



Detection of Oil Seepages in Oceans by Remote Sensing

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Summary

The detection of oil seepage in oceans is of foremost importance from the exploration point of view since they are the primary manifestations of any sort of oil accumulation beneath the ocean bottom and offer clues as to where oil deposits may be located in ocean basin. In this paper, a general review of all the spectral regions in which remote sensing for the detection of oil in oceans are carried out along with their advantages and disadvantages had been discussed. Of the different passive sensors used for detection, the thermal infra red sensors can be designated as good sensors but for their poor discriminatory capacity between oil and oil like objects. It functions on the basis of variation of the thermal inertia of the oil with respect to the surrounding water which causes it to be visible to the thermal sensors. Among the active sensors, the laser fluoro-sensors working on the ultraviolet wavelength are useful due to its unique capability of identifying oil in all backgrounds like water, ice and snow. Most of the laser fluorosensors used for oil seepage detection uses a laser operating in the range between 0.3 to 0.355 μm . The oil absorbs the ultraviolet light radiated by the fluorosensors and emits radiation in the visible range of 0.4 to 0.65 μm with a sharp peak at 0.48 μm . This technique also helps to discriminate in between light refined crude and heavy crude by comparing the fluorescent response of the oil with traces of various known oils. Another active sensor that is fit especially for oil seepages is the radar which is not only powerful but also a cost-effective platform for offshore seepage detection. This apart, it has a great detecting capacity and can work in the night and in all weather conditions with wide swath coverage. Radar images map seepages which appear as flat patches of the surface due to the dampening effect of the oil on the capillary wavelets, compared to the background waves. The information from the above spectral regions used separately or together can serve as an effective tool for offshore oil exploration.

Introduction

The focus of oil exploration is moving inex-orably into ultradeep water, as exploitation of the accessi-ble parts of the world's continental shelves reaches a satura-tion point. But as the industry moves into increasingly deeper waters the costs of exploration also increases manifold. Satellite remote sensing, after some 25 years of patient development, has now reached maturity as a respectable technology and can offer the industry an effective, low-cost, high coverage service which is adaptable to any exploration environment. Many enlightened major companies now use satellite remote sensing as a routine part of their initial exploration phase, to unravel complex structure and geology ahead of expensive fieldwork or seismic programmes. Satellite Remote Sensing has the ability to image surface oil seeps that originate by slow leakage from oil- and gas-filled traps. Multitemporal satellite data over such seeps provide the locations for follow-up surface sampling from which key geochemical in-formation on the reservoired oil can be obtained ahead of the drill.

Seeps and oil fields

A good definition of a seep is "the surface expression of a migration pathway, along which petroleum

is currently flowing, driven by buoyancy from a sub-surface origin" (Fig 1) (NPA, 2004). 80% of offshore oil exploration starts by searching for seeps. The U.S. National Academy of Sciences (NAS) completed studies of the sources, fates, and effects of crude oil in the marine environment. One component of these studies is natural oil seeps. In 2002 the estimates of known crude-oil deposits in offshore North America, particularly in the Gulf of Mexico and offshore southern California, resulted in an estimate of global rate of crude-oil seepage of 160,000 metric tonnes/ annum for North American waters.

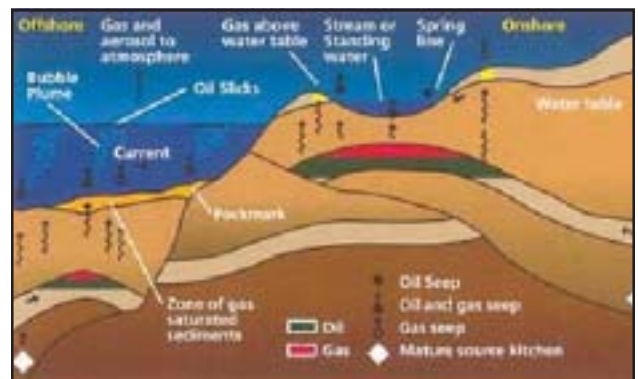


Fig 1: Mechanism of oil seepage from a reservoir below ocean surface

Work published by BP and others in the early 90's (NPA, 2004) demonstrated that over 75% of the world's petroliferous basins contain surface seeps.

Most seeps represent tiny but detectable volumes of oil and gas which are not significantly depleting the reservoir. Exceptions would be in some recent onshore fold and thrust belts where accumulations have either been breached or redistributed to tertiary traps and where the link between surface seeps and the leaking traps is more complex. Such geology, however, is rarely encountered in offshore basins so that problem does not arise. Confirmation of the presence of seeps, therefore especially in offshore basins, is positive and in the vast majority of cases is not indicative of breached or depleted traps.

The knowledge that surface seepage has a direct link to subsurface oil and gas accumulations is not new. Indeed, seepage was the stimulus for the exploration drilling by the pioneers of our industry as long ago as the 1860s in Pennsylvania and in Azerbaijan. The subsequent decades spanning the late nineteenth century and the first half of the twentieth century heralded the first discoveries. Surface seepage was associated with Sumatra (1885), Texas (1901), Oklahoma (1905), Persia (1908), Mexico (1910), Venezuela (1922), Iraq (1927), east Texas (1930), Bahrain (1932), and Kuwait (1938) (NPA, 2004).

Nevertheless, seeps are not ubiquitous and their geographic distribution, as mapped by satellite, has helped to define the present-day black oil play fairway and may also provide part of the explanation for the disappointing results of the dry wells.

Offshore oil seep

In the offshore, seeping oil and gas are often easier to detect due to the fact that oil is normally transported from the sea-bed vent to the surface as oil-coated gas bubbles. At the surface, the gas bubble bursts and the oil remains on the surface as a thin oil film (Fig 2a). In calm sea conditions, these can often be viewed as beautiful, iridescent concentric shapes, typically 0.5 to 1 metre in diameter, known as 'oil pancakes'. As seepage continues over time, these coalesce to form larger slicks that are detectable from aircraft (Fig 2b) and space]

Detection of oil in ocean in various spectrums

Detection in the ultraviolet region

Ultraviolet images can be used to map films of oil (as thin as 0.15 μm) firstly due to their high reflectivity and

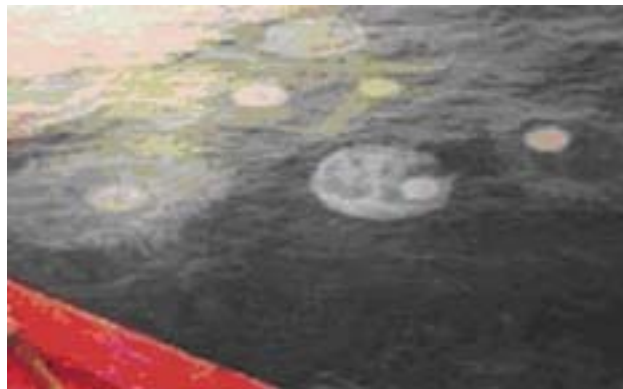


Fig 2a. Surfacing oil pancakes (gas bubbles burst and lost to atmosphere)

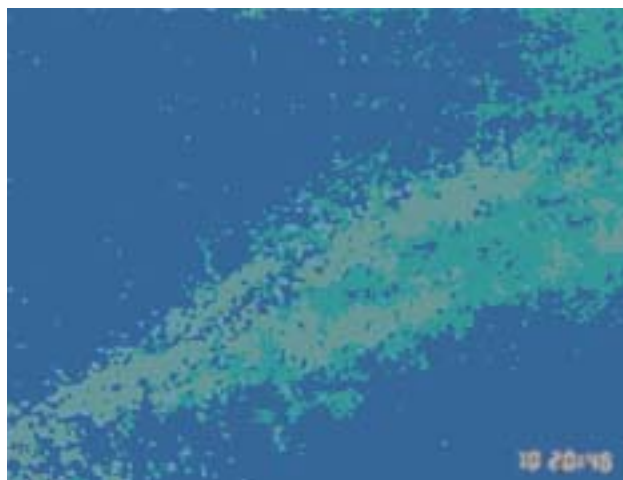


Fig 2b. Coalescing oil pancakes forming large oil seepage slick (aerial view)

secondly since in this region the difference in the spectral response of oil and water is the maximum here. Also, it is found that in the presence of solar radiation, many oils show the phenomenon of Fluorescence in the ultraviolet part of the spectra.

However, this type of detection systems has their own disadvantages. One is that, this is dependent entirely on the sun as its source of radiation and hence can work only during daytime and that also in a clear weather. Another disadvantage is that, there is a great deal of selective scattering by the atmosphere as the ultraviolet rays travel back from the target to the sensor and this in turn causes a very low contrast in the signal. However, the effect of scattering is found to be much less for images that are acquired at an altitude of 1000m or less and hence a low flying aircraft is used in this case rather than any space based platform.

To overcome the shortcomings of the passive ultraviolet system, active ultraviolet systems are being used



where laser fluorosensors illuminate the sea surface immediately below the platform with a narrow beam of ultraviolet energy and induce fluorescence in the oil. Most of the laser fluorosensors used for oil slick detection uses a laser operating in the range between 0.3 to 0.355 μm . The oil absorbs the ultraviolet light radiated by the fluorosensors and emits radiation in the visible range of 0.4 to 0.65 μm with a sharp peak at 0.48 μm . This technique also helps to discriminate in between light refined crude and heavy crude by comparing the fluorescent response of the oil with traces of various known oils. Also the power of the fluorescence return permits the measurement of the oil thickness in the range between 0.15 μm to 10 mm. This technique is used for the detection of oil spill worldwide where the sensors are mounted on a low flying aircraft but it has a drawback that it can be used only in clear weather. Another related instrument is the Fraunhofer Line Discriminator which is a passive fluorosensor using solar irradiance instead of laser. However its low signal to noise ratio doesn't make it much effective.

Detection in the visible region

The visible region does not provide too much of a contrast between water and oil and it needs thorough processing to yield better results. An idea of this can be had from the closeness of the DN values of oil and water in the bands 1 to 3 of LANDSAT TM sensor

TM Band	Spectral Range	DN of oil	DN of water
4	0.76 to 0. 90 μm	13	8
5	1.55 to 1.75 μm	7-50	5
6	2.08 to 2.35 μm	22	3

(Almond , 1999)

The effect of wind causes surface waves in ocean which causes the surface of oil to show a high reflectance than the surrounding water in moderate to high elevation, a phenomenon called Sunglint (Fig 3). This makes it possible to some extent to detect the oil seepages in ocean water.

Detection in the Thermal Infrared Region

The oil is found to show a number of thermal properties that distinguish it from water. These include thermal capacity, thermal conductivity and thermal inertia. Thermal Capacity (c) is the ability of a material to store heat. In case of oil spills the thermal capacity of sea water is found to be twice that of the overlying oil (Asanuma, 1986). The Thermal Conductivity (K) is the measure of the

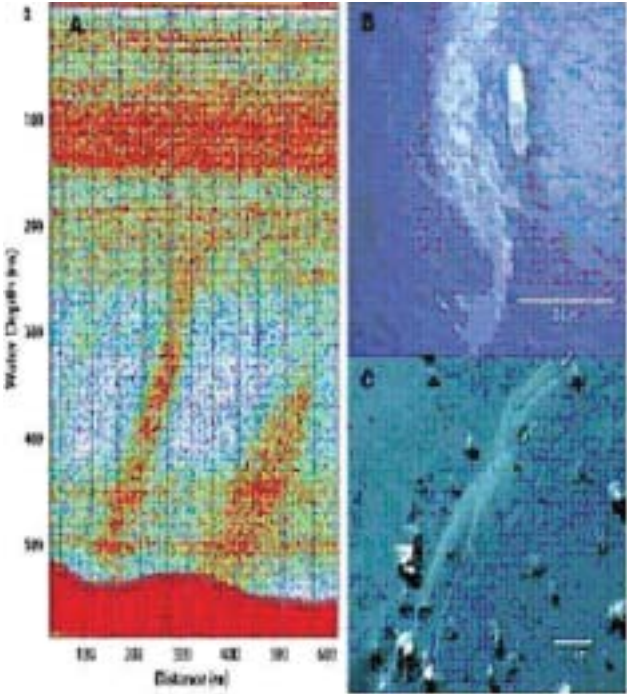


Fig 3: A. Natural oil slicks in the Gulf of Mexico. A west to east echo sounder shows oil and gas rising from two vents of sea floor. B. Oil drops reach the surface and sunglint is enhanced in the area of floating oil. C. Photograph from space shuttle shows sunglints from slicks

rate at which heat will pass through the material. Water usually has a low thermal conductivity. The thermal conductivity depends on the sea state and the surface wind but it is generally found that the thermal conductivity of oil is greater than water. Thermal Inertia (P) is the property of a material to resist temperature changes. When thermal inertia is high, materials show a resistance towards change in temperature resulting in low temperature stability. Materials with a low thermal inertia reach a high surface temperature at day time and at night time cool to a relatively low temperature, vice versa for materials with high thermal inertia (Sabins, 1978).

The sea water is found to have a higher thermal inertia than oil and this causes the oil film to show a larger variation of diurnal temperature than the surrounding water. This means that it will be visible to the thermal sensors during afternoon and due to its high surface temperature, it will act as a black body absorbing heat and becoming warmer than the surrounding sea water. Again during the night the oil body loses heat faster than the surrounding water and this causes it to be cooler than the surrounding water mass. However thin slicks are not thermally distinguishable since the temperature pattern of oil is similar

to that of water as the underlying water heats the oil here. The thermal properties of oil may also change due to the mixing of oil with water or due to the weathering of the oil film.

This method has been used for the detection of oil spills only but it has its own disadvantages. Often cool water currents of oceans present a similar image as oil spills. This problem can be minimized using information from the ultraviolet spectral ranges along with that of the thermal information. Clouds also act as a barrier to thermal sensing, as they are good absorbers of the thermal radiation.

Oil Spill detection in the microwave region

Since 1992, a powerful and cost-effective platform for offshore seepage detection has emerged. This is satellite-borne active microwave radar or SAR (Synthetic Aperture Radar). This is due to their ability to image surface oil seeps remotely with wide swath coverage (typically 100 x 100km scenes for ERS and 165 x 165kms for Radarsat Wide 1) and at low cost. Moreover, satellite data is free skies and is being continuously acquired, thus providing multi-temporal satellite data over any area of the globe. Such repeat seeps provide the location for follow-up surface sampling from which key geochemical information on the reservoir oil can be obtained ahead of the drill. SAR satellites scan the oceans continuously on fixed polar orbits. They have advantages over optical satellite systems, such as Landsat TM and airborne systems in that they observe night and day and penetrate cloud cover. SAR creates images of the sea surface detailing its morphology. Radar images map slicks (flat patches of the surface) that can be related by analysis to petroleum seepage.

Offshore seeps- detection by SAR technology

❖ Weather dependence

In offshore Basins, oil seeps from reservoir can reach the sea surface, usually in the form of oil coated gas bubbles, and then form slicks identifiable from satellite. This is due to the dampening effect of the oil on the capillary wavelets, which produces an area of relative calm compared to the background waves. The satellite data to be chosen should be screened for weather, mainly for wind speed, as this parameter has a direct implication on slicks (Srivastava, 2005). Wind shear controls the roughness and morphology of the sea surface and wind speed is critical to the remote detection of slicks. In order to observe ultra thin seepage

slicks on radar, local surface wind speeds need to be ideally between ~2m/s and ~5m/s, although thicker slicks can be observed at wind speed up to ~10m/s. The mm-cm wavelength capillary and gravity waves develop in this wind speed range, and area "available" for dampening by oil. If the sea surface is too smooth, at wind speeds below ~2 m/s, the sea surface is becalmed (i.e capillary waves have not developed) and seepage-slicks can be obscured or "camouflaged" by dense natural slicks. At wind speeds from ~5 m/s, the local wind shear rises to a point where the capillary and gravity waves are destroyed, and slicks are dispersed mechanically and are not observed by radar. If the higher wind speed persists, a swell develops in which body waves are aligned in the wind direction (Srivastava, 2005). Slicks can develop on these body waves only if the local wind shear is low; this is the case for long traveled (mature) swell generated outside the region of observation. At least two wind-complaint (dual images) radar scenes are required for radar interpretation.

❖ Slick interpretation

Slicks are interpreted on the SAR imagery as dark patches. The pollution slicks are thicker than the seepage slicks. The seepage slicks are ultra thin films. They do repeat in time, but often not observed and they often form in clusters because seepage vents are never singular. (Figure 4)

❖ Slick categorization

Satellite SAR systems are very effective at observing slicks, both man-made and natural, but very few slicks result from hydrocarbon seepage—very rarely more than 5% of the total number of slicks detected (NPA, 2004). Only these seepage slicks are of exploration interest. A consistent and systematic analysis scheme to discriminate seepage slicks from other slicks has been developed (Figure 5a and b). Three main categories of slicks are distinguished: seepage slicks, pollution slicks, and natural film slicks (Williams, 2002). Natural film slicks are formed from an ultrathin layer of long-chain organic molecules—derived largely from decayed plankton—and appear on low wind-speed images.

Some of the parameters used to categorize and discriminate seepage slicks (Williams, 2002):

Size: The minimum resolvable seepage slick is ~100–150 m long, dependent on sea state and sensor. Slicks smaller than this will not be resolved by SAR.

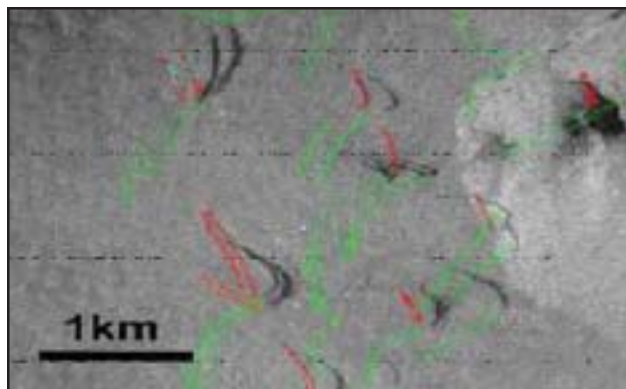


Fig 4: Seepage Slicks repeating in time in Gulf of Mexico. The coloured polygons outline slicks mapped on satellite radar acquired on dates different from the image shown. The region shown has been sampled four times over a three-year span. (NPA Group, 2004)

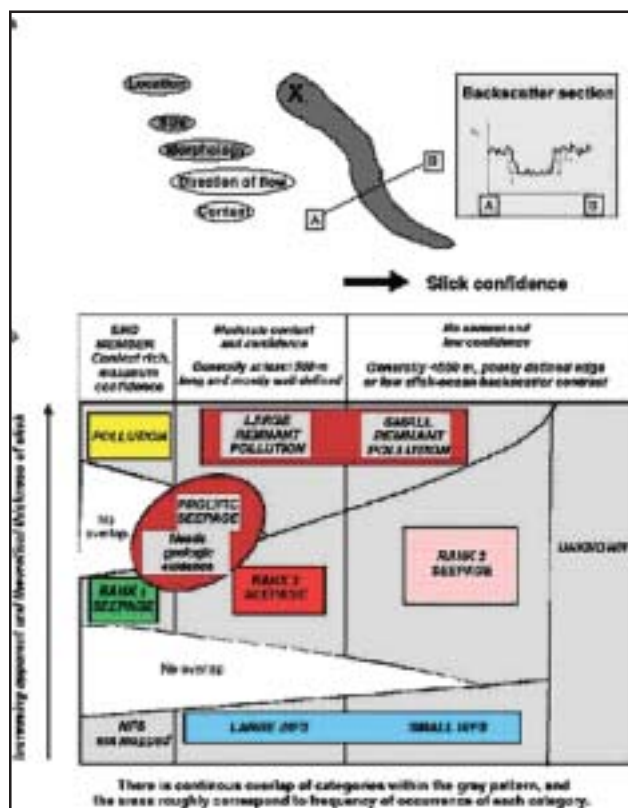


Fig 5 : Slick Categorization (a) Parameters and principles; (b) Slick categorization template, showing confidence and overlap of slick categories. Williams, 2002

Location: Slicks located in known or predicted sedimentary basins (as opposed to areas of oceanic crust or basement terrains) are potentially of interest.

Morphology: Seeps are generally elongated, with high aspect ratios (length to width), and with a recognizable emission point.

Direction of flows (streaming direction): Seepage slicks will conform to dominant wind and current directions (and/or tidal effects). Fresh pollution slicks, especially from ships, are typically straight and have a distinct feathered edge where older material is blown by wind.

Context: This is either geologic (i.e., location over plausible migration conduits) or geographic (i.e., location within shipping lanes or in areas of oil production).

Backscatter reduction: Oil slicks (seeps and pollution) generally have a greater contrast and edge enhancement (i.e., sharpness) than natural films have, but this property is dependent on wind speed.

Edge characteristics (i.e., sharpness) and relation to wave facets, current, and wind: These details are critical to the analysis because they depend on the slick thickness and material.

Repetition: A repeating emission point is shown on successive images. This is the most compelling parameter but is restricted to the leakiest basin types (episodic seepage is a feature of most seepage and in most offshore basins).

Ocean features: These features have to be analyzed and accounted for in the slick analysis.

The confidence with which a slick can be categorized on weather-compliant images is derived from considering all the above parameters. Seepage slicks are ranked 1, 2, or 3, based on these confidence limits (Figure 6 a, b, c).

❖ Seep sampling

The most valuable by-products of satellite seep detection is providing sea-surface locations for follow-up slick sampling from which crucial geochemical information of the reservoir oil can be obtained. Although some slicks may be partly biodegraded, a sufficient concentration of biomarkers will be present to enable the seep to be characterized (by GC-MS, carbon isotopes, etc.) and for oil-source correlations to be established. The satellite records the position of a slick to within $\pm \sim 300$ m. Seepage slicks are located at sea using GPS, and are sampled from small boats (Figure 2a), ideally in tandem with a light aircraft to help position the boat over the active seep.

Conclusion

If applied correctly, remote sensing serves as an important tool that provides the early detection of the oil

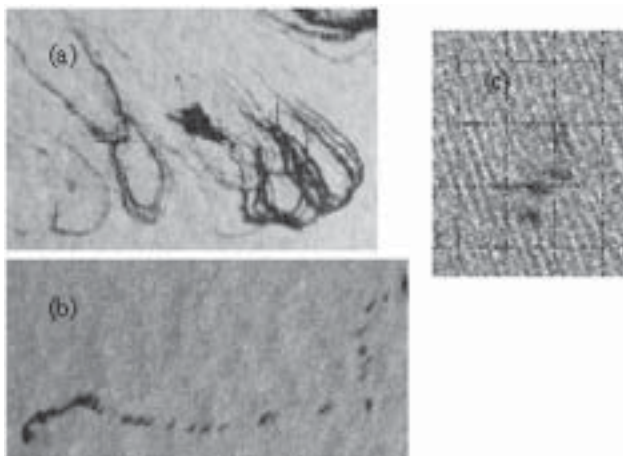


Fig 6. (a) Rank 1: nested multiple source slicks. Image is 30km across (b) Example of Rank 2 (remnant) pollution slick. (Fragmented pollution from ship, six days after discharge) (c) Rank 3: small cluster slicks are ~ 120m long (NPA Group, 2004)

seepages and oil spills, provides size estimates, and help predict the movement of the slicks and possibly the nature of the oil. Though the entire electromagnetic spectrum beginning from the ultraviolet can be utilized in remote sensing of oil, the best results are obtained in the ultraviolet, thermal and microwave regions of the spectrum. Of these, the active microwave sensors come near to the description of an ideal remote sensing system with large ground coverage, round the clock operations under all weather conditions, cost effective and are useful for detection of both oil seepages and oil spills. These technology can offer the oil industry an effective, low-cost technique for reducing risk in high cost exploration environment.

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