IBP1776_14

EVALUATION OF REMOTE TECHNOLOGIES APPLIED TO NATURAL SEEP MAPPING AND THEIR IMPACT IN OIL EXPLORATION

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Abstract

The geographic location of oil seeps adds valuable information to the exploratory model and to the knowledge of the natural dynamic of petroleum systems. So far, the remote investigation of oil seeps focused only on detections of seepage slicks on the sea surface, using SAR (Synthetic Aperture Radar) images. However, depending on the hydrodynamics of the interest region, the oil position on sea surface can be more than one hundred kilometers far from its origin at the seafloor. To overcome this limitation, we combined SAR images with hydrodynamic and inverse modeling to remotely estimate the location of natural oil seep areas at the seafloor (not on sea surface anymore). The hydrodynamic model rebuilds the ocean circulation scenario and the inverse modeling simulates the trajectory of oil, going back in time and space, from the sea surface until its origin on the seafloor. This work evaluated the effectiveness of these remote technologies following two main steps: (1) mapping of seafloor oil seep areas in Santos Basin, Brazil; and (2) comparing the results with available in situ data (piston cores, wells and oil fields). The rates of cores and wells with HC evidence were both greater in the group close to the seep areas mapped by remote technologies. The percentage of cores inside seep areas with HC evidence was 61.5% (against 25.7% considering the total samples). The results showed that remote technologies are really effective and does contribute to increase exploratory success rates.

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1. Introduction

Natural oil seeps indicate not only the presence of source rocks, but also the thermal maturation and migration of the generated oil. Thus, the geographic location of seeps adds valuable information to the exploratory model and to the knowledge of the natural dynamic of petroleum systems in the region.

In the meantime, the oil exploration is moving more and more toward ultra-deep waters, demanding heavy and expensive logistics for in situ investigation. Thus, the importance of obtaining remote information about oil seeping increases.

So far, the remote investigation of oil seeps focused on detections of seepage slicks on the sea surface, using Synthetic Aperture Radar (SAR) images (Miranda et al., 1998; Miranda et al., 2004 and Almeida Filho et al., 2005). This approach has been considerably used in order to support the petroleum system characterization in offshore basins of exploratory frontiers. However, depending on the hydrodynamics of the interest region, the oil position on sea surface can be more than one hundred kilometers far from its origin at the seafloor, mainly if you are dealing with ultra-deep waters.

To overcome this limitation, we combined SAR images with hydrodynamic and inverse modeling to remotely estimate the location of natural oil seep areas at the seafloor (not on sea surface anymore). The hydrodynamic model rebuilds the ocean circulation scenario and the inverse modeling simulates the trajectory of oil, going back in time and space, from the sea surface until its origin on the seafloor. The objective is to map areas in the seafloor where active petroleum systems leak, using only remote technologies (remote sensing and computational modeling). This way, it is possible to investigate any offshore region in the world without going in situ, which means a meaningful reduction of exploratory, environmental and operational risks.

But do these remote technologies really increase the ability of finding natural oil seep areas? Can the location of seep areas help in increasing the exploratory success rate? Does the natural oil leakage mean no commercial accumulation? This work tried to answer these questions following two main steps: (1) mapping of seafloor oil seep areas in Santos Basin, Brazil; and (2) comparing the results with available in situ data (piston cores, wells and oil fields production). The choice of Santos Basin considered data availability and oceanographic and geological aspects necessary to evaluate the effectiveness of the technology. The region presents a complex hydrodynamic, with eddies and vertical inversion of current flows, and known geological features. Figure 1 presents the study area and the position of the cores and wells used.

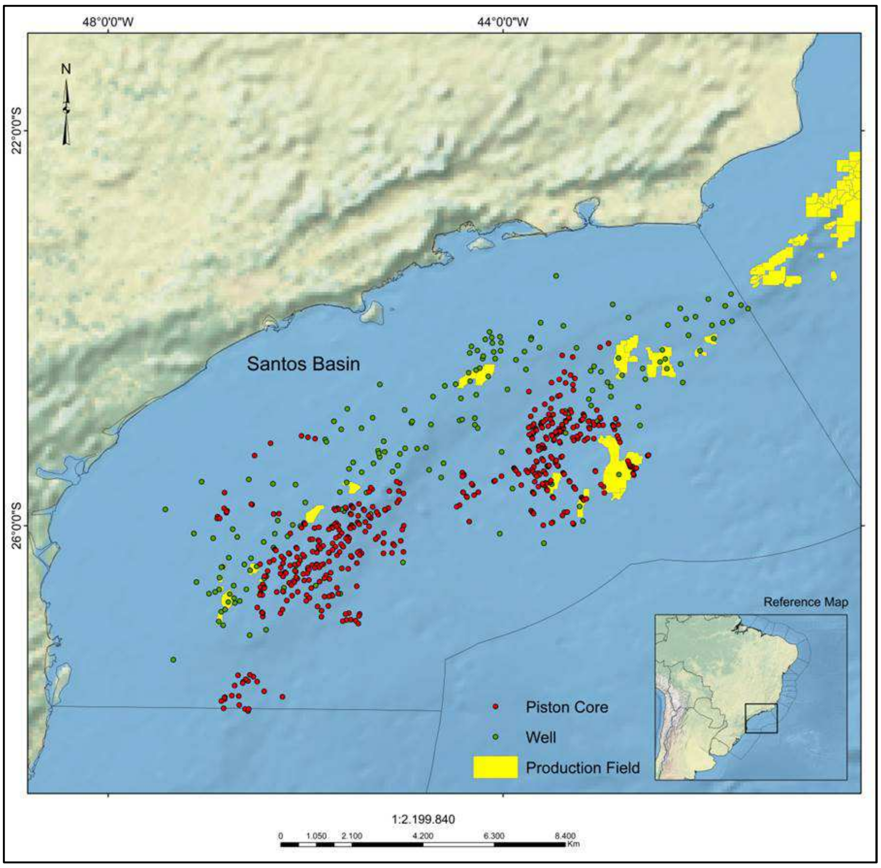

Figure 1. Study area: Santos Basin, Brazil, showing the position of in situ data (piston cores, wells and oil fields) used to evaluate the results of remote technologies

2. Methodology

The methodology consists of two main steps: (1) application of remote technologies to map seep areas on the seafloor, and (2) evaluation of the remote technologies effectiveness using in situ data.

2.1. Remote Technologies

Two main remote technologies were used in this work: remote sensing and computational modeling. Satellites are used to detect oil features on the sea surface. Usually, oil seeps are characterized by a thin layer that can be detected within some days on the ocean surface. The detection is possible due to the dampening of the ocean surface capillary waves, caused by oil presence. This physical phenomenon can be captured in SAR images (Figure 2). SAR systems can screen large areas, keeping high spatial resolution, operating night and day and obtaining data in any meteorological conditions. Nowadays, several satellites operating in C and X-bands are able to detect oil features on the sea surface. Each image was taken in full resolution mode and a textural classification algorithm was performed in each one to extract the features indicative of seepage slicks on the sea surface. A total of 250 oil slicks were detected on the sea surface and used as an input to the inverse modeling.

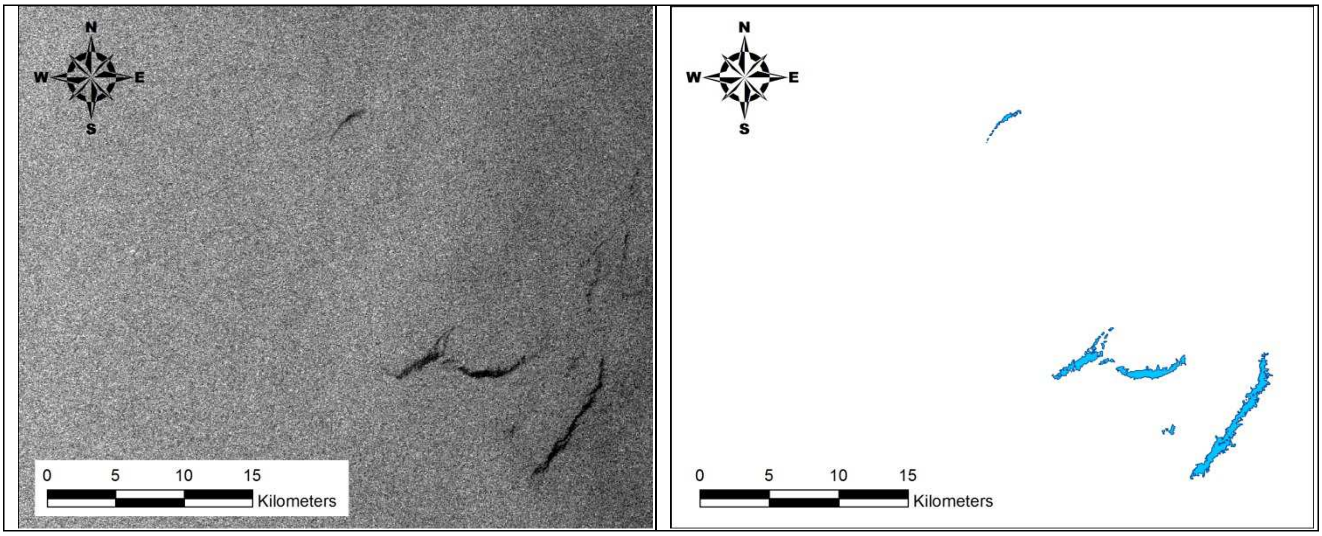

Figure 2. Left - SAR image showing dark patches interpreted as oil features at sea surface. Right – the results of an unsupervised classification showing blue polygons representing oil seeps.

For each oil seep detected, the inverse modeling goes backward in time and space to estimate the trajectory of the oil between the position on the sea surface, where it was detected by satellite, and its origin at the ocean bottom (Figure 3).

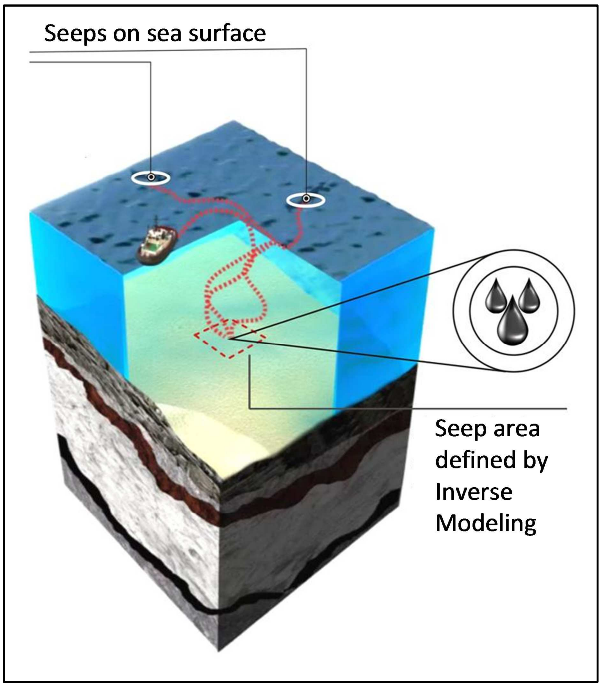

Figure 3. Inverse modeling scheme showing the seep on surface and its origin on the seafloor.

To run the inverse modeling, it is necessary to recreate the ocean circulation at each date of SAR image where a seep was detected. In the hydrodynamic modeling step, each seep is associated to a three-dimensional ocean circulation and to a wind field, which vary in time, in hourly basis. The wind fields are retrieved from satellite and the circulation is obtained using data assimilation. The model grid is designed to represent the main oceanographic features in the region of interest (Mano, 2007; Mano et al., 2010; Mano et al., 2011).

The 3D current and wind fields from hydrodynamic modeling are imported by the inverse model. For each seep, the model runs several simulations. In this study, more than 6,000 inverse modeling simulations were performed to map the seep areas at seafloor. The definition of the seep areas is based on the calculation of the spot where the maximum convergence among the set of solutions occurs. Algorithms were developed to automatically estimate these areas.

2.2. In-situ Data

To evaluate the effectiveness of the remote technologies, the inverse modeling results were compared with piston cores, wells and oil fields data. Figure 1 presents the position of this in situ data.

The piston core data was acquired from Geochemical Solutions International Inc. (GSI). Two sediment samples from 506 cores (total of 1012 samples) were analyzed using 3 different screen techniques: TSF (Total Scanning Fluorescence), UCM (unresolved complex mixture of hydrocarbons) and headspace gas (C2-C4). Increasing fluorescence generally corresponds to greater petroleum concentrations in samples. UCM concentrations determined by gas chromatography provide an estimate of total extractable hydrocarbons and are an important seep indicator. In seep sediments, petroleum hydrocarbons are characterized by the dominance of a broad unresolved complex mixture (UCM) in chromatograms. For gas analysis, headspace gas concentrations of C2 – C4 components (ethane through butane) are frequently elevated at sites of hydrocarbon seeps.

Following Bernard et al. (2008), the results of TSF, UCM and C2C4 were plotted for all samples in order to define regional thresholds for their backgrounds. Values above the backgrounds were considered anomalies. If a sample presented TSF and UCM values greater than backgrounds, it was considered as an indicative of liquid HC (hydrocarbon) presence, due to the anomalous values of the indicators. In the same way, if the sample presented C2C4 concentrations above the background, it was classified as sample with anomalous values for gaseous HC indicators. Thus, anomalous values for liquid or gas were considered as a HC evidence.

Despite knowing that seep areas do not point locations for drilling, as the oil can horizontally migrate tens of kilometers from the reservoir, we speculate that including remote technologies in the exploratory program can impact the success rates. To estimate this impact, a total of 178 pioneer exploratory wells data, available in the Brazilian Exploration and Production´s Database (BDEP), with known results for hydrocarbons evidence, were assessed. For the statistical analysis, the result "dry well without evidence of oil" indicates no evidence of HC (gas or liquid), whilst any other result indicates HC evidence.

Finally, all the present oil fields in Santos Basin were mapped, according to BDEP data. The objective was to evaluate any spatial relation between the location of seep areas and the commercial accumulations'.

3. Results

The cores were grouped according to their distance to a seep area mapped by remote technologies. Five groups of cores were considered: inside seep areas; up to 10 km far from a seep area; up to 20 km; up to 30 km and a group with all cores. Table 1 presents the results of HC evidence for each group. Although the number of cores (13) inside seep areas is statistically small, it is worth highlighting the percentage of cores with anomalous values for HCs indicators: 61.5%, against 25.7% considering all cores, which means a performance improvement of 139%. Figure 4 summarizes the percentage of positive HC evidence of cores according to their distance to a seep area. The performance of each group grows exponentially as it gets closer to a seep area, confirming the effectiveness of the remote technologies. These numbers show a significant improvement in the ability of finding oil presence in sediment samples.

Table 1. Results of HC evidence of cores according to their distance to a seep area mapped by remote technologies.

	OIL OR GAS EVIDENCE		
	YES	NO	%YES
PISTON CORES	(# cores)		
Inside a seep area	8	5	61.5%
within a distance up to 10 km from a seep area	28	35	44.4%
within a distance up to 20 km from a seep area	49	99	33.1%
within a distance up to 30 km from a seep area	69	153	31.1%
All	130	376	25.7%

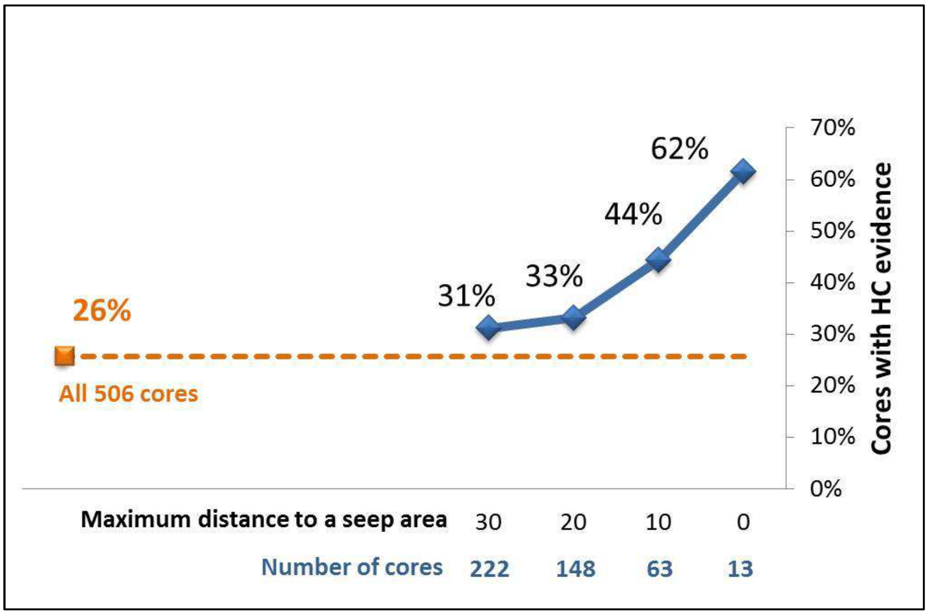

Figure 4: Percentage of hydrocarbon indication in the cores according to their distance to a seep area.

Since there is no well inside seep area and considering that seep areas do not indicate points for drilling or commercial accumulations, wells and oil fields were divided only in two groups, according to their distance to a seep area mapped by remote technologies:

Group 1: wells and oil fields within a distance up to 30 km from a seep area

Group 2: wells and oil fields more than 30 km far from a seep area

Table 2 presents the results of HC evidence for each group, considering the 178 wells. Figure 5 shows the performance increase of Group 1 (wells close to seep areas). The rate of wells with HC evidence in Group 1 is 45.2% greater, when compared with Group 2 (68.4% against 47.1%, respectively), which means a significant positive impact in the exploratory success rate.

The improvements for cores and wells were obtained considering a different distribution of them, as can be seen in Figure 1.

Table 2. Results of HC evidence of wells according to their distance to a seep area mapped by remote technologies. Group 1 indicates data close to seep areas and Group 2 indicates data far from seep areas

	OIL OR GAS EVIDENCE		
	YES	NO	%YES
WELLS	(# wells)		
Group 1	26	12	68.4%
Group 2	66	74	47.1%
All	92	86	51.7%

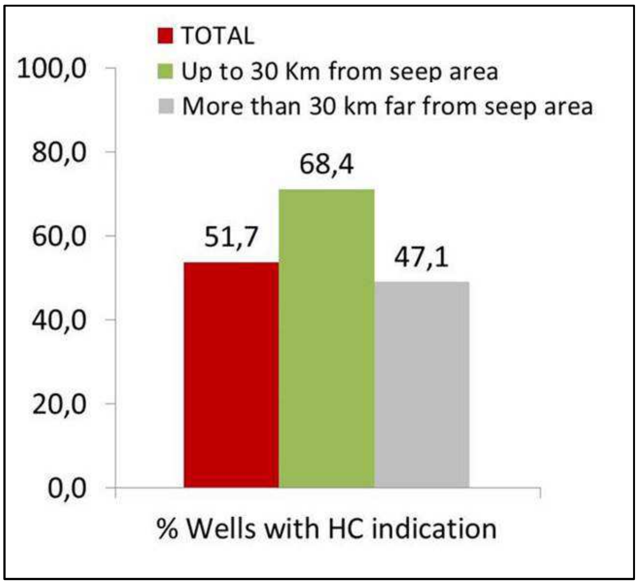

Figure 5: Percentage of hydrocarbon indication in the wells of each Group

Regarding oil production, half of present oil fields in Santos Basin are within 30 km of a seep area (the average distance between seep areas and oil fields was 9.8 km in this case). Although these numbers do not allow any spatial relation between oil fields and seep areas, they confirm that natural oil seepage does not mean absence of commercial accumulation of oil.

4. Conclusions

Answering the introduction questions, the results showed that mapping seep areas on the seafloor by remote technologies is really effective and does contribute to increase exploratory success rates. Besides that, the better rates in finding hydrocarbon evidences can be converted into oil production, as showed by the proximity between seep areas and oil fields.

The percentage of cores with positive HC evidence grows exponentially as they get closer to a seep area. The result of cores inside a seep area with HC evidence (61.5%) demonstrates a significant performance increase when compared with all the cores (25.7%). This improvement with the use of remote technologies can be converted in lower operational and environmental risks and shorter time, lower costs and higher number of new discoveries.

We speculate that the use of remote technologies in the beginning of the oil exploration can positively impact the whole chain. As they reduce the area and time of investigation, the cost/benefit rates of other classic tools, like seismic and piston core, can be also improved, playing a complementary role with in situ tools and contributing to a more efficient oil exploration. Additionally, as the methodology is totally remote, the more the exploration goes offshore, the higher are the exploratory risk and the lack of available data, and, thus, the bigger is its impact in the exploratory chain.

5. Acknowledgements

We would like to thank FAPERJ - Rio de Janeiro agency for science, technology and innovation-, who financially supported this study. Another important acknowledgement is to Craig Schiefelbein, from GSI, for the technical support.

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