessment of oiling condition. Augmenting the shoreline SCAT surveys, field teams also conducted surveys in the subtidal zone (snorkel SCAT). The focus of the subtidal snorkel SCAT was to locate and delineate SOMs in the AOR to guide Operations activities (Appendix B). During the OSAT-3 review process, knowing the Z component (elevation relative to mean sea level) was important to better understanding the characteristics of SOMs relative to shoreline morphology. As a result, OSAT-3 recommended that the snorkel SCAT data collection process include this additional parameter; and this was implemented in subsequent snorkel SCAT assessments.

The SCAT teams characterized oiling by category (no oil to heavy oiling), as defined in the *Nearshore and Shoreline Stage I and Stage II Response Plan* (NOAA 2010a) (*http://gomex.erma.noaa.gov/layerfiles/23155/metadata/houma_cumulative_scat.htm*). SCAT datasets included whether oiled material was observed, the oiled material location, number of materials found (if known), size of material, and if relevant, weight of material removed from a segment. The raw SCAT data evaluated in this report are found on the Environmental Response Management Application (ERMA®) Gulf Response website, at *http://resources.geoplatform.gov/news/mapping-response-bp-oil-spill-gulf-mexico*.

Time series data of material weight, material size, and SCAT oiling category for each segment were evaluated by the OSAT-3 team for spatial and temporal patterns across the range of shoreline types in the AOR. It should be noted that SCAT and Operations teams did not always recover all of the material observed during segment surveys. These data were evaluated within the context of antecedent wind and wave patterns obtained from nearby NOAA observation stations, oiling history during the time oil was coming ashore, and characteristics of the material found (e.g., angularity, and degree of weathering). In addition, photographs taken during the MC252 spill response (including many provided by the state and federal MC252 spill response and natural resource agency groups) were examined. GIS layers were developed for georeferenced photographs to allow easy sorting (by date, location, or activity) and viewing (Figures 2.4 and 2.5).

2.3 Development of Hydrodynamic Models to Evaluate Potential Longshore Transport

A subgroup of coastal experts (Appendix C) designed a set of objectives to address the potential for SRB movement alongshore. The specific objectives of this subgroup's effort were to:

- Identify spatial patterns in longshore current direction and velocity
- Identify zones of convergence and longshore current reversal
- Identify potential sediment and SRB sinks
- Estimate SRB movement along the coast
- Determine the influence of tidal currents on SRB mobility and transport in the vicinity of tidal inlets.

The underlying approach was to develop and analyze numerically modeled estimates of the mobility and transport of sand and SRBs. Numerically modeling a time series of wave and current conditions from the start of the MC252 spill to the time of the OSAT-3 study would prohibit results from being easily extended to future time periods. Therefore, a scenario-based modeling approach was established. Wave conditions over the 25-month period from April 2010 to May 2012 were analyzed along the Gulf Coast from Florida through Louisiana. Two separate modeling efforts for the Eastern states AOR included:

(1) Florida and Alabama (U.S. Geological Survey Coastal and Marine Science Program)

(2) Mississippi and East Louisiana (University of New Orleans Pontchartrain Institute for Environmental Sciences).

Figure 2.4 Aerial image of Pensacola Pass with georeferenced photos collected during MC252 spill response. Each green symbol designates the location of a georeferenced photograph. Panel a) is an aerial image of Pensacola Pass collected by the Civil Air Patrol showing boom along segments FLES1-077 (photo taken 7/27/2010). Submerged oil mats (SOMs) were associated with anchored boom that held oil in place longer, allowing sand to mix due to wave action. Panel b) shows cleanup crews working along segment FLES1-043 (photo taken 10/16/2010). Georeferenced photographs were a valuable source of information for OSAT-3.

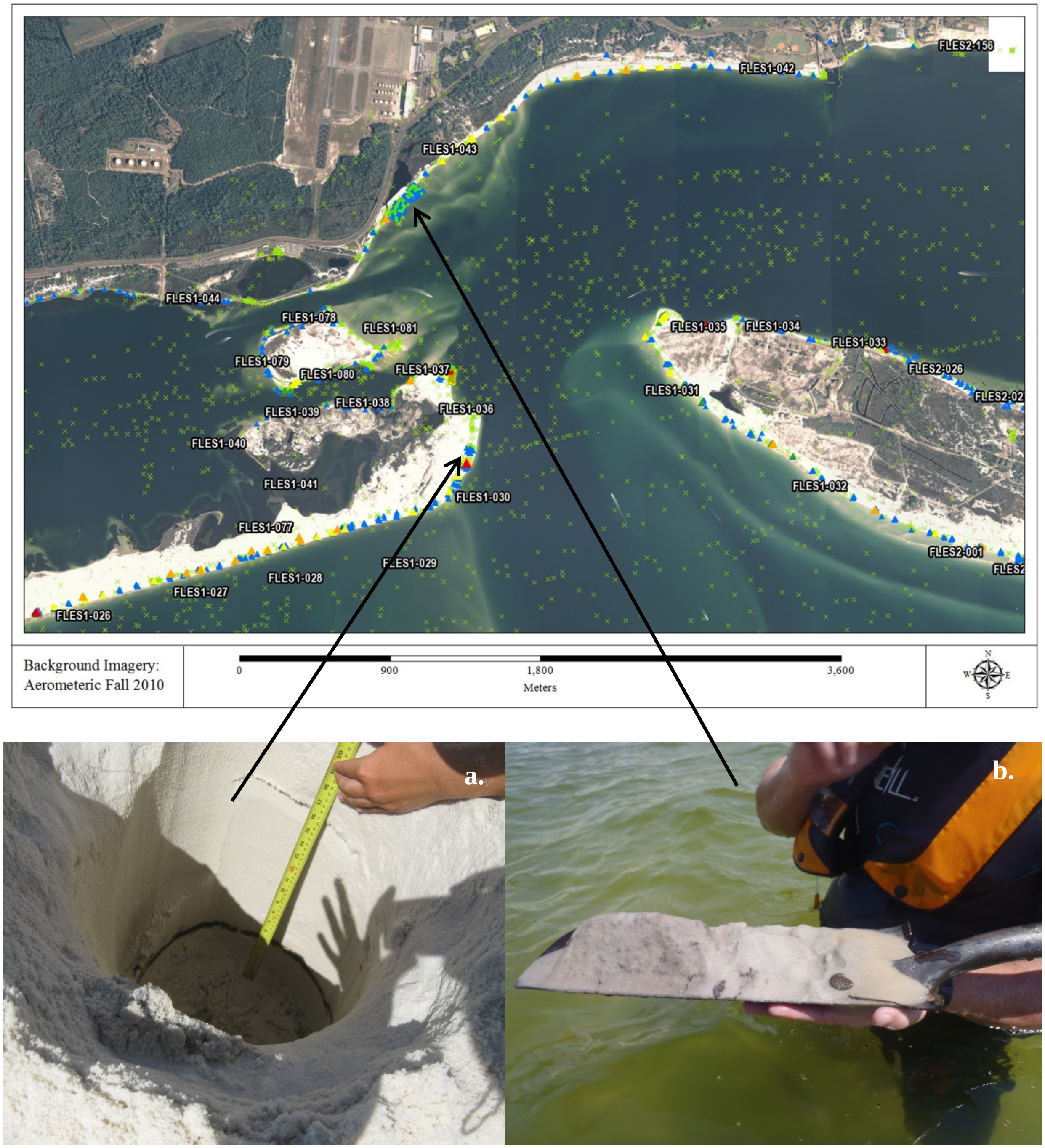

Figure 2.5 **Aerial image of Pensacola Pass with locations of georeferenced photographs of SCAT subsurface assessments.** Each green symbol designates the location of a georeferenced photograph. Colored triangles identify SCAT pit locations. Panel a) is a SCAT pit along segment FLES1-030 showing a layer of buried oil (photo taken 10/2/2010). Panel b) is a snorkel SCAT sample taken along segment FLES1-043 (photo taken 9/8/2010). This sample was taken after the removal of a submerged oil mat (SOM) in the area.

The modeling approach utilized for OSAT-3 is standard for the industry and has widespread application to hydrodynamics, sediment transport and morphology in estuarine and coastal environments. Details on methods, model validation, and results for Florida and Alabama are described in Plant et al. (2013). Appendix C contains details for models for Mississippi and East Louisiana.

The characterizations of wave scenarios, the time-weighted average of SRB mobility and potential alongshore flux, and the inlet tidal dynamics cases have been archived in GIS format. SRB and sand mobility were estimated by comparing the modeled wave- and current-induced bottom shear stress to critical values. SRBs were characterized using six size classes: 0.03 centimeters, 0.5 centimeters, 1.0 centimeters, 2.5 centimeters, 5.0 centimeters, and 10.0 centimeters. SRBs or sand grains will begin to move when the shear stress force associated with the combined action of waves and currents exceeds a size- and density-specific critical threshold value. These threshold values were estimated using a semi-empirical Soulsby-Van Rijn relationship (Soulsby 1997). The Soulsby-Van Rijn method accounts for currents, which are the dominant forces in longshore transport, and waves, which contribute a stirring action that keeps particles in motion and allows them to move with current velocities otherwise too weak to support transport. Localized turbulence and wave-to-wave variations can cause any individual particle to move at calculated stress values below threshold; however, the formulations used, on average, have been found to be accurate for surf zone calculation (Deigaard and others, 1991; Soulsby and others, 1993).

Variation in weather conditions affecting SRB mobility and transport was modeled with a total of 80 scenarios defined with five wave height bins bounded by 0.0 meters, 0.5 meters, 1.0 meters, 1.5 meters, 2.0 meters, and 5.0 meters, and 16 wave direction bins, each spanning 22.5 degrees, from 0° to 360°. The scenarios were compared to a time series of wave conditions taken from NOAA Wavewatch III operational model output at the location of NOAA buoy 42040 located 64 nm south of Dauphin Island, AL. For each scenario, a representative time in the record was chosen that best matched that scenario. The corresponding output was used to drive the boundary conditions of a higher-resolution coupled wave-flow model. Variations in water levels were accounted for in the time-series simulations. Water levels imposed at the model boundaries were obtained from the TPXO (version 7.2) global tide model, which uses a numerical tidal model and satellite-derived observations of tide elevation to produce tidal constituents (Egbert and Erofeeva 2010).

Bathymetry was supplied by the northern Gulf Coast digital elevation map (Love et al. 2012). Where available, these data were supplemented with additional sources including:

- Topographic Lidar: Louisiana Coast, Lake Pontchartrain and Mississippi Barrier Islands Lidar (NOAA 2010b)
- U. S. Geological Survey Barrier Island Comprehensive Monitoring Program (Kindinger et al., 2013)
- Digital elevation models derived from stereo-imagery collected during the MC252 spill response.

The range of hydrodynamic conditions was assumed to be well represented by the scenario approach; the validity of this assumption was quantified by comparison of reconstructed waves to observations within the model domains. The shear stress, mobility, and potential flux calculations have been applied to solid, sand-sized, round particles, and were assumed to be valid for SRBs that are sand/oil aggregates and may be non-spherical and sparsely distributed. The use of a range of critical stress values was designed to capture this uncertainty associated with particle shape and mobility. Cross-shore transport or processes in the extremely shallow swash zone were not explicitly accounted for in the model conditions. Static bathymetry was used to resolve sea-floor sand features (e.g., sand bars) 30 meters in size or greater, and that resolution was further smoothed to an alongshore grid spacing of 250 meters, assuming that variable bathymetry and smaller scale features resulted in a small impact to large-scale longshore transport patterns (within Little Lagoon Alabama, the alongshore resolution in the model increased to ~ 1.0 meters). The boundary conditions supplied by larger scale models were tested and were assumed to be accurate.

Mobility of sand was calculated to determine the potential for burial and uncovering of residual oil. The potential alongshore flux in the surf zone was also calculated for each critical stress level and SRB size class in order to identify locations of decreasing flux and hence an increased likelihood of deposition. Flow characteristics, including maximum and median surf zone, longshore current, and locations of current convergences and decelerations in the direction of flow were used to identify more probable areas of deposition for each of the 80 scenarios of wave conditions. In addition, time-weighted averages of SRB mobility and potential alongshore flux were calculated to identify likely long-term alongshore distribution patterns.

The results of the numerical modeling allow specific conclusions to be drawn for a given time period of interest based on the scenario evaluated or on scenario-averaged results that indicate patterns in alongshore currents and their gradients, sediment and SRB mobility and potential transport, gradients, and complexities associated with tidal inlets under specific conditions. The modeling results were used by the OSAT-3 team to evaluate potential SRB redistribution, burial and uncovering to provide a better understanding of the alongshore processes and movement of SRBs in the AOR.

The hydrodynamic model output (GIS data layers) for sand and SRB mobility for each of the 80 wave scenarios and time-weighted averages can be used to evaluate sources and mechanisms of re-oiling in the future (if they occur). The modeling reports (Appendices C, D, and Plant et. al 2013), provide detail beyond the scope of this report. The detailed reports contain finer resolution analyses and animations on areas of special interest during spill response, such as Little Lagoon, Alabama, and Pensacola Pass, Florida. Data are available at *http://restorethegulf.gov*.

2.4 Utilization of Aerial Imagery to Evaluate Potential SOM Formation and Persistence

High-resolution, multi-epoch aerial imagery provided a primary source of information on the physical shoreline configuration in the AOR at the time of initial oiling and on changes to shoreline/nearshore morphology thereafter. In total, eight epochs (limited periods of time during which specific seasonal aerial image acquisition efforts were undertaken) were utilized (Table 2.1). Source imagery immediately prior to/coincident with initial oiling/stranding (May/June 2010) was acquired by the NOAA National Geodetic Survey (NGS) Remote Sensing Division. Subsequent to initial oil landfall a consecutive series of Fall and Spring aerial image-acquisition efforts was undertaken by AeroMetric, Inc., under contract to BP (cooperative agreement reached by the Trustees and BP representatives on the Natural Resource Damage Assessment Aerial Imaging Technical Work Group[3]). All imagery used meet American Society for Photogrammetry and Remote Sensing Class 2, 1:2,400 scale accuracy requirement that provides

[3] http://www.gulfspillrestoration.noaa.gov/wp-content/uploads/2011/02/2010_10_11_AERIAL_IMAGERY_Shoreline_and_SAV_Requests.redacted.pdf

a quality of co-registration beyond that needed for this project. Details on the image collection and processing are provided in Appendix E.

MC252 Spill Response Aerial Imagery Acquisition		
NRD Project Name	**Acquisition Start Date**	**Acquisition Completion Date**
NOAA MC252 2010 *	5/5/2010	6/14/2010
NRDA Fall 2010	10/7/2010	10/21/2010
NRDA Spring 2011	4/28/2011	7/30/2011
NRDA Fall 2011	9/27/2011	11/11/2011
NRDA Spring 2012	4/23/2012	6/3/2012
BP-Sponsored NRDA Pre-Isaac 2012	8/25/2012	8/27/2012
NOAA Post-Isaac 2012	8/31/2012	9/3/2012
NRDA Fall 2012	8/25/2012	10/30/2012
Composite Date Range	5/5/2010	10/30/2012
* Note that this listing does not reflect all NOAA NGS pre-oiling acquisitions. The referenced imagery can be found at Environmental Response Management Application (ERMA®) Gulf Response interactive viewer, at *http://resources.geoplatform.gov/news/mapping-response-bp-oil-spill-gulf-mexico* NRDA imagery collected by AeroMetric, Inc.		

Table 2.1 Imagery used in evaluation of potential SOM formation and persistence.

The quality of imagery enabled the capture and use of two key derivative data sets in a multi-epoch assessment of shoreline change since initial oiling. The first of these vector derivatives was the apparent land-water interface (LWI) that was digitized from the respective orthoimage data sets of each epoch at a constant interpretive scale of 1:1,200. This work was conducted by AeroMetric, Inc. for post-oiling imagery in Florida, Alabama, and the barrier islands in Mississippi and by the OSAT-3 team in all other locations and epochs.

The second set of vector derivatives was generalized nearshore landforms along selected Gulf-facing beaches. These landforms were delineated and each was attributed with one of the nine generalized landform categories shown in Figure 2.6 and Table 2.2. For this analysis, “nearshore” was defined as approximately 100-150 meters from the LWI Gulfward, and 10-25 meters landward of the LWI. These features were digitized at a scale of 1:1200 by staff at the U.S Geological Survey National Wetlands Research Center in Lafayette, Louisiana.

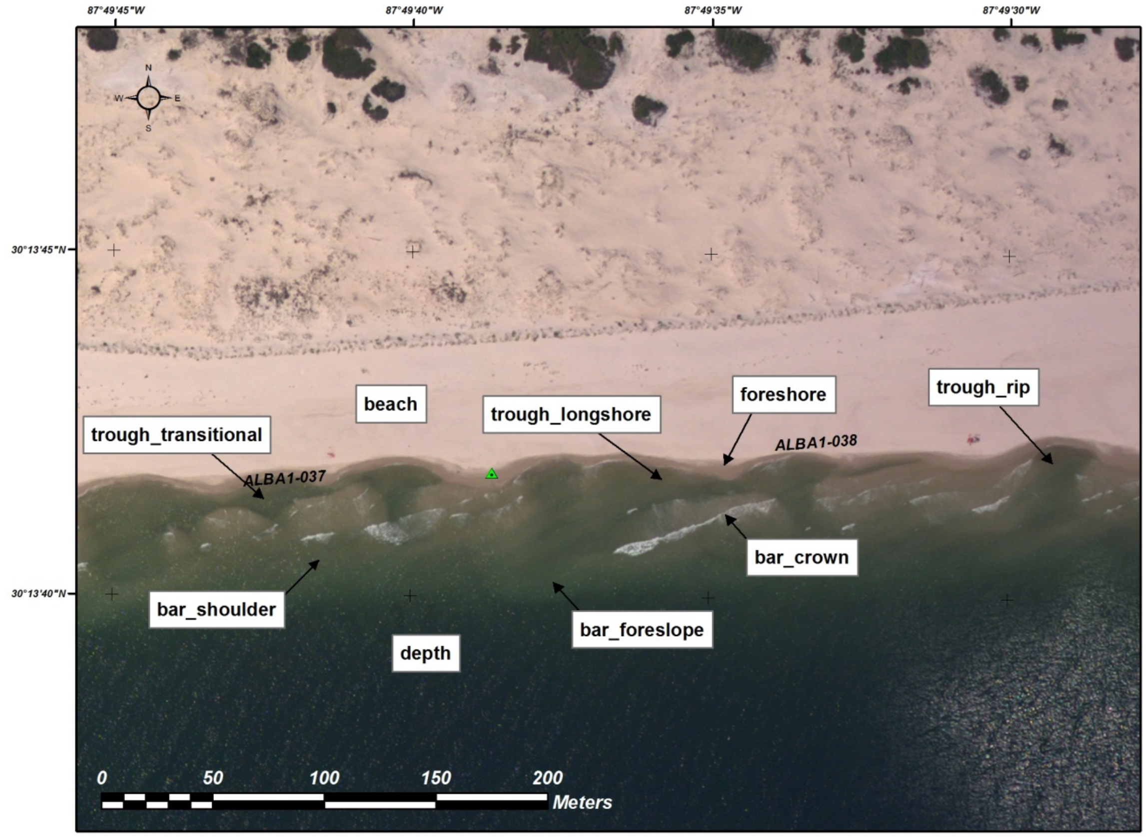

Figure 2.6 Aerial image of ALBA1-037 and ALBA1-038 showing generalized nearshore landform features used in the OSAT-3 assessment. Definitions for the landforms are summarized in Table 2.2.

All of the referenced aerial image data sets were collected with sufficient overlap to support 3D stereoscopic compilation. A limited number of SCAT shoreline segments at which recurring oiling issues had already been identified by interested parties were chosen by the OSAT-3 team for more in-depth 3D analysis (see Table 2.3). At these selected segments standard and through-water digital stereo-compilation of 3D terrain data was carried out at an interpretive scale of 1:800 to 1:1,200 by AeroMetric, Inc., based on the NOAA NGS pre-oiling imagery and five subsequent, seasonal NRDA collections (Fall 2010, Spring 2011, Fall 2011, Spring 2012, and Fall 2012). The digital terrain model (DTM) data, in the form of 3D mass points and break lines, were collected at a density sufficient to represent the detailed local vertical relief discernible in the stereo models. Elevations from the DTM surfaces for each epoch were then interpolated at a 2-meter horizontal sampling distance to produce raster digital elevation models (DEMs).

Geomorphic Feature	Description
Beach	The supratidal zone landward of the LWI above apparent high tide (i.e., continuous dry, white sand; backshore).
Foreshore	The intertidal zone at the LWI margin. In imagery it appears as light toned, continuous, exposed wet sand and slightly submerged, lower intertidal sands that are slightly darker.
Bar crown	The portion of the first or adjacent bar from shore that is or would be emergent within the ordinary tide range. These can be discontinuous features transected by rip troughs or may be anchored to the foreshore in places or may be separated from the foreshore by longshore trough features. Bar crowns generally have a greater longshore aspect ratio and typical cross-shore dimension of ~15 meters. In imagery they appear as light-toned exposed, wet sand and/or slightly submerged, slightly darker sand; typically indicated by breaking waves.
Longshore trough	Longshore trough features typically lie between the foreshore and bar crown (as described above), have a relatively large longshore aspect ratio. They may occasionally adjoin beach or bar-shoulder features. In imagery they appear as darker toned, submerged, lower intertidal or slightly subtidal.
Transitional trough	Neither longshore trough nor rip channel, but located between the foreshore and bar crown with an aspect ratio ~1. They are typically smaller than either longshore or rip features, and do not fully separate or transect a given bar feature.
Rip trough	Cross-shore channel formed by rip currents that transects the bar crown to/into the bar-shoulder. In imagery these are indicated by cusps at the foreshore/beach that are typically deeper/darker than longshore troughs.
Bar-shoulder	The subtidal zone, to a depth of ~1.5 meters, that are typically Gulfward of/adjacent to bar crown features. Bar-shoulders are generally continuous, but may be transected by rip troughs; may also adjoin foreshore or longshore troughs where a bar crown has not fully formed/emerged. In imagery they do not typically show breaking waves, and are where gentle sloping extends to abrupt change in tone.
Bar-foreslope	The subtidal zone from the bar-shoulder to the inflection at/near the base of the bar. Generally continuous; may have a steeper grade and typical depth from 2.0 to 4.0 meters. In imagery the foreslope extends from the bar-shoulder Gulfward, sometimes indicated by second abrupt change in tone at large trough feature between first and second bar.
Depth	The ~bottom of large trough feature between first and second bar (>3.5 -4 meters depth, indicated by darkest tones).

Table 2.2 Generalized nearshore landform descriptions used by OSAT-3.

SCAT Shoreline Segments
ALBA1-038 through ALBA1-044
ALBA2-002 through ALBA2-012
FLES1-003 through FLES1-008
FLES1-035, FLES1-036, FLES1-037
MSJK1-016 through MSJK1-021

Table 2.3 MC252 spill response shoreline segments with digital elevation models (DEMs).

Although the individual DEMs for each epoch maintained local vertical integrity, slight but discernible biases among the epochs with respect to one another and to NAVD88 were evident. In order to achieve sufficient vertical co-registration of the DEMs and reference all to a common, absolute vertical reference system (i.e., NAVD88), each epoch was separately indexed to relatively permanent, stable, identifiable, and common features (e.g., hard surfaced road intersections) and their corresponding NAVD88 elevations as represented in LiDAR-based surface models acquired in the Spring of 2010 by the U.S. Army Corps of Engineers Joint Airborne Lidar Bathymetry Technical Center of Expertise and published by NOAA[4]. Final vertical alignment of the DEMs was further aided/confirmed by the presence and use of the Gulf water surface itself, which was ordinarily at or near local mean sea level (LMSL) at the time of image exposure (and, in this region of the Gulf of Mexico, a reasonable approximation of NAVD88 zero for this application).

2.5 Evaluation of Potential SOM Formation and Persistence

The objective of this activity was to identify areas where there is higher potential for SOMs to be sources of residual oil and shoreline re-oiling. Data analysis show that nearshore areas at the time of initial oiling that were similar (e.g., morphology, depth, and distance from shoreline) to locations where SOMs were confirmed and that did not display evidence of being eroded since initial oiling were considered more likely to have SOMs remaining. In addition to the modeling results and aerial imagery analysis, SCAT and operational data were evaluated to provide a more comprehensive assessment of SOM formation and persistence.

MC252 spill response efforts in the AOR prior to the OSAT-3 process documented SOMs as deposits that were generally parallel to the shoreline and located between the first sand bar and the upper intertidal zone on Gulf-facing beaches but not in deeper zones or in protected bays (OSAT 2010, GCIMT 2010, GCIMT 2011, Wang et. al 2010). Given the importance of SOMs as potentially actionable sources of recurring oiling, the potential for SOMs to form in deeper water and in inland bays was investigated using output from the hydrodynamic models (described above) to corroborate/refute findings from previous investigations conducted earlier in the MC252 spill response. Sand/oil mixing processes were examined using analysis of wave

[4] http://csc.noaa.gov/dataviewer/webfiles/metadata/usace2010_al_fl_template.html
http://csc.noaa.gov/dataviewer/webfiles/metadata/usace2010_la_ms_template.html

energy dissipation during the initial oiling window coupled with modeled estimates of sediment suspension. Details of approach and findings can be found in Appendix D.

Modeling results support the premise that energy required to mix sand and oil to form SOMs on Gulf-facing beaches is confined to the zone of breaking waves and associated run-up inside the first sand bar. These findings corroborate field data collected in the AOR as part of the MC252 spill response for both the presence of SOMs in the nearshore areas and the absence of SOMs offshore and in shallow bays; consequently all subsequent assessments of SOMs as sources of recurring oiling were focused in the nearshore.

Data from SCAT trenches and surveys within intertidal and subtidal areas, also known as snorkel SCAT, were overlaid on NOAA NGS digital color orthoimagery collected close to the time of initial shoreline oiling. All available oblique photographs and field data collected during the time weathered oil was moving onshore were reviewed to provide additional detail. To establish characteristics of locations that were amenable to SOM formation at the time of initial oiling, known SOMs (from Operations data) and areas characterized as heavy/moderate deposits by the snorkel SCAT team were analyzed utilizing the GIS system for the following: associated nearshore landform at the time of oiling; length, width, and aspect of the deposit; aspect of shoreline; distance to shoreline; wave patterns during oiling, and oiling history.

During this assessment process, an association between anchored boom and documented SOMs was observed in locations with different characteristics than most of the SOMs located along Gulf-facing beaches. In low-wave energy areas, where energy to mix sand and oil would be below levels predicted to form SOMs, nearshore booming during the MC252 spill response trapped oil, increasing the contact time and thereby enhancing the formation of mats (and patties).

Four criteria were established by the OSAT-3 team to evaluate the potential for formation of SOMs in areas not surveyed across the AOR:

- Combination of wave energy, sand, and oiling history that matches conditions associated with SOMs formation, as predicted by the hydrodynamic models
- Morphological characteristics similar to areas with documented SOMs

- Documented history of > 5 centimeters and angular SRBs in the intertidal zone that may indicate a SOM is present in the vicinity
- Evidence of anchored boom, marsh vegetation, and peat platforms (based on aerial reconnaissance) that could trap oil in shallow, low energy locations, thereby increasing potential for SOMs formation in these areas (Figure 2.7).

Figure 2.7 Weathered oil trapped by boom and vegetation.
In low-wave energy areas, boom and vegetation trapped oil, increasing the contact time with sand thereby enhancing the formation of submerged oil mats (SOMs) and patties. This material was removed manually to minimize impact to the vegetated shoreline. Panel a photo location is MSJK1-037 (Gulf Islands National Seashore) (photo taken 8/15/2010). Panel b and c photo locations were MSJK1-056 (Gulf Islands National Seashore) (photo taken 8/15/2010).

The characteristics of known SOMs were used to identify additional locations with similar characteristics in nearshore areas at the time of oiling. Based on their location, associated depth profile, and morphological similarity to areas with known SOMs, the landform feature types listed in Table 2.2 that were considered amenable to SOM formation at the time of oiling included: foreshore, bar crowns, longshore troughs, transitional troughs and, to a lesser extent, rip troughs. As noted previously, bar-shoulder, bar-foreslope and depth features were not considered amenable to SOM formation. The extent of known heavy and moderate deposits and the nine landform categories were examined with the 3D DEM data in order to examine depth profiles associated with SOM formation.

The potential for SOMs to persist through time was evaluated by assessment of change in shoreline morphology since initial oiling. The persistence of areas with documented heavy and moderate deposits (data from snorkel SCAT) and those locations identified as amenable to SOM formation at the time of oiling were assumed to contain SOMs and were further evaluated. The evaluation process utilized three separate methods of detecting erosion in the nearshore area over time:

1. Lateral changes in the LWI since initial oiling along all Gulf-facing beaches
2. Changes in geomorphic features from the time of oiling along all Gulf-facing beaches
3. Changes in depth profiles since the time of initial oiling (based on 3D DEMs) in the nearshore for a subset of segments described in Table 2.3.

Information from these three approaches was combined into an assessment of the potential for SOMs to remain in a given area. *Because it is unlikely that SOMs formed in all of the areas identified as having similar characteristics to documented deposits, and it is further likely that erosion occurred between image collections used in the analysis, this approach was considered the most inclusive and conservative (i.e., this approach likely overestimated the potential formation and persistence of SOMs in the AOR).*

Lateral Changes in Land-Water Interface (2D)

Lateral changes in the position of the apparent LWI were examined directly/sequentially from or near the time of actual oiling and through each subsequent aerial image epoch on the GIS/stereo-workstation. The 2D LWI vector features for all available epochs were intersected and subdivided for subsequent spatial analysis to determine the most shoreward LWI elements and their associated epoch. This semi-automated process yields a 2D geospatial feature data set of shoreline sub-segments at which continuous shoreline accretion since initial oiling was indicated. Utilizing this dataset, the percent change of the 2D LWI vector feature from or near the time of actual oiling of each segment was calculated (Appendix F). An example series of imagery and associated LWI data, its intersection, and analysis results are shown in Figure 2.8.

Note that Figures 2.8 through 2.11 follow the same shoreline segments through a series of analytical steps to illustrate the OSAT-3 evaluation process.

Locations where the LWI had prograded Gulfward since the time of initial oiling (i.e., where the imagery indicated the shoreline had accreted since the time of oiling) were considered candidates for the persistence of SOMs, assuming they formed. *In all likelihood, erosion between epochs occurred in this AOR, therefore this approach results in an overestimation of the extent and magnitude of potential persistence of SOMs.*

Changes in Geomorphic Features (2.5D)

Changes to intertidal and nearshore subtidal geomorphic features were examined directly/sequentially on the GIS/stereo-workstation. In order to evaluate the intertidal and nearshore subtidal zones for potential SOM formation and persistence, the 2D polygonal/areal features described previously (and attributed with generalized landform categories) were subjected to further spatial analysis. Because each landform/morphological category (see Table 2.2) has an implicit depth profile, the polygonal/areal feature data sets for each epoch were designated as “2.5D” in recognition of the approximate vertical range/position of the features. In addition, each landform category had an assigned numeric code that corresponded to its relative depth in sequence from “beach,” which was coded as “1,” to “depth” which was coded as “9” (see Table 2.4). The polygonal/areal features for the available epochs were then intersected to produce a single “2.5D” geospatial feature data set in which each unique and discrete polygonal feature maintained the landform category codes associated with each epoch for the coextensive region defined by the intersected polygon features (Figure 2.9). The landform categories and corresponding depth profile/sequence codes were supported/confirmed by evaluation against available 3D stereo-imagery data.

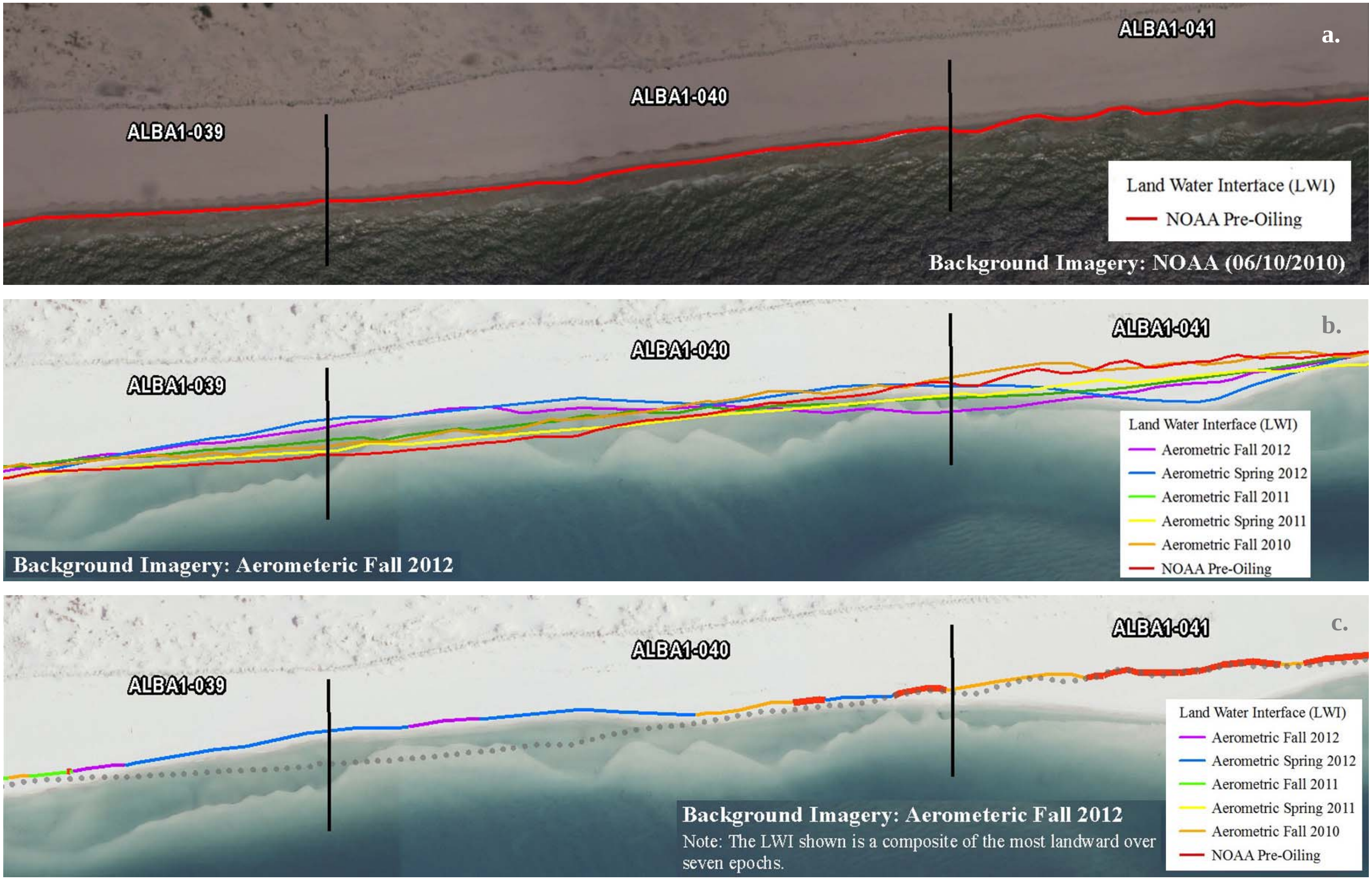

Figure 2.8 Example of lateral change in land-water interface (LWI) for segment ALBA1-040.
Panel a) shows the LWI captured from NOAA NGS orthoimagery at/near the time of initial oil landfall. Panel b) shows the intersection of LWIs captured from orthoimagery for all available epochs. Panel c) shows the composite of the most landward LWI over all epochs with respect to the LWI at/near the time of initial oil landfall (dotted line). The red portion of the LWI in Panel c identifies areas that did not show evidence of erosion.

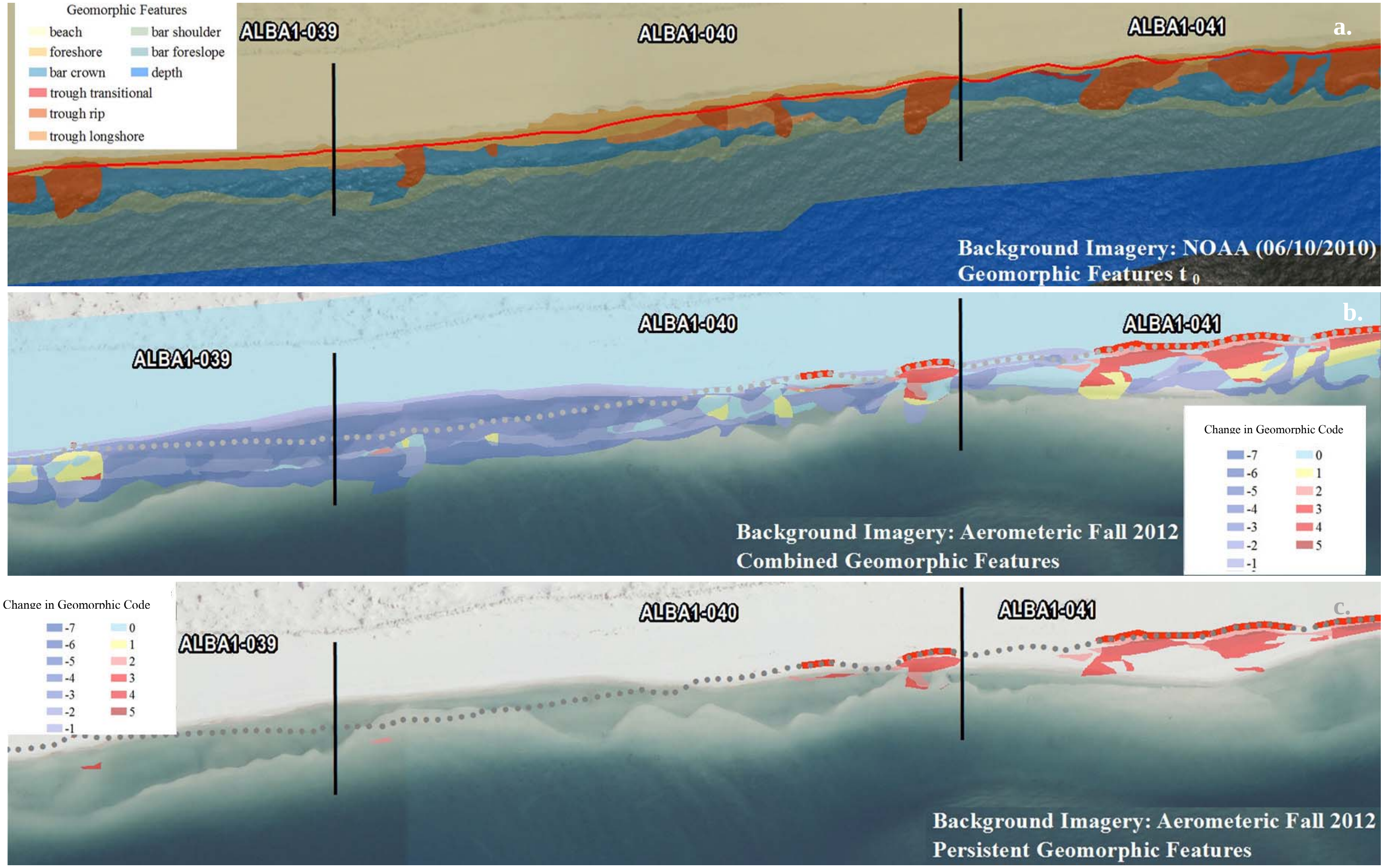

Figure 2.9 Changes in nearshore geomorphic features for segment ALBA1-040.

Area shown in this figure is identical to Figure 2.8. Panel a) shows the geomorphic landforms captured from NOAA NGS orthoimagery at/near the time of initial oil landfall. Panel b) shows the change in geomorphic landform across all available epochs. Panel c) shows the results of evaluation of category/depth code at the time of initial oil landfall against maximum category/depth code over all subsequent epochs, indicating areas of burial/persistence.

Feature Name	Code
Beach	1
Foreshore	2
Bar crown	3
Trough_transitional	4
Trough_longshore	5
Trough_rip	6
Bar-shoulder	7
Bar-foreslope	8
Depth	9

Table 2.4 Assigned codes for each geomorphic landform

Evaluation of potential persistence of a given intersected feature polygon began with the simple difference of its category/depth code at the time of initial oiling (t_0) minus the maximum depth code attained in any subsequent epoch. When this simple difference resulted in values of zero or less, the t_0 feature was considered eroded; when greater than zero, the potential for burial and persistence remained (with greater values indicating increased likelihood for persistence and/or greater depth of burial). As foreshore, bar crown, and transitional/longshore trough features at the time of initial oiling were considered most amenable to potential stranding, they were given additional weight in the analysis. Based on hydrodynamic modeling results, those features with a t_0 category/depth code of 7 or greater (bar-shoulder, bar-foreslope, depth) were not considered likely candidates for initial SOM formation. This comprehensive spatial and temporal assessment yielded a data set of the areal extent of potential SOM formation and persistence in the intertidal and subtidal zones. *Similar to the 2D assessment, this approach results in an overestimation of SOM persistence.*

Changes in Depth Profiles since the Time of Oiling (3D)

The GIS/stereo-workstation was used to assess changes in nearshore features stereoscopically (in 3D) from or near the time of initial oiling through each subsequent aerial image epoch. In order to evaluate the potential for SOM formation and persistence, the vertically co-registered 3D DEM data sets described previously (Table 2.3) were subjected to further spatial analysis. The initial step was integration of the five DEMs developed from the available NRDA aerial imagery (acquired from Fall 2010 through Fall 2012) and extraction of a minimum topographic surface. In this process, the elevations for each epoch were evaluated at every raster cell (2 m).

The lowest value at a given cell location was selected and written to the corresponding cell location in a new/empty DEM file. This process continued until every cell had been evaluated and the new file completely populated with minimum elevation values. Next, the NOAA NGS pre-oiling or t_0 DEM (Figure 2.10a) was subtracted from the NRDA minimum topographic surface DEM (Figure 2.10 b) to produce an isopach showing the maximum extent to which the initial surface was eroded (negative values) and/or the minimum amount of accreted overburden (positive values).

An example isopach in hypsographic form at 0.5-meter intervals is shown in Figure 2.10c. Increasingly saturated blue colors indicate increasing amounts of erosion, and increasingly saturated red colors indicate increasing overburden and associated likelihood of potential persistence of the t_0 surface feature. Assuming they were present, SOMs would not be expected to remain intact in areas that eroded below the level of the pre-oiling surface. However, smaller material could be deposited/reburied after erosion events in these areas.

Integrated Assessment of SOM Formation and Persistence

For the MC252 spill response, it was essential to identify areas with potential for SOMs to remain. Morphological changes in the nearshore (lateral and vertical) were assessed utilizing the combined output from the 2D, 2.5D, and 3D analyses. From this analysis, locations were identified at which SOMs (if present) could have persisted since initial formation. Locations at which morphological change indicated depths were sufficient to remove SOMs underwent additional scrutiny through live/direct manual 3D feature assessment. Based on this combined analysis, areas with morphology similar to known SOMs that did not display evidence of being eroded in the post-oiling imagery were identified as potential locations for remaining buried oil. This information was evaluated along with field data of oiling history (Operations and SCAT), subsurface oiling conditions (auger, trenching and snorkel SCAT data), locations of delineated and/or removed SOMs, and hydrodynamic model results (Figure 2.11). In addition, geocoded oblique aerial photographs taken by the Civil Air Patrol during the period that oil was coming ashore, and geocoded field photographs taken by SCAT and Operations, provided visual evidence of oiling conditions during the course of the MC252 spill response. Altogether, this provided a comprehensive assessment of the potential formation and persistence of SOMs across the AOR.

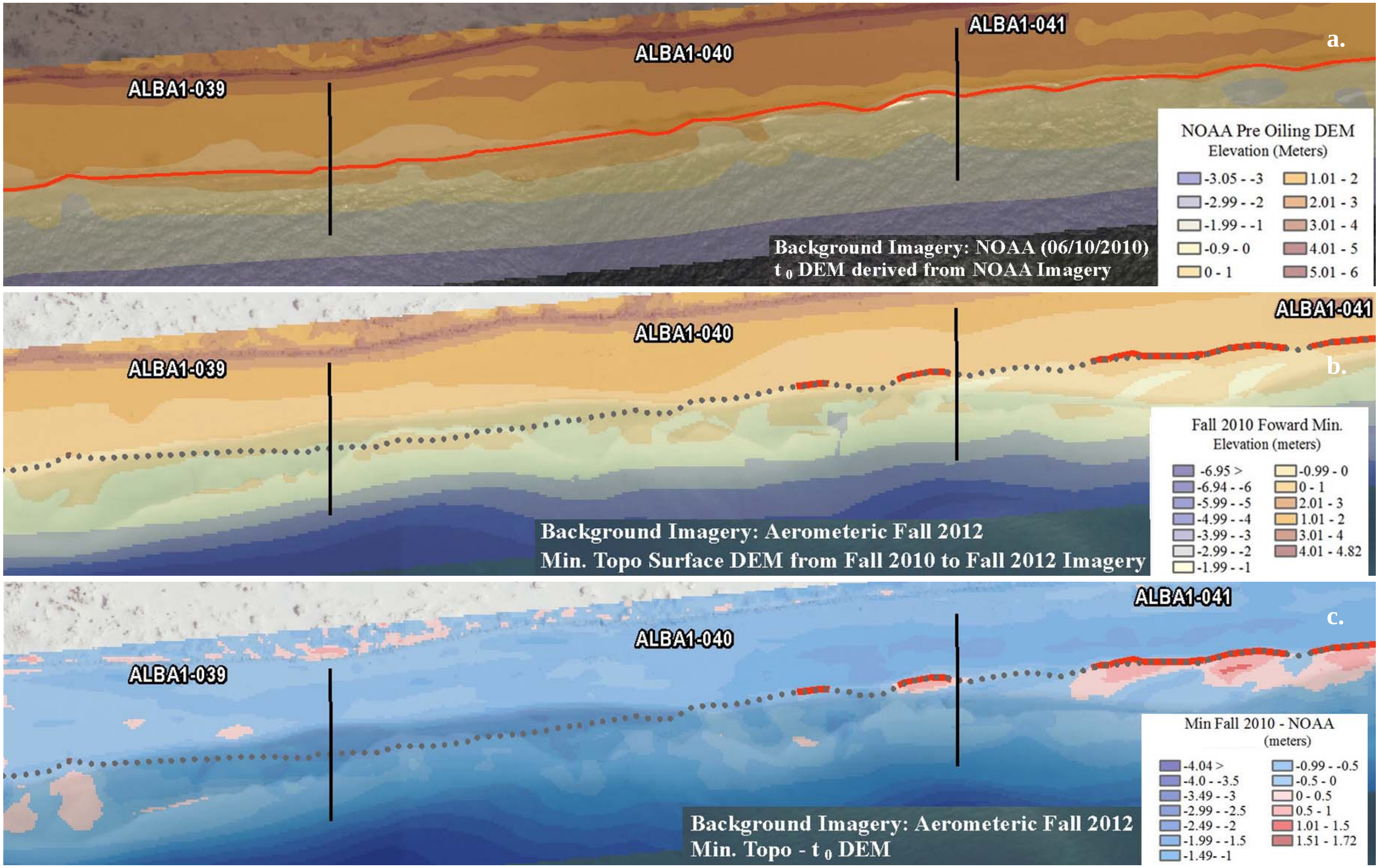

Figure 2.10 Changes in depth profile for segment ALBA1-040.

Area shown in this figure is identical to Figures 2.8 and 2.9. Panel a) shows the t_0 DEM Developed from NOAA NGS stereo imagery at/near the time of initial oil landfall. Panel b) shows the minimum topographic surface DEM developed from Fall 2010 through Fall 2012 NRDA stereo imagery. Panel c) shows the isopach of the minimum topographic surface DEM minus the t_0 DEM indicating extent of possible erosion or accreted overburden since initial oil landfall.

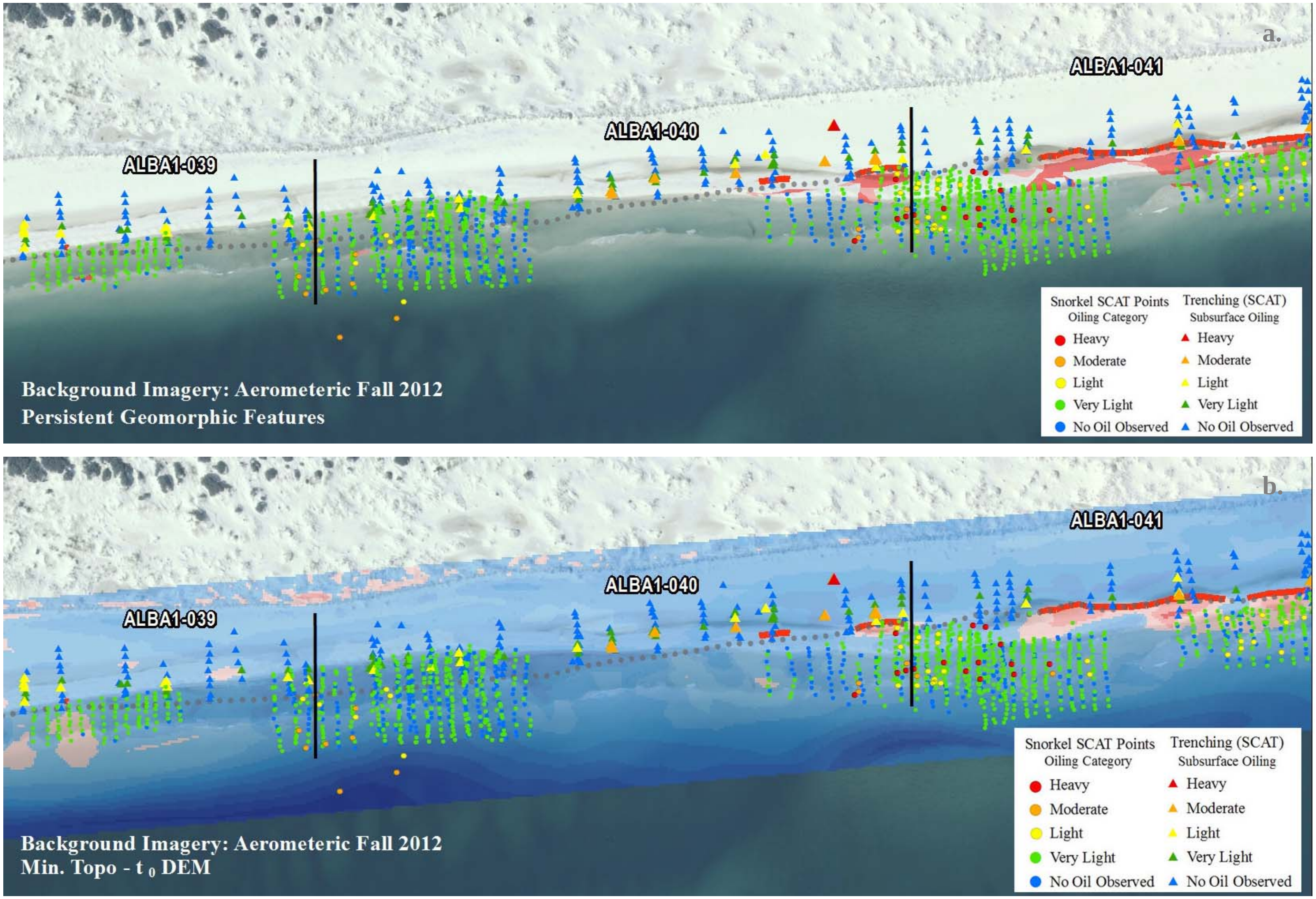

Figure 2.11 Integrated assessment of SOM formation and persistence for segment ALBA1-040.
Area shown in this figure is identical to Figures 2.8 through 2.10. Panel a) shows combined view of results of the 2D land-water interface (LWI) and 2.5D geomorphic feature analysis, together with field observations. Panel b) shows the combined view of results of the 2D LWI and 3D digital elevation model (DEM) analysis.

2.6 Integrated Assessment Sources and Mechanisms for Re-Oiling

Integrated assessments of the data and information were conducted during review sessions with participating state and federal response and natural resource agency groups and coastal experts. Maps are provided for selected segments that illustrate the range of shoreline types, sources and mechanisms identified in the AOR (Appendix F). These maps show data used during the review sessions, including pre-oiling imagery, the landward extent of the LWI from NOAA NGS pre-oiling through NRDA Fall 2012 epochs, location of available photos, SCAT trenching/augering data, Operations augering data, and snorkel SCAT data. The OSAT-3 science team consulted with coastal experts and field-level personnel (SCAT teams, Operations teams, state and federal MC252 spill response and natural resource agencies, U.S. Coast Guard, private land owners, and university researchers) to gain a better understanding of recurring oiling of shorelines. Environmental Response Management Application (ERMA) provides a geospatial representation of the data used in the OSAT-3 report. Along with the mapping, attached to the layer is a summary of the collections and SCAT data used to support the analyses. These data can be found at *http://www.restorethegulf.gov*.

The most essential task for OSAT-3 was assessing the potential for SOMs to be ongoing or future sources for recurring oil. If SOMs were unlikely to persist in close enough proximity to contribute to recurring oiling for the segment of concern, then focus was shifted to assessment of potential and conditions favorable for longshore transport and deposition based on results from the hydrodynamic models. This assessment was followed by a thorough examination of segment-specific data and consultation with field-level personnel on re-oiling conditions, limitations of the data, and characteristics of the material. The combined efforts of the OSAT-3 team, state and federal response and natural resource agency groups, and local experts provide the basis for a determination of the likely source(s) and mechanism(s) for recurring oiling for every segment that failed to meet SCCP endpoint criteria as of June 1, 2012.

3.0 Results and Discussion

In order to understand the re-oiling sources and mechanisms across the AOR, integrated assessments (spatial and temporal) of multiple data sets were required. The complexities of recurring oiling causing segments to not meet SCCP endpoint criteria are associated with the interaction among multiple potential sources (local or distant, diffuse or concentrated, supratidal, intertidal, or subtidal) and varied mechanisms (uncovering, remobilization, cross-shore transport, and longshore transport). These assessments were conducted during working sessions with participating state and federal response and natural resource agency groups and coastal experts and utilized the GIS capabilities developed to support the OSAT-3 project. This included the 2D and 3D visualization of shorelines near in time to initial oiling and changes over time (aerial imagery), and integration of multiple sources of geospatial data (SCAT, Operations, and ancillary data from weather buoys and tidal stations) into a fully integrated GIS platform.

The OSAT-3 team applied a weight-of-evidence process that accounted for the strengths and weaknesses of different lines of evidence to arrive at a consensus on the relevant sources and mechanisms for re-oiling of individual segments. In addition to the group assessments, the OSAT-3 team consulted with coastal experts and field-level personnel (SCAT teams, Operations teams, state and federal MC252 spill response and natural resource agency, U.S. Coast Guard, and university researchers) to gain a better understanding of recurring oiling of shorelines in the AOR.

Within a segment, multiple sources and mechanisms may contribute to re-oiling. The relative contribution of different sources and mechanisms can vary within a segment depending on conditions.

Based on the integrated assessments, four major types of re-oiling across the Eastern states AOR were observed:

1. Cross-shore transport/uncovering of diffuse material referred to as surface residual balls (SRBs) or patties (depending on size) in the intertidal and nearshore subtidal zones (most prevalent mechanism for re-oiling).
2. Cross-shore transport of material broken off of submerged oil mats (SOMs) in the intertidal zone in close proximity to the stranding (limited extent).

3. Longshore transport and deposition of SRBs from diffuse sources occurring predominantly during storm events (limited extent).

4. Simple uncovering of material of all sizes (buried since initial oiling and/or residual oil from cleanup operations) across tidal zones (common, but not prevalent mechanism for re-oiling).

A segment-by-segment summary of pertinent information utilized and a statement on likely sources and mechanisms for re-oiling for the 634 segments in the Eastern states AOR that had not met SCCP endpoint criteria as of June 1, 2012 is provided Appendix F. All data utilized as part of OSAT-3 are available on *http://www.restorethegulf.gov*. The material below provides a more detailed summary of the integrated assessments for the four major types of re-oiling in this AOR.

Cross-Shore Transport/Uncovering of Diffuse Material

Based on review of SCAT survey data and photos combined with records of material removed by Operations, small SRBs are the most common form of re-oiling material observed in the segments investigated in the Eastern AOR. The degree and nature of the weathered oil that came ashore was not always amenable to the formation of SOMs, even if defined as heavy oiling condition by SCAT (Figures 3.1 and 3.2). Extensive SCAT surveys (trench and snorkel SCAT) provide evidence that as of June 1, 2012, diffuse deposits of < 2.5 centimeters material are widespread and larger SRBs, patties and SOMs are relatively scarce across the segments evaluated by OSAT-3 in this AOR.

Figure 3.1 SCAT classified heavy oiling on Gulf-facing beaches amenable to submerged mat (SOM) formation. Panel a) shows segment ALBA1-037 (Bon Secour National Wildlife Refuge) (photo taken 6/11/2010), while panel b) shows segment ALBA2-009 (photo taken 6/23/2010).

Figure 3.2 SCAT classified heavy oiling demonstrating the range of sizes of sand/oil mixtures that formed during initial oiling.
Panel a) shows SCAT survey results in segment ALBA2-009 on 6/23/2010), while panel b) shows SCAT survey results in segment MSHR3-033 (photo taken 6/29/2010). Locations amenable to the formation of patties and smaller-sized deposits could be a source of recurring oil if not recovered prior to burial by sand.

In addition to removal during the MC252 spill response, coastal processes have reworked sand-oil mixtures that formed at the time of initial oiling (primary) into diffuse deposits (secondary). It is not possible to remove all remnant oil due to a combination of ecological, operational, and safety considerations; therefore diffuse material remains. The mechanisms and source locations of re-oiling from the remaining diffuse deposits include uncovering (intertidal or supratidal) and cross-shore transport from the subtidal to intertidal zones. SRBs are likely to become buried and exposed under normal sand transport processes because they are less mobile than native sediment, thereby lengthening the time SRBs take to move onshore. Local diffuse deposits of material < 2.5 centimeters are a contributing source of re-oiling in every segment investigated.

Submerged Mats as a Potential Source

The potential for SOMs to be a source of recurring oiling was based on a combined assessment of formation and persistence. Snorkel SCAT data provided the most reliable data on the presence of SOMs (Figure 2.11). It should be noted that SOMs could be missed (false negative) if they were present deeper than shovelable depth under snorkel SCAT field conditions. All heavy and moderate deposits as identified by snorkel SCAT (Appendix B) and areas with similar morphological characteristics were identified and mapped using NOAA digital color orthoimagery collected nearest in time to initial oiling. All of these areas (across the AOR) were then evaluated for persistence by detecting erosion in the nearshore area over time using imagery collected after oil came ashore. An overview of the review process used on the segments meeting these characteristics is outlined below for two segments (ALBA1-040 and ALBA1-042 in Bon Secour National Wildlife Refuge, AL). Similar images for additional segments (FLES1-005 and FLES1-008 in Perdido Key, FL; FLES2-018 in Pensacola Beach, FL; and MSJK1-016 and MSJK1-017 in Horn Island, MS) are provided in Appendix F.

The first step in determining persistence involved evaluating lateral changes in the LWI (Figure 3.3). The entire length of ALBA1-042 showed evidence of erosion across the epochs. Approximately 14 percent of the length of ALBA1-040 did not show evidence of erosion.

Next, persistence was evaluated by tracking changes in geomorphic features across the epochs. Areas that began the analysis period as amenable to SOM formation were considered as potential locations with remaining SOMs. There were no areas along ALBA1-042 that at the time of initial oiling were identified as having the potential for SOM formation and persisting through all subsequent epochs (Figure 3.4). There were areas in ALBA1-040 that were amenable to SOM formation and persisted in each of the subsequent epochs.

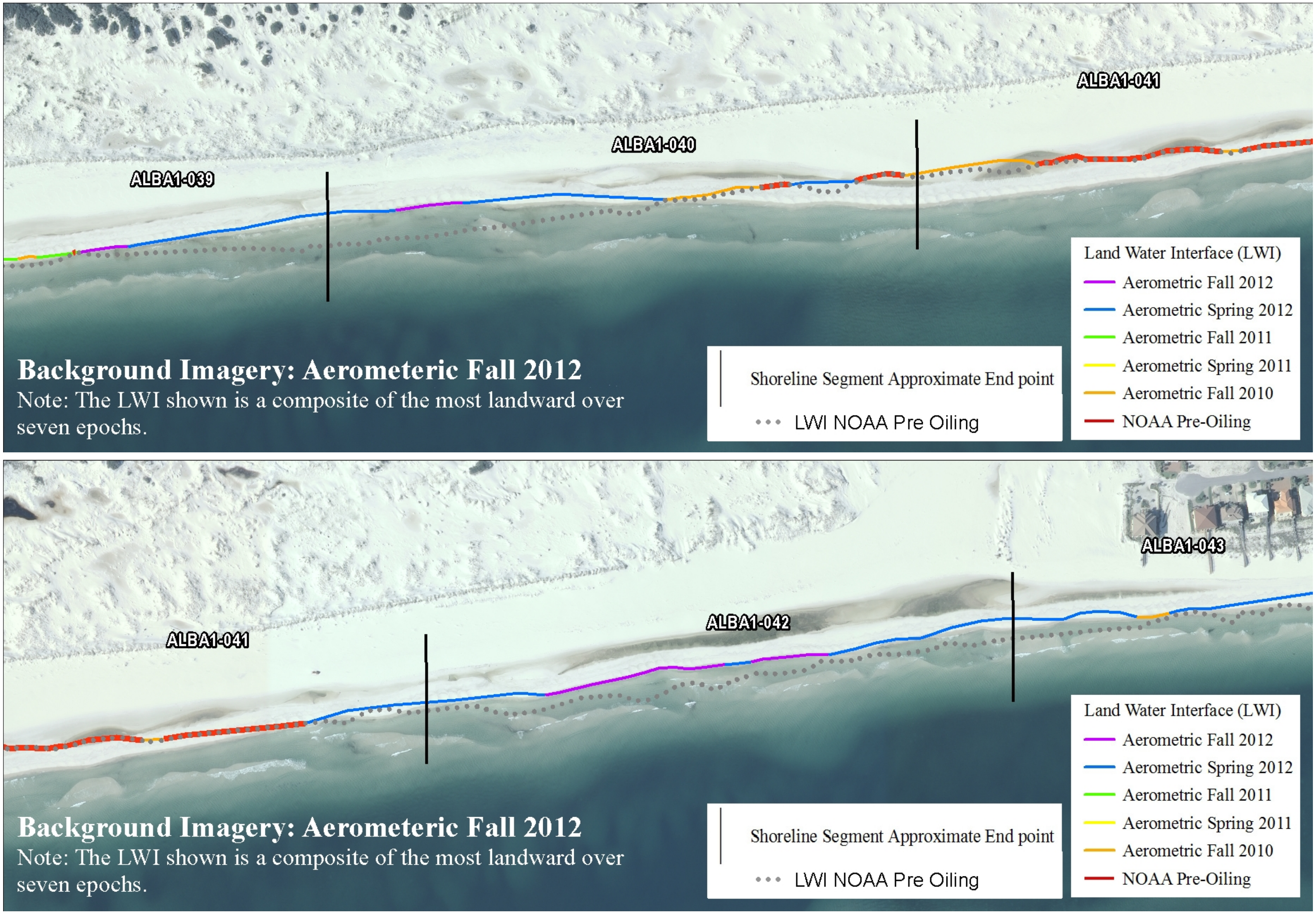

Figure 3.3 Change in land-water interface (LWI) along segments ALBA1-040 and ALBA1-042.

Figure 3.4 Persistent features as determined by the analysis of change in geomorphic features in segments ALBA1-040 and ALBA1-042. Note the correspondence between 2D analysis and change in geomorphic features.

Along ALBA1-040, 3D topographic surfaces were developed based on the imagery. The topographic surface nearest in time to oiling was compared to each subsequent post-oiling epoch (Figure 3.5). Areas that had depth profiles in subsequent epochs that dipped below the elevation at the time of oiling were considered eroded and were removed from further analysis. There were areas along ALBA1-040 that did not show evidence of erosion after initial oiling.

The evaluation process utilized the change in the LWI and morphological features to identify portions of nearshore areas where SOMs may have persisted. Within some segments with documented SOMs, terrain models were also incorporated into the assessment. Areas of potential SOMs identified by the terrain models were consistent with those identified by change in LWI and morphological features. In addition, at a subset of areas that were determined to have eroded below the elevation that existed at the time of oiling, subsequent aerial imagery epochs were evaluated utilizing the 3D workstation to cross-check that depths below the initial elevation were reached. Because it is unlikely that SOMs formed in all of the areas identified as having similar characteristics to documented deposits, and it is further likely that erosion occurred between image collection used in the analysis, this approach was considered the most inclusive and conservative (i.e., this approach likely overestimated the formation and persistence of SOMs).

Longshore Transport

Modeling results suggest that, under the most commonly observed low-energy wave conditions, larger SRBs (>2.5 centimeters) are not likely to move very far alongshore. This finding suggests that, under non-storm conditions, large SRBs from one source location may not be redistributed to other alongshore locations. Deposition of SRBs (and sand) will occur in areas of convergences in longshore currents (e.g. flow reversals), in areas of spatially decelerating longshore currents, and in areas where the shear stress forces drop below critical thresholds to initiate or maintain SRB movement. When SRBs do move alongshore, output from hydrodynamic models indicate that there are regions that are more conducive to accumulation than others.

A primary objective of the OSAT-3 modeling effort was to identify regions of varying alongshore current speeds and directions, resulting in areas of persistent convergence and divergence of alongshore currents and, by inference, the deposition of SRBs. A striking example of convergence was detected in the model at Pensacola Pass where, because of the bend in the shoreline, alongshore flows and therefore potential SRB flux were directed toward the inlet (Plant et al. 2013). In this situation, SRBs occurring nearshore would be transported toward the inlet. This situation could lead to an increase in the complexity of SRB transport because waves, alongshore flows, and tidal currents would all interact with the sediment and SRBs.

Simple Uncovering by Wind and Waves

Segments MSHA1-032 in Cat Island, MS and MSHR3-035 in Long Beach, MS are examples of segments where the simple uncovering of larger material (SRBs and patties) is a significant contributor to re-oiling and failure to meet SCCP endpoint criteria. Both segments have relatively low amounts of material collected by Operations and sparse re-oiling of material but both have some larger SRBs (>5 centimeters) and patties found in SCAT surveys (three out of eight surveys in MSHA1-032, fifteen out of twenty-one surveys in MSHR3-035, Appendix F). Longshore current velocities estimated from hydrodynamic models are below the critical level required to move SRBs; therefore transport from distant sources is very unlikely along these low energy segments, especially for larger-sized material. In addition, along low energy mainland shorelines, the nature and degree of oiling coupled with the low wave energy is not amenable to the formation of SOMs. It is unlikely there are SOMs offshore contributing to the recurring oiling in segments with these characteristics.

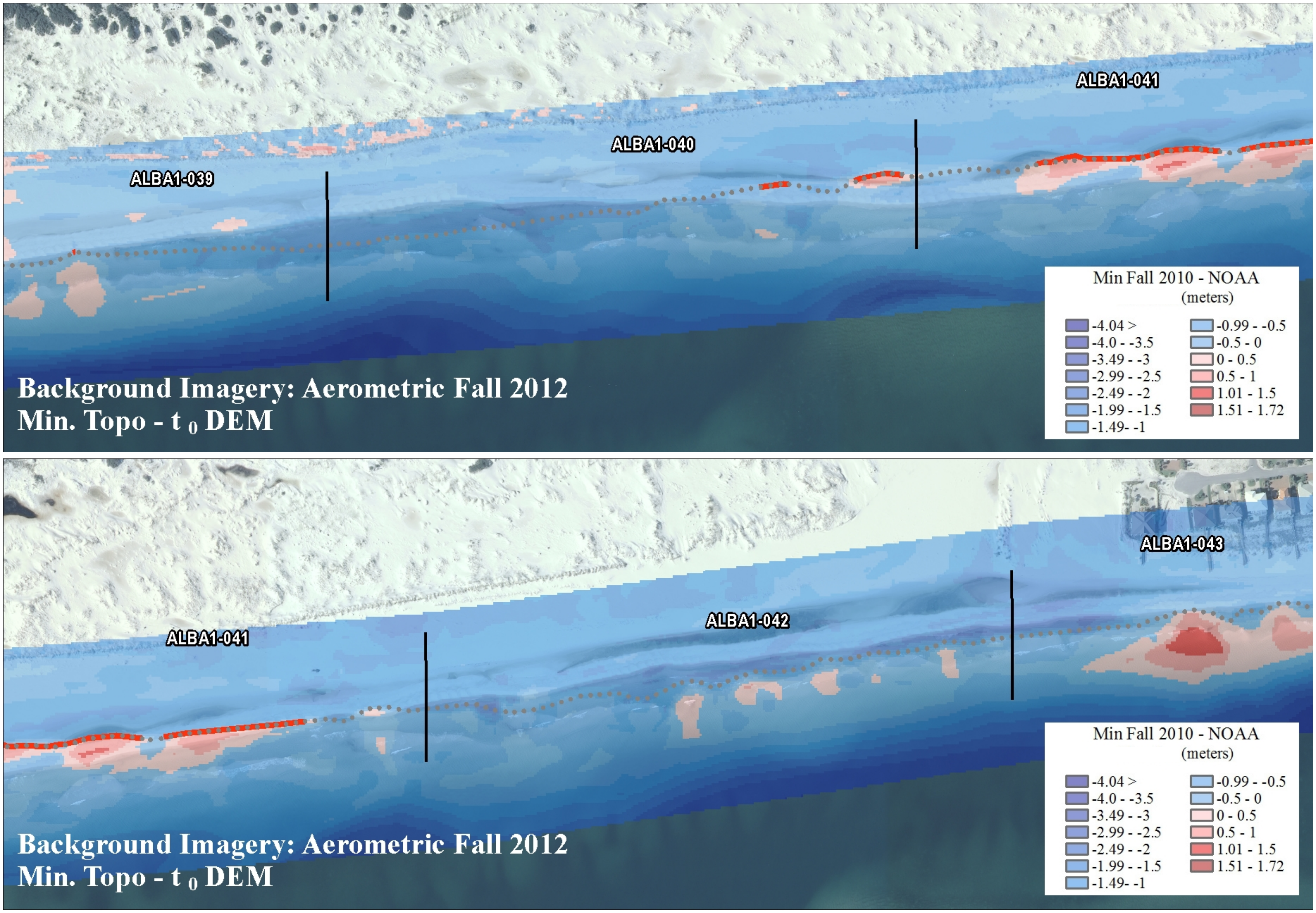

Figure 3.5 Erosion patterns for ALBA1-040 and ALBA1-042 as determined by analysis of topographic surfaces across the epochs. Note the correspondence between 2D analysis and 3D assessments.

For segment MSHA1-032, examination of SCAT field reports and georeferenced photographs shows the larger material located in the supratidal zone (Figure 3.6) intermingled with marsh vegetation. Best management practices for operational activities in vegetated areas are focused on minimizing impact to native vegetation. The material in the supratidal zone was likely deposited during initial oiling and later exposed by wind or storm waves removing the sand overburden.

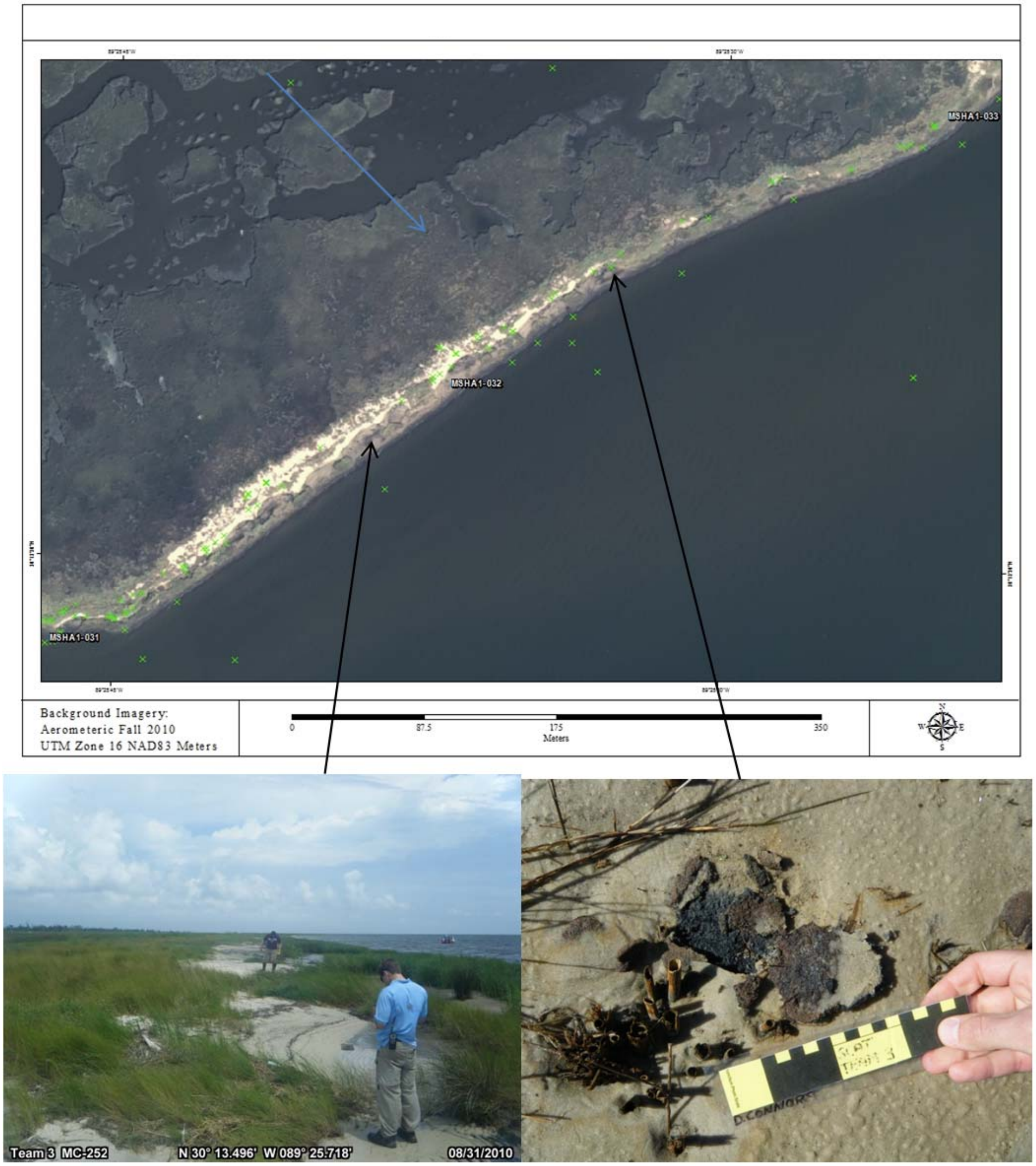

Figure 3.6 Patty-sized material found along segment MSHA1-032 is mixed with vegetation. Photos taken 8/31/2010 and 3/11/2011).

MSHR3-035 has similar characteristics to MSHA1-032, but the source of the material is likely in the lower intertidal and subtidal zone. This segment is an amenity beach and the SCCP standard is No Observable Oil (NOO). Operational activities likely removed most of the oil in the supratidal zone. SRBs and patties were frequently found in the intertidal zone (Figure 3.7). Along this segment (and likely other Mississippi mainland amenity beach segments), some (but not all) of the larger SRBs and patty-sized materials are exposed in the lower intertidal and subtidal zones during extreme low, wind-driven tides.

Figure 3.7 Patty-sized material found along segment MSHR3-035 exposed during extreme low tides. Photos taken 1/22/2012.

An integrated assessment was performed across the AOR to evaluate the sources and mechanisms of re-oiling causing segments to not meet SCCP endpoint criteria. As illustrated by the examples discussed above, recurring oiling along some segments is due to a combination of the identified sources and mechanisms. *Based on this comprehensive assessment, diffuse deposits of material are widespread across the shoreline types present in the AOR that were evaluated by OSAT-3 and contribute to re-oiling in every segment investigated. The formation and persistence of SOMs is limited to isolated areas along Gulf-facing beaches.*

Although the shoreline and nearshore areas have undergone normal erosion/deposition cycles, there are isolated (smaller than segment) areas that based on the aerial imagery do not appear to have eroded to a depth necessary to remove SOMs, if they formed. Given the importance of SOMs as potentially actionable sources of recurring oiling, the most essential task for OSAT-3 was identifying areas with the highest probability for their formation and persistence.

As part of the overall assessment of sources and mechanisms, areas with morphology similar to known SOMs during the time oil was coming ashore and that may not have eroded since that time were delineated. In an effort to remove SOMs from the environment in as expeditious a manner as possible, the delineated areas were prioritized based on a combination of characteristics including size, spatial density, proximity to known SOMs, density/validity of snorkel SCAT data, and oiling/operational history. A list of segments where these high priority areas were identified is presented in Table 3.1. The location and extent of these “target areas” were provided to the BOP team for further evaluation. Information gathered through BOP activities was provided back to the OSAT-3 science team and used to verify and refine the assessment process. For example, in segment FLES2-018 in Pensacola Beach, FL, a SOM and associated debris from its natural degradation were found and removed by the BOP in April 2013 (Figure 3.8). This material was found in only a portion of the area identified by OSAT-3 as having the potential for SOMs. An overview of the BOP, including status and results of investigations in each of the target areas identified by OSAT-3 is provided in Appendix G.

ALBA1-001	ALBA1-021	ALBA1-038	FLES1-024
ALBA1-002 *	ALBA1-022	ALBA1-039	FLES1-025
ALBA1-005	ALBA1-023	ALBA1-040	FLES1-026 *
ALBA1-006	ALBA1-024	ALBA1-041	FLES2-018
ALBA1-007	ALBA1-025	ALBA1-043	FLES2-019
ALBA1-008	ALBA1-026	ALBA2-011	FLES2-020
ALBA1-010	ALBA1-027	ALBA2-012	FLES2-021
ALBA1-011	ALBA1-028	FLES1-005	FLES2-022
ALBA1-012	ALBA1-029	FLES1-006	FLES2-023
ALBA1-013	ALBA1-030	FLES1-007	FLES2-024
ALBA1-015	ALBA1-031	FLES1-008	FLES2-025
ALBA1-016	ALBA1-033	FLES1-009 *	FLES3-001 *
ALBA1-017 *	ALBA1-034	FLES1-020	MSJK1-017
ALBA1-018	ALBA1-035	FLES1-021	
ALBA1-019	ALBA1-036	FLES1-022	
ALBA1-020	ALBA1-037	FLES1-023	

* A feature starts in adjoining segment to west and carries that ID, but overlaps into segment flagged.

Table 3.1 List of segments containing high priority areas for further evaluation under the Buried Oil Project.

Figure 3.8 Large surface residual balls (SRBs) and pieces of submerged oil mat (SOM) found buried as part of the Buried Oil Project (BOP). Photos taken 4/7/2013.

The results of the OSAT-3 activities provide a better understanding of sources and mechanisms of recurring oiling in the AOR, hydrodynamic models to identify areas more prone to deposition, locations where buried oil may persist and a fully integrated GIS system to facilitate visualization and evaluation of multiple data sources for decision-making purposes. In addition to individual segments assessments and data utilized, a summary of the key findings based on OSAT-3 team reviews with technical experts and the state and federal response and natural resource agency groups are presented, as follows:

Sand-oil mixtures formed at the time of initial oiling (primary) are being reworked by coastal processes to form more diffuse deposits (secondary). Extensive SCAT surveys provide evidence that diffuse deposits are widespread across the segments evaluated by OSAT-3 in this AOR. Understanding the influence of remobilization and transport of material across the AOR is fundamental to determining sources and mechanisms of re-oiling.

Observations of shoreline re-oiling (patterns in size, shape, and amounts) must be evaluated within the context of oiling processes during the time oil was coming ashore, response activities (nearshore booming, removal operations), and shoreline erosion/accretion post-oiling. Similarities and differences in shoreline re-oiling patterns across the range of shoreline types provided valuable information on the sources and mechanisms for re-oiling. However, *examination of patterns in re-oiling alone was not sufficient to meet all OSAT-3 objectives* because a number of factors not related to sources of residual oil can influence collections and therefore obscure short-term (weekly/monthly) patterns that may be associated with source and transport mechanisms. Factors that can influence daily collections and observations include: tide level, time since last survey, debris on beach, and avoidance of areas due to environmental and/or cultural resource issues.

Re-oiling patterns and dominant mechanisms vary across shoreline segment types and can vary within a segment depending on conditions. Re-oiling mechanisms are determined by a combination of interrelated factors associated with formation, source, mobilization, transport, and deposition. Factors that influence re-oiling include: degree of and nature of initial oiling (i.e. volume, patchiness, frequency, and degree of weathering), shoreline morphology/wave energy during the period of initial oiling, erosion/deposition patterns since post-oiling, the success of response activities to remove oil, and wave-energy/current patterns during mobilization/transport.

For the segments that were investigated, four major types of re-oiling mechanisms have been observed across the AOR*: (*1) cross-shore transport/uncovering of diffuse material referred to as surface residual balls (SRBs) or patties (depending on size) in the intertidal and nearshore subtidal zones (most prevalent mechanism for re-oiling); (2) cross-shore transport of material broken off of submerged oil mats (SOMs) in the intertidal zone in close proximity to the stranding (limited extent)*;* (3) longshore transport and deposition of SRBs from diffuse sources occurring predominantly during storm events (limited extent); and (4) simple uncovering of material of all sizes (buried since initial oiling and/or residual oil from cleanup operations) across tidal zones (common, but not prevalent mechanism for re-oiling).

"Heavy" oiling as defined during SCAT surveys covers a wide range of oiling conditions and does not always equate to the presence of SOMs. SCAT assessments are designed to provide a simple, comprehensive, systematic and standardized approach to shoreline oiling conditions in order to recommend cleanup methods and endpoints. OSAT-3 review teams utilized SCAT survey data as part of an integrated assessment of the likelihood and potential for SOMs to be contributing to segment re-oiling. The integration of georeferenced aerial images, photographs, boom location, hydrodynamic model output, field notes, and data (Operations and SCAT) collected during the response into a temporal and spatial referenced GIS system was a key component in the assessment of formation and persistence of SOMs.

Since initial oiling, a majority of the shoreline and nearshore areas have undergone enough erosion (vertically and laterally) to result in breakup and/or redistribution of the initial sand/oil deposits (other than those actively removed). Although the shoreline and nearshore areas have undergone normal erosion/deposition cycles, there are isolated and identifiable areas where SOMs may remain.

All evidence supports the premise that SOMs formed landward of the first sand bar**.** Analysis of tide and wave patterns during shoreline oiling coupled with observed associations between documented SOM locations and nearshore morphology (inside the first sand bar) support the formation of SOMs by stranding of oil on receding tides and/or by mixing with sand in the zone of active wave-breaking (not shoaling). Based on wave-energy dissipation and suspended sediment calculations focused on the time period of initial stranding of weathered oil, the energy dissipated outside of the zone of active wave breaking is below the levels necessary to thoroughly mix sand and floating oil. Although sand is very likely in suspension, analysis using hydrodynamic models shows that concentrations of sand reaching the surface are below levels observed in SOMs and levels likely required to decrease buoyancy enough to sink weathered oil. It is not likely that enough sand reaches the surface of the water column to mix with oil except in the zone of active wave breaking/run-up (where sand and floating oil mix). Differences in locations and characteristics of SOMs across the AOR are related to oiling history, wave energy, tidal range, morphology inside the first bar, and boom deployment.

SOMs in protected areas and near inlets are often associated with anchored boom, marsh vegetation or peat platforms. Anchored or stranded booms adjacent to shallow areas held floating oil in place, which enhanced oil mixing or infiltrating sand. Vegetation and peat platforms intermixed with sand also enhanced mixing with weathered oil.

The occurrence of large (greater than 5 centimeters in diameter) and angular (lack of smoothing due to transport along the seafloor) SRBs and patties may be diagnostic of SOMs in the vicinity. While SOMs are a source of re-oiling, interpretation of the presence of SOMs based on field observations must consider the possibility that the material washing up onshore at any particular time may not be a by-product of remaining SOMs being broken up by wave action. Large SRBs and patties are less likely to move than smaller SRBs; therefore it is possible that transport processes will segregate sizes. For instance, deposits of large SRBs and patties may be created and subsequently buried or uncovered by the movement of local sediment.

Increases in material collections/observations of small SRBs (less than 5 centimeters in diameter) along a segment are not a definitive diagnostic for potential concentrated sources such as SOMs. Conversely, extended periods of low recoveries may not be indicative of lack of SOMs as concentrated deposits do not breakup/transport and contribute to the re-oiling if covered by sand. Low recoveries of material could be due to reworking of diffuse deposits or SOMs may be a source of material. If covered by sand, concentrated deposits of buried oil are not reworked and transported onshore as they are shielded from wave action and currents.

Under conditions where native sediment is mobilized, buried SOMs can become partially/fully exposed, break apart, and contribute to re-oiling.

The process of burial/uncovering/cross-shore transport of diffuse sources of smaller SRBs (less than 2.5 centimeters in diameter) is responsible for most of the recurring oiling causing segments to not meet SCCP endpoint criteria. Since SRBs are less mobile compared to sand, they are likely to become buried and uncovered under normal sand transport processes, thereby lengthening the time SRBs may take to move onshore. Based on extensive onshore augering and trenching data, and snorkel SCAT assessments in the intertidal zone, smaller diffuse deposits (SRBs less than 2.5 centimeters) are much more common and widespread than concentrated sources, such as SOMs. Along Gulf-facing segments, failure to meet SCCP endpoint criteria is associated with SRBs found in the intertidal zone. The complexity of re-oiling (source, burial, uncovering, and transport of SRBs) is explained in the predicted variation in the timing and spatial extent of SRB and sediment mobility.

Differences in initial oiling (less oil and more patchy distribution) and lower wave energy along the protected areas (those areas that are not exposed to wave action from the Gulf of Mexico, such as mainland beaches and marshes of Mississippi and the back side of Mississippi barrier islands) compared to Gulf-facing beaches results in sand/oil mixtures with different characteristics in these environments. SCAT teams frequently documented “patty”-sized (less than 1.0 meters diameter) and SRB deposits along protected segments and they are often described as “gooey” or “less weathered” compared to deposits on Gulf-facing beaches. These characteristics are consistent with the lower wave energy environment where patches of floating oil mixed with just enough sand to sink and persist (less exposure/breakup/reburial).

Along protected areas (those areas that are not exposed to wave action from the Gulf of Mexico, such as mainland beaches and marshes of Mississippi and the back side of Mississippi barrier islands) re-oiling and failure to meet SCCP endpoints is primarily due to the simple uncovering of larger deposits (large SRBs and patties) most likely deposited and covered until discovery since initial oiling. Along low-energy segments, failure to meet SCCP endpoint criteria is associated with the discovery of patties and SRBs that were buried during initial oiling and later uncovered in close proximity to initial stranding. Patterns of re-oiling along low-energy segments are evident in both the supratidal (uncovered by wind/rain/tides) and intertidal zone (exposed during wind-driven extreme low tides). Hydrodynamic modeling results support this simple uncovering mechanism as wave energy required for longshore movement of material only occurs during extreme events during which SRBs and patties are likely broken into smaller pieces. Sand that extends farther out from the shore such as sand bars associated with culverts and other structures provides an expanded area for potential formation of patties and SOMs.

Aside from storm conditions and near tidal inlets, SRBs from one source location may not be redistributed to distant down-current locations. Based on results from hydrodynamic models, SRBs greater than 2.5 centimeters in diameter along Gulf-facing beaches are not, under the most commonly observed low-energy wave conditions, likely to move very far along the shoreline. Longshore current velocities estimated from hydrodynamic models are below the critical level required to move SRBs. Conditions for longshore movement of SRBs along sheltered segments (marshes, protected beaches such as Mississippi mainland beaches, and the back side of barrier islands) are much less common compared to the Gulf-facing beaches. During infrequent high-energy events (e.g., winter storms and Hurricane Isaac), energy is sufficient to move a greater range of SRB sizes and potentially expose and break apart patties and SOMs.

When SRBs do move alongshore, output from hydrodynamic models indicate that there are regions that are more conducive to accumulation than others. Deposition of SRBs (and sand) is governed by convergences in longshore currents (e.g. flow reversals), in areas of spatially decelerating longshore currents, and in areas where the shear stress forcing drops below critical thresholds to initiate/maintain SRB movement. Segments in these depositional areas are expected to have chronic re-oiling of smaller SRBs. Areas with structures that interrupt longshore flow (i.e. jetties, groins, culverts, and piers) are also depositional areas.

Areas adjacent to inlets are active transport/deposition zones. Flow and SRB mobility patterns around inlets indicate patterns in hydrodynamic forcing that influence redistribution of both SRBs as well as the transport of surface oil that mixed with suspended sediment to form oil mats in the first place.

Nearshore areas where conditions at the time of initial oiling (beach morphology, wave climate, and oiling pattern) may have been conducive to the formation of SOMs and have not since displayed evidence of erosion were identified and provided to the Buried Oil Project (BOP) for potential field evaluation. This approach was considered the most inclusive and conservative (i.e., this approach likely overestimated the formation and persistence of SOMs) because it is unlikely that SOMs formed in all of the areas identified as having similar characteristics to documented deposits and it is further likely that erosion occurred between aerial image collections used in the analysis.

Not all buried oil has been removed from this AOR, due to a combination of ecological, operational and safety considerations. The decision on whether or not this oil is amenable to removal actions lies with the FOSC. Most of the re-oiling in this AOR is from diffuse secondary sources (not SOMs) and that pattern is likely to continue. Future re-oiling of some segments in the AOR may occur, but the frequency and intensity of re-oiling will dissipate over time due to natural processes. Conditions needed to remobilize buried oil and the location of these re-oiling occurrences are generally predictable. Of the segments evaluated in this AOR, the patterns observed are predominantly indicative of diffuse sources being reworked by coastal processes. Using the knowledge generated during this program on areas with the highest potential for remaining buried oil deposits combined with an understanding of the mechanisms of transport and deposition of SRBs through hydrodynamic modeling will allow better understanding and predictability of locations for future re-oiling.

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5.0 List of Acronyms

AGL – Above Ground Level

AITWG – NRDA Aerial Imaging Technical Work Group

AOR – Area of Responsibility

BOP – Buried Oil Project

DEM – Digital Elevation Model

DOQQQ – Digital Ortho Quarter-Quarter-Quadranges

DSS – Digital Sensing System

DTM – Digital Terrain Model

ERMA – Environmental Response Management Application

FOSC – Federal On-scene Coordinator

GCIMT – Gulf Coast Incident Management Team

GIS – Geographic Information System

GPS – Global Positioning System

GSD – Ground Sample Distance

IMU – Inertial Measurement Unit

LWI – Land-Water Interface

LMSL – Local Mean Sea Level

MC252 Spill – Deepwater Horizon MC252 Spill of National Significance

NAVD – North American Vertical Datum

NGS – NOAA National Geodetic Survey

NRDA – Natural Resource Damage Assessment

NOAA – National Oceanic and Atmospheric Administration

OSAT-3 – Third Operational Science Advisory Team

SCAT – Shoreline Cleanup Assessment Technique

SCCP – *Deepwater Horizon Shoreline Clean-up Completion Plan* (2011)

SOMs – Submerged Oil Mats

SRBs – Surface Residual Balls

SSC – Scientific Support Coordinator

UTM – Universal Transverse Mercator

6.0 Appendices

Appendix A: OSAT-3 Charter and Membership

Appendix B: Snorkel SCAT Methodologies and Standard Operating Procedures

Appendix C: Application of Hydrodynamic and Sediment Transport Models for Cleanup Efforts Related to the Deepwater Horizon Oil Spill Along the Coast of Mississippi and Louisiana

Appendix D: Application of Hydrodynamic Models in Support of the Buried Oil Project

Appendix E: Aerial Image Acquisition and Processing

Appendix F: Summary of Oiling Condition by Segment Based on Operations and SCAT Surveys and OSAT-3 Re-Oiling Sources/Mechanisms Designation

Appendix G: Buried Oil Project (BOP) in the Eastern States AOR, Sept. 30, 2013