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[EA]Oil Seeps Detection in Offshore Frontier Areas Based on Multitemporal Satellite SAR Data and Manual Interpretation: Levantine and Natal Basins, Selected Historical and Recent SAR Data*

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Abstract

For years, remote sensing has been more and more widely accepted by geoscientists as a useful tool in the early stages of exploration campaigns to unveil natural oil seeps. Satellite data has much to offer in today's exploration budgets. Acquisition and interpretation are very fast and provide a valuable additional information to be combined with other geological and geophysical datasets. The technology is perfectly suited to frontier ventures where dense seismic might be lacking, and where pollution, one of the major arguments brought against seeps studies, might be less hostile or diffuse. Remote Sensing stands out as a very affordable asset compared to other exploration expenditures and will strengthen the knowledge on a petroleum system within a basin or province. One fast and cost-effective solution is to gather archives SAR (radar) data from around years 1990 to about 2010. Today's European programs such as Sentinel enables reaching another landmark.

Our innovative approach relies in the coupling of archives data - which can first highlight small specific zones of potential among very wide areas - with brand new data acquired days or weeks ago, which can confirm the initial potential. Seeps interpretation heavily relies on the person seating behind the computer. In a time of worshipped Big Data, where the industry gets thrived by the progress of Artificial Intelligence, there is still, nevertheless, a point to make by discussing the benefits of manual interpretation. Seeps detection has little to do with binary concerns, it is quite never all true or all wrong: it is often "in-between" and in the end, it is all in the eyes of someone that has seen seeps around the world in several different contexts. Seeps have their own signatures, but they can easily be confused with "lookalikes" (algae, bathymetrical or atmospheric artefacts, etc). If we are not ready enough to trust computers to make automatic interpretations, how can humans become more accurate? One of the answers might be found in the multitemporal approach of the methodology that allows us to highlight recurrences and spatial proximity of active seepages.

Areas of Study

North African and South African spurs, with a focus respective on Levantine and Natal basins (Figure 1), bear some common features. They can both be considered as frontier as they remain quite undrilled. The Levantine Basin hosts some giant gas discoveries such as Leviathan and Zohr, however, the western part of the basin is sparsely drilled except for some Ocean Drilling Programs (ODP 160). In South Africa, the main areas of interest of our seep study, Natal and Zululand basins, are relatively unknown compared, for example, to prolific neighbor Outeniqua Basin lying in to the southwest.

Seep-wise, the two areas of study are very different: Levantine belongs to a restricted sea-context, with very heavy pollution such as can be found in the Mediterranean Sea, while Natal is located in an open ocean with pollution routes very easy to detect. The Levantine seep study covers about 94,000 square kilometres, while the Natal seep study covers more than 500,000 square kilometres.

Petroleum Systems of Levantine Basin

At least two petroleum systems seem to be present in the Levantine Basin which correspond to a major subsidence area since Triassic times, which could be roughly similar stratigraphically to the Palmyrides area in Syria. It is only in the recent times (Neogene), and thanks to the progressive implementation of the Cyprus and Latakia accretion ridges, that the Levantine Basin became an important foredeep depocenter. Two kinds of fluids have been discovered and produced so far:

1) On the Eastern and Southern edges of Levantine Basin, the light oils of the Mango 1 well and of the Yam-Yafo wells, respectively in Cretaceous sands and in Jurassic carbonates. These oils are correlated either to the Triassic Amanus Shale or the Upper Cretaceous shales (Barrier et al., 2014).

2) In the center of the Levantine Basin in Israel, Cyprus and Egypt offshore, very large gas discoveries have been made in the last decade (Tamar, Zohr) thought to be of biogenic origin from the Mio-Pliocene rapidly subsiding series.

On the western side in the Eratosthenes Seamount (ESM) area, for the time being, only the ODP leg 160 has commenced to recognize the very nature and stratigraphy of this huge closure (Robertson, 1998). ODP leg 160 is made of 3 penetrations (sites 965-966-967) which have encountered shallow water carbonates in Santonian, passing to deep sea carbonates in the Maastrichtian and Eocene; then, an important uplift took place leading to an Oligocene hiatus, a Miocene shallow carbonates deposition and the subsequent very thin or non-deposition/erosion of the Messinian salt, followed by shale deposition in Plio-Quaternary.

According to the few seismic sections available, it is, however, clear that below the Upper Cretaceous series still exist bedded seismic markers, witnesses of a possible thick Triassic to Lower Cretaceous sequence which could host similar petroleum systems such as the one identified in offshore and onshore Syria, Israel or north-eastern Egypt.

Geological Background of Natal Basin

Our Natal seep study is targeting the Natal Basin, also featuring the Durban and Zululand basins (Figure 3). Zululand Basin was developed in Jurassic times (Reeves et al., 2016) as a response of the Gondwana super-continent break-up followed by the separation between South Africa and Antarctica. Later on, during Cretaceous times, South Atlantic Ocean rifting started separating the Falklands Plateau from the Africa Craton. Zululand Basin is located between two majors transfer faults: the Agulhas-Falkland Fracture Zone, witnessing the separation with South America and the Mozambique Fracture Zone, witnessing the separation with Antarctica.

These periods exhibited intense tectonism, mainly marked by normal and strike-slip faulting which may have led to the development of syn-rift mini-grabens and tilted blocks, probably in Jurassic-Lower Cretaceous, lacustrine, restricted, source-rock prone environments. These sediments were then draped over by marine-prone Upper Cretaceous series which exhibited well-known Aptian and Cenomano-Turonian source rocks. It is probably during this sag phase that Tugela proto-river started to build an offshore depocenter which will get its acme in Tertiary times. This has resulted in a thick sedimentary prism (Tugela Cone) which could permit the maturation of the Cretaceous syn-rift or sag periods.

Shallow and deep offshore parts of the basin are underexplored and not drilled yet, except the very shallow DSDP 249 penetration located on the Mozambique Ridge, which exhibited (Simpson et al., 1974) very thin Lower and Upper Cretaceous (Cenomanian) layers. Pronounced unconformities (Middle Miocene resting onto Maastrichtian) indicate a probable regional uplift (Oligocene?) and subsequently erosion that was able to feed the basin with thick turbidites.

Seep Methodology

The seep methodology used to highlight seep anomalies relies on five main equally important principles:

a) Large datasets based on the coupling of old and recent data, enabling a SAR data retrieval from before 2000 to 2018. The more SAR images you interpret at different dates, the more it is possible to flag shipping rails and master the context and conditions of a study zone;

b) Large datasets also enable a multitemporal approach highlighting recurrences of seepages in the same location;

c) A man-made manual discrimination between oil seeps (seeps considered as natural, rising from the seafloor and noticed on the sea-surface), pollution (spills, considered as ship discharges or related to human activities) and "lookalikes" (all kind of signatures potentially bearing seep characteristics but considered as atmospheric, bathymetric, oceanic artefacts or algal blooms);

d) A focus on the immediate context of seeps rather than on the seepage itself: no seepage can be ranked based on its signature solely, only the surroundings of a seep can enhance or decrease the confidence in it;

e) A close attention to what can be labelled as "weak signals": seep signatures can often be very soft, most of all when the context on the SAR image is very clean.

Oil Seeps Evidence in Levantine Basin

On the eastern side of Levantine Basin, where the presence of both onshore and offshore seepages is vastly acknowledged within the Latakia ridge, our seep study confirmed the presence of very numerous (35), recurrent (28 different SAR dates) and concentrated natural oil seepages structuring a "star-shape" anomaly (right side of Figure 2) with a clear emission point.

On the Western flank of Levantine Basin, within Eratosthenes area, one promising seep anomaly (left side of Figure 2) was spotted. Seeps are numerous (24) and recurrent (17 different dates). There is no clear emission point such as in the Eastern side anomaly, however seeps are concentrated and superimposed with various orientations while the close local context is spared from the otherwise relatively intense pollution observed within this part of Mediterranean Sea. Some of the seep properties are very soft but it confirms how instrumental the "weak signals" are and the key aspect of the context (swell, algae, atmospheric conditions) surrounding a seep.

Discussion and Conclusion

Within the Levantine Basin, the seep anomalies detected by SAR data interpretation are well in line with the following oil generation and migration hypothesis: the extremely huge quantities of recently generated gas may have displaced the oil from the center of the basin to its very margins. This may be the reason why we see all these oil shows on the eastern and southern edges of the Levantine Basin and now confirmed by the present study on the western edge of Levantine Basin. This is a breakthrough because it is clearly where prominent Eratosthenes Seamount stands (which remains one of the biggest structural closures yet to be drilled for hydrocarbons in Europe). Ultimately, Eratosthenes might represent a giant dormant prospect similar to the Palmyrides petroleum system with Lower Triassic Amanus source rock and Middle Triassic Kurrachine dolomite reservoir capped by Upper Triassic evaporites.

Within the Natal Basin, some of the seep anomalies are clearly linked to the thick Tugela Cone and match the 3-4 kilometers sediment thickness burial zone which could easily fit the oil kitchens for Cretaceous source rocks. Northwards, the main seep anomalies suggest active oil migration conduits along main faults inside the Zululand and Durban basins (Figure 3) featuring both repeating, past and recent seeps.

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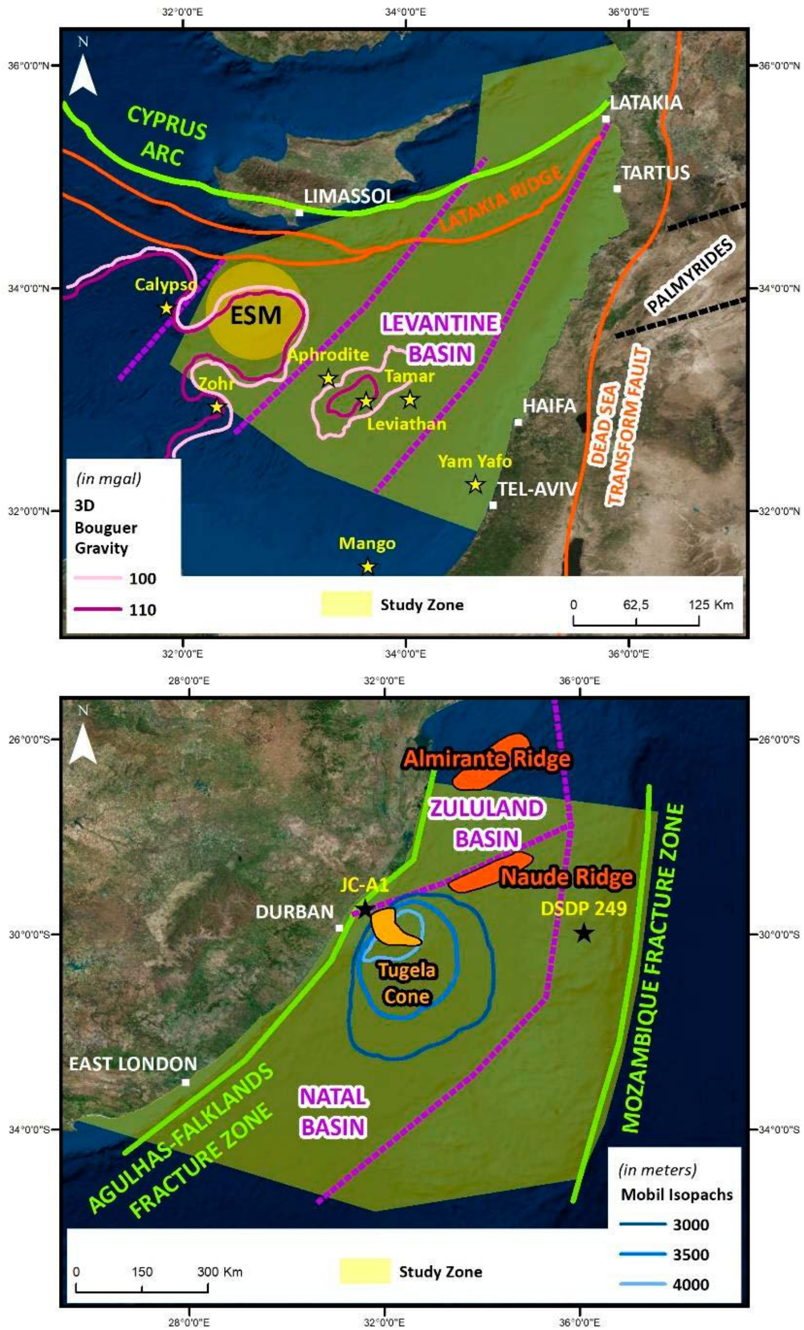

Figure 1. Levantine and Natal basins study areas.

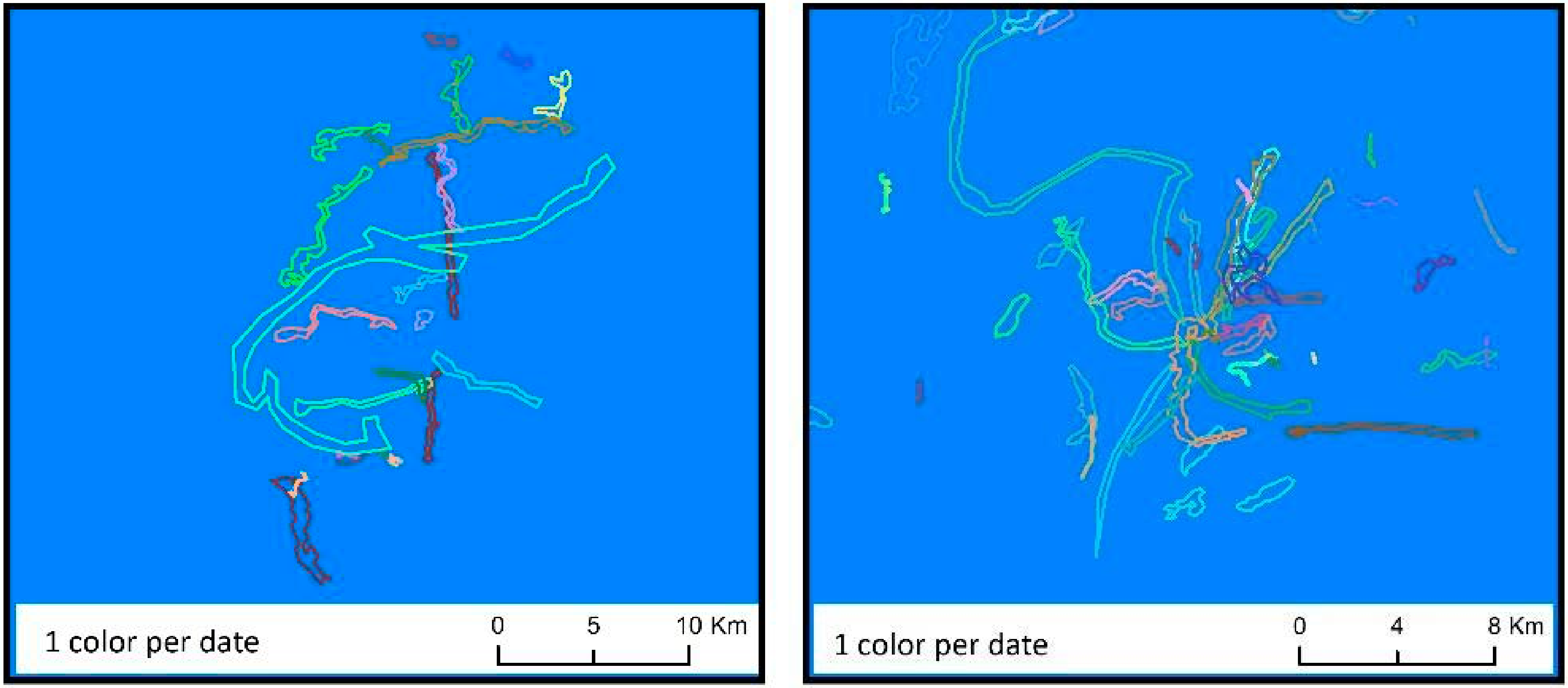

Figure 2. Seep anomalies in the western (left) and eastern (right) Levantine Basin.

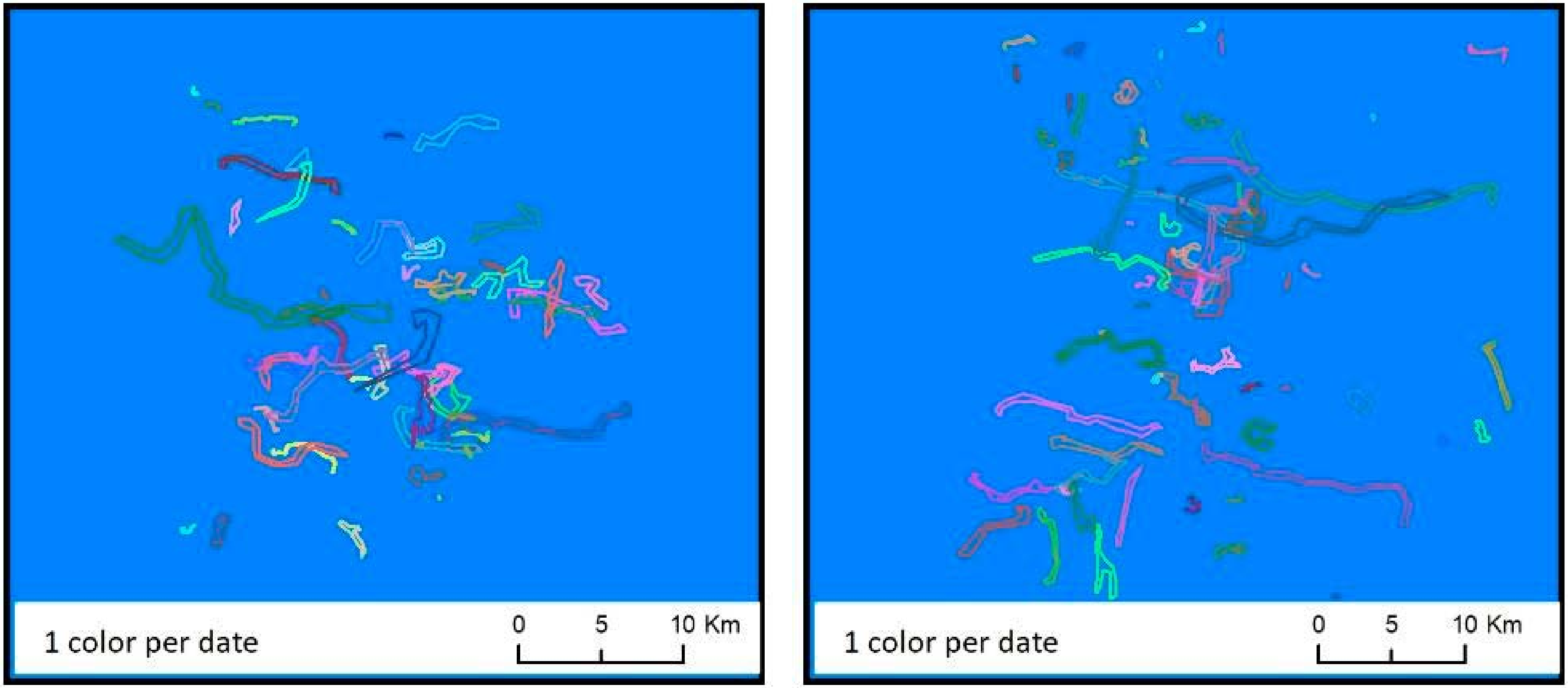

Figure 3. Seep anomalies on Durban (left) and Zululand (right) basins.