The use of RADARSAT-derived information to investigate oil slick occurrence in Campeche Bay, Gulf of Mexico

Gustavo de Araujo Carvalho [1]
Luiz Landau [1]
Fernando Pellon de Miranda [1,2]
Peter Minnett [3]
Fabio Moreira [1]
Carlos Beisl [1]

[1] Universidade Federal do Rio de Janeiro - UFRJ
Instituto Alberto Luiz Coimbra de Pós-Graduação e Pesquisa de Engenharia - COPPE
Programa de Engenharia Civil - PEC
Laboratório de Métodos Computacionais em Engenharia - LAMCE
Laboratório de Sensoriamento Remoto por Radar Aplicado à Indústria do Petróleo - LabSAR
ggus.ocn@gmail.com
landau@lamce.coppe.ufrj.br
fmoreira@labsar.coppe.ufrj.br
beisl@labsar.coppe.ufrj.br

[2] Petróleo Brasileiro - PETROBRAS
Centro de Pesquisas e Desenvolvimento Leopoldo Américo Miguez de Mello – CENPES
fmiranda@petrobras.com.br

[3] University of Miami - UM
Rosenstiel School of Marine and Atmospheric Science - RSMAS
Department of Ocean Sciences - OCE
pminnett@rsmas.miami.edu

Abstract. The Mexican oil company (Pemex) has in Campeche Bay (Gulf of Mexico) a well-established activity engaged with the oil and gas exploration and production industry. Because of the associated risk of petroleum pollution in this region, an archive containing 14,210 oil slicks (i.e. man-made oil spills and natural oil seeps) observed between 2000 and 2012 has been produced using RADARSAT-derived information. This database is used in the current study to reach the objective of investigating the oil slick occurrence in Campeche Bay. The evidence of the considerable influence of oil naturally seeping out of the Cantarell Oil Seep is shown. Even though the total number of oil seeps (n=6,202; 43.6%) is smaller than the observed oil spills (n=7,456; 52.5%), the total superficial area coverage of all oil seeps (31,447 km^2; 67.4%) is larger than oil spills (14,352 km^2; 30.7%). Conversely, if the massive influence of the Cantarell Oil Seep is disregarded (19,743 km^2; 42.3%), oil seeps (11,704 km^2; 25.1%) cover less of the ocean surface than the oil spills (14,352 km^2; 30.7%). Most oil slicks have small (< 1 km^2) superficial area coverage (n=9,398; 66.2%). The average size of oil spills (1.9 km^2) is smaller than oil seeps (5.1 km^2). Oil spills usually tend to occur in water depths < 100 m, which correspond to the location of the Campeche Bay petroleum activity, whereas oil seeps in this region commonly occur in water depths > 1000 m.

Keywords: Oceanography, oil spill, oil seep. Oceanografia, derrame de óleo, exsudação de óleo.

1. Introduction

Oil released to the environment can result in serious ecosystem contamination, as it represents an imminent hazard capable of causing wild sea-life die-offs, major problems to seawater desalination systems and to different industry sectors such as tourism, fisheries, aquaculture, shellfish beds, etc. (NRCC, 2003). Throughout this manuscript, the oil floating at the sea surface is described with the following terminology:

- Oil seep: Natural occurrence of oil coming out of the seafloor reaching the sea surface;
- Oil spill: Oil solely attributed to man-made activities related to oil rigs;
- Illegal oil dumping (IOD): Oil for which ships are the identified source; and
- Oil slicks: Indicate the oil footprint seeped naturally or spilled from human intervention.

Instruments flying onboard satellites can be used for detecting oil slicks floating at the sea surface. The most useful sensors are single wavelength side-looking radars operating in the microwave region of the electromagnetic spectrum – i.e. synthetic aperture radars (SAR).

However, this technology may yield false positives, thus causing ambiguous interpretations. The so-called look-alike features range from atmospheric phenomena (e.g. weak wind, rain cells) and oceanographic features (e.g. eddies, upwelling zones), to other events such as biogenic oil films, grease ice, and ship's stern wake turbulence.

Satellite measurements can bring tremendous benefits directly linked to the oil and gas exploration and production industry (OGEPI), as well as to societal stakeholders (e.g. the general public, resource managers, fishing industry, and the scientific community). Undeniably, monitoring systems that provide accurate oil slick identification are a major requirement for distinct applications such as environmental contingency measures and legal responsibility for prosecuting the petroleum polluter (McHugh, 2009).

The Mexican oil company (Petróleos Mexicanos – Pemex) has in the Gulf of Mexico's southernmost bight a well-established strategic activity engaged with OGEPI. In fact, Campeche Bay has what once was the most important petroleum province of the Western Hemisphere – the Cantarell Field (Pemex, 2007).

The eminent and associated risk of operational petroleum pollution in this region leads Pemex to be in a continuous state of alert for reducing possible negative influences on marine ecosystems. However, these are not isolated environmental issues as oil naturally seeps in different sites throughout Campeche Bay. Consequently, the fragile and delicate coastal environment along the shoreline of this embayment, fringed by beaches, inlets, bays, river mouths and highly sensitive mangroves, is in constant jeopardy due to the proximity to these various potential oil sources.

Over the past decade different studies have used satellite resources to identify the oil contribution to Campeche Bay – e.g. Pedroso et al. (2007) and Bannerman et al. (2009). Such studies have verified that the most prominent oil input in area coverage, dimensions, flow magnitude and persistence is the Cantarell Oil Seep (Figure 1). The oil in this locality seeps intensely in clearly noticeable pulses and, once at the sea surface, usually moves to the west forced by the prevailing easterly wind (Miranda et al., 2004).

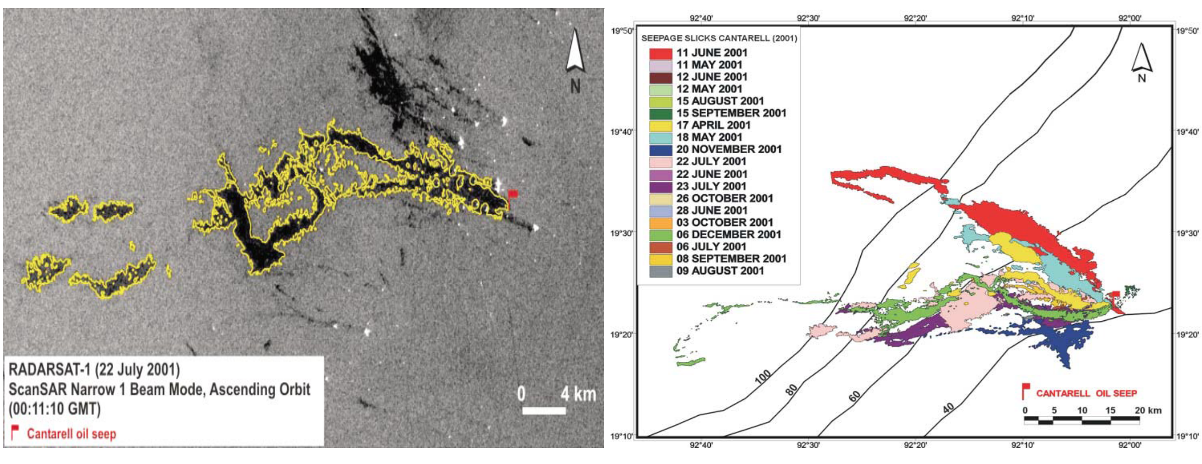

Figure 1. Left panel: RADARSAT-1 scene (22/June/2001) showing the Cantarell Oil Seep. Right panel: 2001 Cantarell Oil Seep cluster. Source: Miranda et al. (2004).

The goal of the current study is to use RADARSAT-derived information to investigate the occurrence of oil slicks in Campeche Bay. Section 2 offers a description of the dataset used in the course of this study.

2. Data and Methods

In the search for a reliable approach to survey oil seeps and oil spills in the Campeche Bay region, Pemex developed a plan to overcome the reliance on classic oceanographic surveillance. A large historical archive of oil slicks observed in this region has been produced using RADARSAT-derived information. Here, such dataset is referred to as the Campeche Bay Oil Slick Satellite Database (CBOS-SatData). This data collection spans in a continuous manner about 13 years (2000-2012), when areas at risk of oil leakage have been monitored. During this period it has been possible to observe 14,210 different oil slicks.

One of the most relevant characteristics of the CBOS-SatData is the regular acquisition of RADARSAT images, averaging one scene per week that includes both RADARSAT satellites (Bannerman et al., 2009). Hence, a large amount of SAR data (661 images) have been analyzed to inspect the occurrence of oil seeps and oil spills in Campeche Bay.

Once the RADARSAT images have been selected and processed (Roriz, 2006), they are digitally classified with the application of the Unsupervised Semivariogram Textural Classifier algorithm (USTC; Almeida-Filho et al., 2005). The USTC outcomes are polygons delimiting the borders of potential oil slick candidates or look-alike features. These shapes of interest are recognized by visual inspection of human operators in which the identified oil slicks are classified into oil seeps, oil spills or IODs – i.e. the *Category* attribute. These are then manually divided by the identity of its point source – i.e. the *Class* attribute:

- Cluster: Oil seeps with repeated occurrences about the same location far from OGEPI facilities – at least three oil seeps are needed to identify a given cluster (e.g. see Figure 1).
- Brightspot: Oil spills from different oil rigs within the same OGEPI complex – in reference to the bright appearance of platforms on SAR imagery;
- Ship spill: Because IODs are always observed in random localities with a large variety of causers (i.e. ships), these form a single class;
- Orphan seep: Oil seeps lacking site repeatability.
- Orphan spill: Oil spills not belonging to any specific brightspot; and

The information about each identified oil slick (i.e. slick-feature attributes) is inserted into a tabular database. Some relevant information is exclusive to each oil slick polygon, such as the identification number (*ID*) and site location represented by centroid´s geographical coordinates – latitude (*cLAT*) and longitude (*cLONG*). Particular information from the satellite scene acquisition includes the SAR overpass date (*SARdate*) and time (*SARtime*). Two basic shape variables are calculated: area (*Area*) and perimeter (*Per*). A contextual attribute is also given, i.e. the water column depth (*Wdepth*) for the centroid.

3. Results and Discussion

While the actual start of the RADARSAT acquisition dates from 10 July 2000, the last image accounted for is from 15 December 2012. However, a few archived images from 1997 and 1999 (5 scenes with 33 oil slicks) are included based on the inspection of previous considerations of the utilized methodology. Because RADARSAT-1 measurements have been utilized for a longer period to image the Campeche Bay region (Bannerman et al., 2009), there are more RADARSAT-1 scenes (n=385; 58.2%) compared to RADARSAT-2 scenes (n=276; 41.8%). About 90% of the oil slicks were imaged with ScanSAR Narrow modes: SCNA (n=8,777) and SCNB (n=4,115).

The local overpasses of the RADARSAT satellites above Campeche Bay are: early morning (5am-7am: descending) and late afternoon (5pm-7pm: ascending). The latitude of the observed oil slicks varies from 18°N to 26°N and the longitude range from 85°W to 96°W. However, most oil slicks (98%) in the CBOS-SatData are observed below 23°N and between 91°W and 95°W.

Figure 2-left portrays that the number of oil slicks among the three oil categories is unevenly distributed. While about half of the 14,210 oil slicks observed in Campeche Bay are classified as oil spills (n=7,456; 52.5%), oil seeps represent 43.6% (n=6,202), and the remaining 3.9% (n=552) are IODs.

Figure 2-right portrays the total area coverage of all oil slicks. The area of all oil spills (14,352 km^2; 30.7%) is less than half of the area covered by all oil seeps (31,447 km^2; 67.4%).

The greater part of the IODs has various point sources with very few observations associated with the same source (i.e. ship). However, some IODs have 8-10 different observations, and two vessels catch the attention with 22 and 65 oil slick incidences. Ships spills cover less than 1,000 km^2 throughout observed period (Figure 2-right).

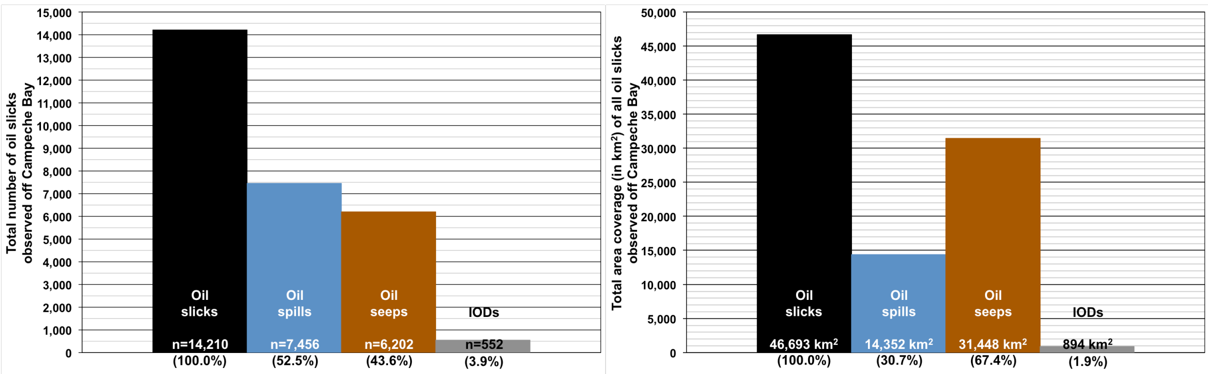

Figure 2. Frequency (left panel) and total area coverage (right panel) of all oil slicks (black) in the Campeche Bay Oil Slick Satellite Database (CBOS-SatData) per *Category* attribute. Blue: oil spills; brown: oil seeps; and grey: illegal oil dumping (IODs).

Figure 3-left shows the frequency of oil spills per class. The vast majority of the oil spills belongs to 71 brightspots (n=5,605; 75.2%). Of these, 61 brightspots have ≤ 99 different oil spill observations (n=1,263; 16.9%) and 10 brightspots have ≥ 100 oil spills (n=4,342; 58.3%). Orphan spills represent 24.8% (n=1,851) of the registered oil spills.

Figure 3-left also shows the frequency of oil seeps per class. Most oil seeps belong to 88 clusters (n=3,957; 63.8%). Of these, 75 clusters have ≤ 99 different oil seep observations (n=2,242; 36.1%) and 13 clusters have ≥ 100 oil seeps (n=1,715; 27.7%). The Cantarell Oil Seep represents 10.5% (n=653) of the observed oil seeps. The remaining 25.7% (n=1,592) of oil seeps are orphan seeps.

Figure 3-right shows the area (km^2) of the oil spill brightspots. The 61 brightspots with ≤ 99 different oil spill observations (5,690 km^2; 39.6%) and the 10 brightspots that have ≥ 100 oil spills (5,434 km^2; 37.9%) cover about the same superficial area. While these 71 brightspots sum 77.5% (11,123 km^2), orphan spills correspond to the remaining 22.5% (3,227.8 km^2).

Figure 3-right also shows the area (km^2) of the oil seep clusters. While the 75 clusters with ≤ 99 different oil seeps observations cover 3,779 km^2 (12.0%), the 13 clusters that have ≥ 100 oil seeps cover 5,168 km^2 (16.4%). These 88 clusters sum 8,948 km^2 (28.4%), whereas the Cantarell Oil Seep has a much larger area (19,743 km^2; 62.8%), and orphan seeps are responsible for only 2,757 km^2 (8.8%).

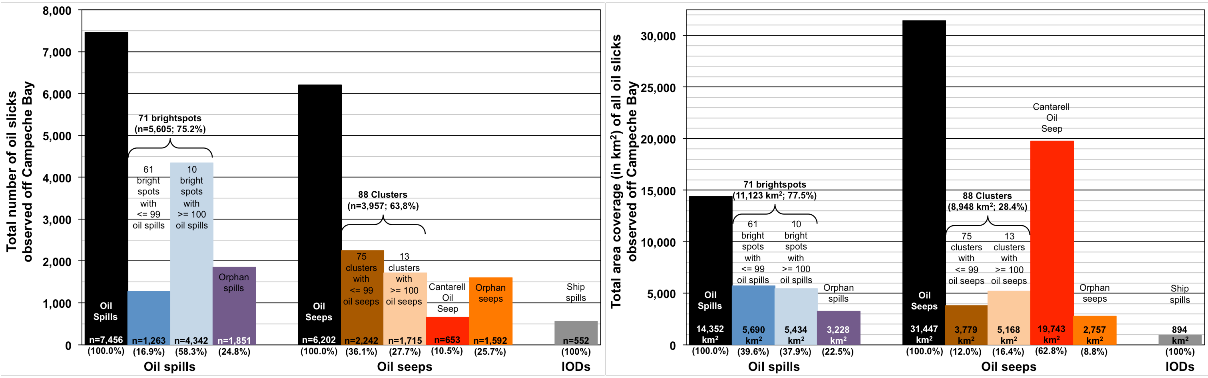

Figure 3. Frequency (left panel) and total area coverage (right panel) of all oil slicks (black) in the Campeche Bay Oil Slick Satellite Database (CBOS-SatData) per *Class* attribute. Cold colors: oil spills; warm colors: oil seeps; and grey: ship spills.

Figure 4-left illustrates the percentage of the number of all oil slicks in the CBOS-SatData. While the 10 brightspots with ≥ 100 oil spills observations represent about one third of the entire dataset (n=4,342; 30.5%), the 61 brightspots with ≤ 99 oil spill observations correspond only to 8.9% (n=1,263) of the identified oil slicks.

Figure 4-left also illustrates the number of occasions in which the Cantarell Oil Seep has been registered (n=653; 4.6%). The 75 clusters with ≤ 99 oil seeps correspond to 15.8% (n=2,242), whereas the 13 clusters with ≥ 100 oil seeps to 12.1% (n=1,715). Orphan spills (n=1,851; 13.0%) and orphan seeps (n=1,592; 11.2%) have about the same incidence, whereas ships spills only occur in 3.9% (n=552) of the cases.

Figure 4-right illustrates that most of the 46,693 km^2 covered by all oil slicks observed in Campeche Bay comes from the Cantarell Oil Seep (19,743 km^2; 42.3%). Nevertheless, if this contribution is omitted, oil seeps (11,704 km^2; 25.1%) cover less than oil spills (14,352 km^2; 30.7%).

Figure 4-right also illustrates that the 61 brightspots with ≤ 99 oil spill observations (5,690 km^2; 12.2%), the 10 brightspots with ≥ 100 oil spill observations (5,434 km^2; 11.6%), and the 13 clusters with ≥ 100 oil seep observations (5,168 km^2; 11.1%) have about the same representativeness. Likewise, the 75 clusters with ≤ 99 oil seeps observations (3,779 km^2; 8.1%), orphan spills (3,228 km^2; 6.9%), and orphan seeps (2,757 km^2; 5.9%) cover somewhat similar areas. Ships spills only cover 1.9% (894 km^2) of the area of all observed oil slicks.

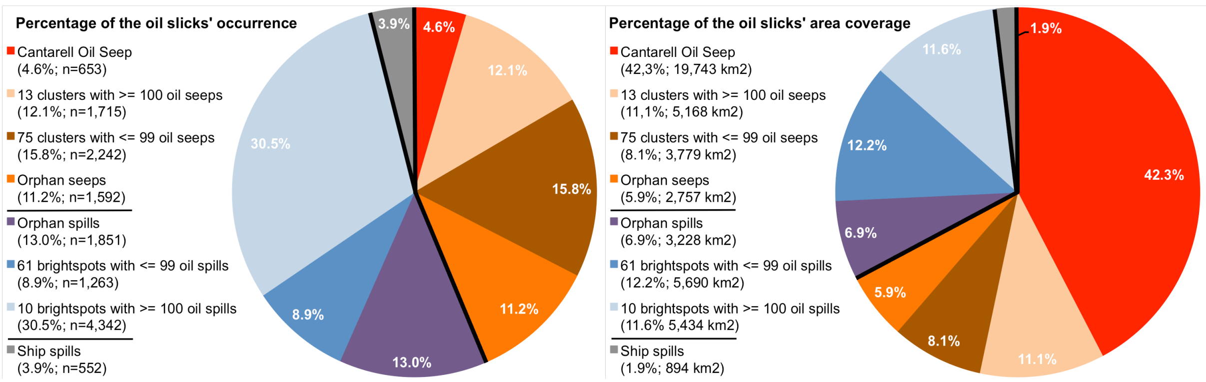

Figure 4. Left panel: Percentage of the number of all oil slicks per *Class* attribute. Cold colors: oil spills (n=7,456; 52.5%); Warm colors: oil seeps (n=6,202; 43.6%); and Grey: ship spills (n=552; 3.9%). Right panel: Percentage of the total area coverage of all oil slicks per *Class* attribute. Cold colors: oil spills (14,352 km^2; 30.7%); Warm colors: oil seeps (31,447 km^2; 67.4%); and Grey: ship spills (894 km^2; 1.9%).

Table 1 depicts that a major aspect about the 14,210 oil slicks observed in Campeche Bay regards their size distribution. Most oil slicks (n=9,398; 66.2%) have small superficial area coverage (< 1 km^2). Considering the oil categories, areas < 1 km^2 correspond to more than 2/3 of the observed oil spills (n=5,746; 77.1%), as well as to about half of the oil seeps (n=3,202; 51.7%), and approximately 4/5 of the IODs (n=450; 81.5%).

Table 1 also depicts that only 5.2% (n=734; Table 1) of the oil slicks have large superficial area coverage (≥ 10 km^2). Among these, there are only 63 observations with major superficial area coverage (≥ 100 km^2): 14 oil spills, 48 oil seeps, and only 1 IOD.

Table 1. Size distribution of the oil slicks (i.e. oil spills, oil seeps, and illegal oil dumping (IODs)) in the Campeche Bay Oil Slick Satellite Database (CBOS-SatData).

Superficial area coverage	**Oil slicks**	Oil spills	Oil seeps	IODs
Oil slicks < 0.5 km^2	**7,088 (49.9%)**	4,657 (62.5%)	2,057 (33.2%)	374 (67.8%)
0.5 ≤ Oil slicks < 1 km^2	**2,310 (16.3%)**	1,089 (14.6%)	1,145 (18.5%)	76 (13.7%)
1 ≤ Oil slicks < 10 km^2	**4,078 (28.6%)**	1,504 (20.1%)	2,482 (39.9%)	92 (16.7%)
10 ≤ Oil slicks < 100 km^2	**671 (4.7%)**	192 (2.6%)	470 (7.6%)	9 (1.6%)
Oil slicks ≥ 100 km^2	**63 (0.5%)**	14 (0.2%)	48 (0.8%)	1 (0.2%)
All oil slicks	**14,210 (100%)**	7,456 (100%)	6,202 (100%)	552 (100%)

Table 2 shows the minimum (0.2 km) and maximum (5,093.2 km) perimeters, as well as the average (18.9 km; 60.5 km) and median (6.9 km; 32.3 km) perimeter for all oil slicks and for those with area ≥ 1 km^2.

Table 2 also considers the statistics about the oil slicks' area: minimum (0.01 km^2) and maximum (1,789 km^2). From this table, it is possible to observe the presence of major outliers, as, independently of the oil category, the largest oil slicks are considerably larger than the second largest ones. The average (1.9 km^2) and median (0.3 km^2) values for all oil spills are lower than the average (7.4 km^2) and median (2.4 km^2) for those with area ≥ 1 km^2.

Table 2. Perimeter (km) and area (km^2) of all oil slicks (i.e. oil spills, oil seeps, and illegal oil dumping (IODs)) in the Campeche Bay Oil Slick Satellite Database (CBOS-SatData).

	Perimeter (km) Oil slicks	**Area (km^2) Oil slicks**	Area (km^2) Oil spills	Area (km^2) Oil seeps	Area (km^2) IODs
Minimum	**0.2**	**0.01**	0.01	0.01	0.01
Maximum 1	**5,093.2**	**1,789.0**	994.1	1,789.0	267.0
Maximum 2	**2,086.9**	**994.1**	533.5	495.8	50.3
Maximum 3	**1,895.4**	**533.5**	500.8	436.2	45.4
Maximum 4	**1,521.2**	**500.8**	277.5	294.5	39.3
Maximum 5	**1,081.6**	**495.8**	264.8	261.6	22.5
Average (all oil slicks)	**18.9**	**3.3**	1.9	5.1	1.6
Median (all oil slicks)	**6.9**	**0.5**	0.3	0.9	0.3
Average (≥ 1 km^2)	**60.5**	**9.1**	7.4	10.0	7.6
Median (≥ 1 km^2)	**32.3**	**2.7**	2.4	2.8	2.4

The water column depth is only given for 40% (n=5,669) of the oil slicks in the CBOS-SatData (Table 3), in which the average and median value of all oil slicks are 484 m and 59 m, respectively. Considering each category (Figure 5-left), the vast majority of oil spills (96%) occurs at shallower regions (< 100 m), whereas most oil seeps (63%) are in deep waters (> 1000 m), and only 10 IODs are registered on waters deeper than 100 m. Oil slicks of various sizes occur at the same water depths (Figure 5-right).

Table 3. Water column depth (m) of the oil slicks (i.e. oil spills, oil seeps, and illegal oil dumping (IODs)) logged in the Campeche Bay Oil Slick Satellite Database (CBOS-SatData).

Water depth (m)	**Oil slicks**	Oil spills	Oil seeps	IODs
Shallower	**2**	2	20	4
Deeper	**3,966**	2,500	3,966	2,000
Average	**484**	72	1,296	81
Median	**59**	50	1,500	48
Number of records	**5,669**	3,461 (61.1%)	1,905 (33.6%)	302 (5.3%)

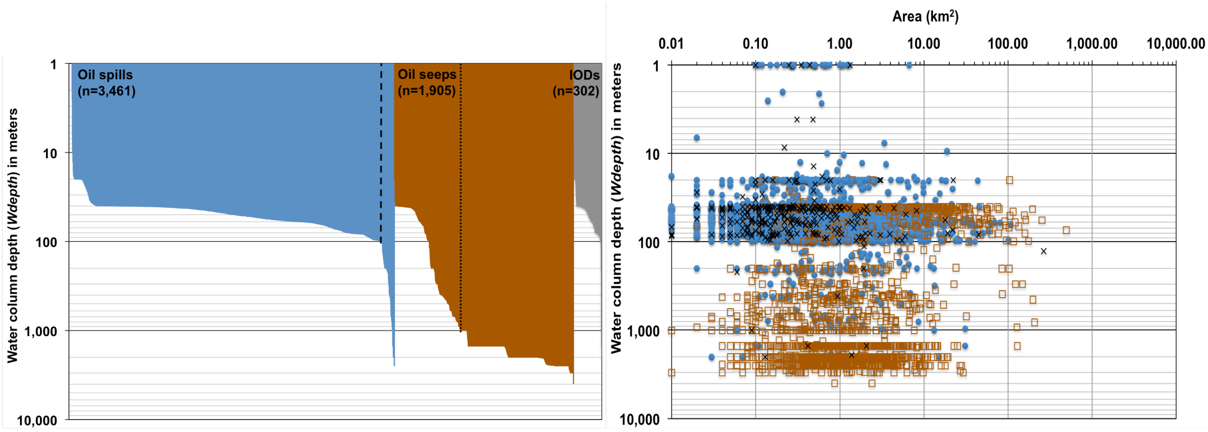

Figure 5. Water column depth (m) of the oil slicks logged (n=5,669) in the Campeche Bay Oil Slick Satellite Database (CBOS-SatData): oil spills (blue; circle), oil seeps (brown; square), and illegal oil dumping (IODs; grey; cross). The dashed and dotted lines in the left panel indicate the limits for 100 m and 1000 m depths, respectively.

4. Final considerations

The familiarization with the content (i.e. slick-feature attributes) of the CBOS-SatData makes it possible to investigate some relevant characteristics related to the occurrence of oil slicks in Campeche Bay. The evidence of the considerable influence of oil naturally seeping out of the Cantarell Oil Seep to Campeche Bay is shown and agrees with previously published studies (Miranda et al., 2004; Pedroso et al., 2007).

Even though the CBOS-SatData shows that there is less oil seeps (n=6,202; 43.6%) than oil spills (n=7,456; 52.5%), oil seeps (31,447 km^2; 67.4%) cover a larger area than oil spills (14,352 km^2; 30.7%). However, a noteworthy aspect to mention about the oil slicks observed in Campeche Bay is that if the massive influence of the Cantarell Oil Seep is disregarded (19,743 km^2; 42.3%), one can clearly notice that the oil seep occurrence (11,704 km^2; 25.1%) is less than the occurrence of oil spills (14,352 km^2; 30.7%).

Another aspect considering the size of the oil slicks observed during the 13 years (2000-2012) of RADARSAT data acquisition is that most of the observed oil slicks have small (< 1 km^2) superficial area coverage (n=9,398; 66.2%). Also, oil seeps (5.1 km^2) tend to be larger than the oil spills (1.9 km^2). Furthermore, in comparison with the average size (~6.5 km^2) of the oil spills analyzed by Bentz (2006) off the SE of Brazil (Campos Basin), the oil spills observed in the Campeche Bay region are indeed smaller.

An interesting point to highlight is that, in Campeche Bay, oil spills usually tend to occur in water depths < 100 m, which correspond to the location of the Campeche Bay OGEPI activity, whereas oil seeps in this region commonly occur in waters > 1000 m.

The effectiveness of using RADARSAT-derived information to investigate the occurrence of oil slicks in Campeche Bay contributes to a better relationship between Pemex and different societal stakeholders. A supplementary application of the satellite synoptic view of OGEPI operations is the recognition of the oil slick type – i.e. distinguishing oil spills from oil seeps. Indeed, if oil spills become distinguished from oil seeps, satellite information can help on the optimization of potential environmental countermeasures avoiding financial penalties, as well as to support monitoring programs directed at finding new and active petroleum systems on offshore exploration frontiers.

The study presented here is part of an ongoing D.Sc. research thesis aiming to use satellite measurements to distinguish man-made oil spills from natural hydrocarbon seeps.

Acknowledgements

Special thanks are due to colleagues from LabSAR (Adriano, Patricia, Rosana), LAMCE (Mônica, Sérgio, Humberto, Ricardo), INPE (Ronald Buss), and Petrobras (Patricia Curbelo, Cristina Bentz, Alexandre Politano). Appreciation is also shown to Sylvia Lima. This study has been funded by Agência Nacional do Petróleo, Gás Natural e Biocombustíveis (ANP).

References

Almeida-Filho, R.; Miranda, F. P.; Lorenzzetti, J, A.; Pedroso, E. C.; Beisl, C. H.; Landau, L.; Baptista, M. C.; Camargo, E. G. RADARSAT-1 images in support of petroleum exploration: the offshore Amazon River mouth example, **Canadian Journal of Remote Sensing**, v. 31, n. 4, p. 289-303, 2005.

Bannerman, K.; Rodríguez, M. H.; Miranda, F. P.; Pedroso, C. E.; Cáceres; R. G.; Castillo, O. L. Operational applications of RADARSAT-2 for the environmental monitoring of oil slicks in the southern Gulf of Mexico, In: International Geoscience and Remote Sensing Symposium (IGARSS '09), IEEE, **Proceedings**... Cape Town, South Africa, 12-17 July, p. 381-383, 2009.

Bentz, M. C. **Reconhecimento Automático de Eventos Ambientais Costeiros e Oceânicos em Imagens de Radares Orbitais**, D.Sc. thesis, UFRJ, COPPE, PEC, Rio de Janeiro, 115 p., in Portuguese, 2006.

McHugh, S. L. **Satellite synthetic aperture radar in the prosecution of illegal oil discharges**, M.Sc. dissertation - Memorial University of Newfoundland, 122 p., 2009.

Miranda, F. P.; Quintero-Marmol, A. M.; Pedroso, E. C.; Beisl, C. H.; Welgan, P.; Morales, L. M. Analysis of RADARSAT-1 data for offshore monitoring activities in the Cantarell Complex, Gulf of Mexico, using the unsupervised semivariogram textural classifier (USTC), **Canadian Journal of Remote Sensing**, v. 30, n. 3, p. 424-436, 2004.

NRCC (National Research Council Committee), 2003, Oil in the Sea III:Inputs, Fates, and Effects, Washington, DC, The National Academies Press, ISBN 9780309084383. Available: <http://www.nap.edu/openbook.php?record_id=10388 >. Accessed on: June 2013.

Pedroso, E. C.; Miranda, F. P.; Bannerman, K.; Beisl, C. H.; Rodríguez, M. H.; Cáceres, R. G. A multi-sensor approach and ranking analysis procedure for oil seeps detection in marine environments, **IEEE**, 6 p., 2007.

Pemex (Petróleos Mexicanos), 2007, Anuario Estadístico. Available: <http://www.pemex.com/files/content/Anuario2007.pdf>. Accessed on: April 2013.

Roriz, C. E. D. **Detecção de exsudações de óleo utilizando imagens do satélite RADARSAT-1 na porção *offshore* do Delta do Niger**, M.Sc. dissertation, UFRJ, COPPE, PEC, LABSAR, Rio de Janeiro, 267 p., in Portuguese, 2006.