

OPERATIONAL SATELLITE MONITORING AND DETECTION FOR OIL SPILL IN OFFSHORE OF UNITED ARAB EMIRATES

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ABSTRACT:

Many satellite-borne image data have been acquired in the Arabian Gulf since the mid 80's by different space agencies and have demonstrated oil spill related features at sea. Severe oil spills were caused occasionally by accidental or deliberate oil sludge dumping from passing ships. Serious damage to fishery, water desalination plants and natural habitats are concerned. The work done is the first step towards oil spill monitoring of the offshore UAE and its adjacent waters.

The interim results of this study demonstrate and confirm that the offshore UAE faces frequent occurrences of oil spills both in the Arabian Gulf and in the Gulf of Oman. Offshore Fujairah shows considerable spill concentration in multi-temporal image analysis. Ballast water containing residual oil is discharged from oil tankers there and is identified as the source of those spills.

Discriminating oil spills is an important step for planning intense monitoring scheme based on space-borne imagery, which is attainable with the current acquisition conditions. As examined on a number of images which were observed by synthetic aperture radar and optical sensor including thermal infrared band between mid 70's and early 2002, continuous data acquisition and rapid analysis are the important factors for the implementation of Oil spill monitoring system. The forthcoming ESA's ENVISAT and near future Japanese ALOS and Canadian RADARSAT-II in conjunction with other internationally available earth observation satellites will play significant roles in continuous oil spill monitoring.

1. INTRODUCTION

Influx of oil from tankers and offshore oil operations are major causes of pollution in the marine environment. Ballast water and other oily water discharged into the Arabian Gulf ranged from 400,000 to 750,000 tones in 1986. According to statistics of the US Coast Guard (1990), sources of oil in the sea are classified into 6 categories. By far the highest contributor to oil pollution in the ocean, about 52%, result from a mix of materials and waste which make up urban runoff and discharge from land-based industrial plants. Another 19% of the oil in the sea is directly attributable to the world's oil industry. Two per cent of this occurs in spills from rigs and platforms during the exploration and production phases, and only 5 % of oil pollution in the oceans attributable to accidents involving oil tankers. On the other hand one big spill may seriously damage to life in the sea and coastal areas. The remaining 13 % of hydrocarbons in the oceans is absorbed from the atmosphere by particle settlement and rain-wash.

The marine environment in the Arabian Gulf region is also under considerable threat from intentional or accidental oil spills, ballast water discharged, dredging and infilling for coastal development, and uncontrolled sewage and industrial wastewater discharges. Oil discharged from ships imposes a much greater long-term threat to the marine environment than one big accident. Monitoring illegal oil discharges is thus an important component in ensuring compliance with marine protection legislation and general protection of the coastal environments.

The study area were selected as evaluation sites for demonstrating oil spill appearance in daily operations and for testing the resolution necessary for oil slick characterization. There have already been several remarkable accidents involving the loss of large quantities of crude oil from disabled tankers (Table 1).

Date	Volume of spilled oil (tones)	Oil type	Location
2001/01/14	1,300 – 1,500	Fuel	1 mile offshore of Jable Ali
2001/01/24	300 – 900	Heavy	7 mile NE offshore Abu Dhabi
1998/01/07	5,000 – 10,000	Crude	5 miles offshore Ajman
1994/03/30	16,000	light	9.6 miles offshore Fujairah

Table 1. major oil spill incidents offshore UAE

In the last 10 years, the satellites-borne SAR sensors have been broadly used for oil spill monitoring and have provided excellent data. Their advantages are the capability of wide coverage under any weather conditions all day long, the near real time data delivery and the improved cost-efficiency when compared with airborne SAR surveillance. Some very successful examples of ERS SAR applications in marine oil spill detection have been reported, such as the near-real-time monitoring in Norway (Pederson et al. 1995), monitoring oil spill pollution with ERS SAR in the Mediterranean (Pavlakis et

al. 1996) and the conviction in an oil-spill case in Singapore (Lu et al., 1999).

For strengthening ties of friendship between Japan and UAE, the Japan Oil Development Co., Ltd. (JODCO) with the collaboration of Japanese Information Centre for Petroleum Exploration and Production (ICEP) created and supported Satellite Image Processing project (SIPP). ICEP supports financially the SIPP as an environment monitoring component in their project "Environmental Protection System in Oil Producing Offshore Areas of Abu Dhabi." JODOCO supports SIPP in its logistic, techniques and scientific aspects. SIPP aims to contribute to development of the basic infrastructure, management and operation of satellite image processing system in the United Arab Emirates University using Japanese technology and assist the UAEU with the development of the practical use of remote sensing data for environmental protection.

2. UTILITY OF SAR IMAGES FOR OIL SPILL DETECTION

The problem of pollution of the oceanic waters by crude oil and oil materials is presently considered as one of the most sharp. As first step for solution of this problem is offered a development and using airborne and spaceborne remote sensing systems for surveillance of the sea surface, detection the pollution and spying for their spreading in space. The requirements to such system were formulated by *Witte (1986)*. Such system must provide the all-weather observation, be independent from illumination conditions and cloud cover, define the position, type and volume of oil spill and work in real scale of time. The sensors of the system must distinguish anthropogenic films from natural biogenic films produced in the sea. Synthetic aperture radar (SAR) is an active remote sensing tool in which an antenna on a satellite transmits microwave signals toward to the ocean surface. SAR signal after interaction with the sea surface returns to the antenna (*Sabins, 1997*). The interaction between the sea surface and microwaves is very sensitive to variations in sea surface roughness. Rough surfaces scatter large amount of energy back to the antenna and have bright signatures while smooth surfaces reflect the energy away from the antenna and have dark signatures. Since short surface waves (ripples and capillary waves) are usually present on the water surface, it effectively scatters microwaves via the Bragg scattering mechanism (*Valenzuela, 1978*) and gives radar signatures. It is well-known, that crude oil and other oil substances form films of various thickness on the sea surface. Oil films locally damp sea surface roughness and give dark signatures, so-called slicks, on the SAR images (*Huhnerfuss et al., 1981; Alpers and Huhnerfuss, 1988*). They look on the SAR images as dark patches among brighter surrounding surface. This fact gives a physical basis for application of spaceborne radars for oil spill detection and monitoring in the ocean (*Huhnerfuss et al., 1981*).

During the lifetime of oil spill in the sea it will be expose to a number of processes, which dramatically influence physical-chemical properties. Called by term weathering, these processes are as follows: spreading, drift, evaporation, dispersion, emulsification, bacterial degradation and photo oxidation (*Kotova et al., 1996*). With time the physical-chemical properties of oil spills are changed due to effect of these processes. These processes play important role in oil spill detection by using space borne SAR. But relative importance of

each process is not well understood. It is also reported that the thick part of oil film usually covers only 10% of spill area, while remaining oil covers up to 90% of an area as blue shine *Sabins (1997)*.

SAR is independent of weather and sun illumination conditions and allow to acquire SAR images day and night under cloud cover that is an advantage over other remote sensing sensors. The detectability of oil slicks/spills in SAR images strongly depends on the wind speed at the sea surface. Under low wind speeds, typically between 0 and 2-3 m/s, the sea surface looks dark on SAR images. In this case the wind-generated waves are not already developed and oil films looks dark on a dark background, - detection in this case is impossible. Wind speed between 3 and 6 m/s is ideal for oil slick detection, the sea surface roughness is developed and oil slicks appear as dark patches on a bright background. However, when wind speed reaches 10-12 m/s, detectability is impossible again or obstructed due to the redistribution of oil spills/slicks by the surface waves and wind-induced mixing in the upper ocean layer (*Scott, 1986*). As the result slick disappears from the sea surface and SAR imagery. The upper wind speed threshold for spill detection with SAR is suggested to be between 10 and 14 m/s (*Gade and Ufermann, 1998; Ivanov, 2000*).

Other detection problem is discrimination between man-made and natural organic oil slicks (*Huhnerfuss et al., 1986*). Natural biogenic films of a very small thickness resulting from life-cycle of plankton and other marine organisms can form surface slicks on the sea surface and, in turn, produce similar dark signatures on the SAR images (see *Gade et al., 1998*, and references herein). Experiments conducted with multi-frequency/multi-polarization SIR-C/X aboard the space shuttle (*Masuko et al., 1995; Gade et al., 1998*), as expected could provide more reliable information for oil slick discrimination, but an important progress has not been achieved. *Gade et al. (1998)* concluded that multi-SAR only capable of discriminating between different kinds of oil slicks under low winds, while discrimination at high winds is impossible.

3. STUDY AREAS AND OIL POLLUTION

3.1 General description

The study area lies between longitude 52°E and 56°45'E, latitudes 24°15'N and 26°N and covers two offshore areas of the UAE; one from Abu Dhabi to the northeast up to Ras al Khaimah Emirate in the Arabian Gulf and the other offshore Fujairah in the Gulf of Oman (**Figure 1**). The Arabian Gulf is about 990 km long: the maximum width is about 338 km. He surface area and volume of the Gulf are estimated as 239,000 km² and 8,630 km³, respectively. It is a shallow sea oriented in NW-SE direction with an opening connected to the Gulf of Oman through the Strait of Hormuz. The average water depth is about 36m. evaporation and wind are major driving forces of water circulation in the Arabian Gulf. Evaporation is stronger in winter due to high wind speed, than summer when the water surface temperature is higher.

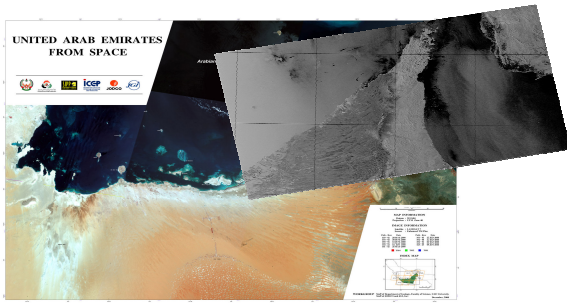


Figure 1. satellite image showing UAE with overlay of a mosaic SAR image used for the study area.

The Arabian Gulf region is the largest offshore oil development area in the world. Bahrain, Iran, Iraq, Kuwait, Qatar, Saudi Arabia, and the United Arab Emirates(UAE) produced over 27% of the world's oil in 2000. The area also holds 65% of the world's oil reserves. The study area have one of the busiest and most important tanker shipping lanes in the world; one ship passes the strait approximately every 6 minutes, another statistic indicates that more than 40 % of the world's total oil transportation passes through the region. The oil sludge, released by tankers cruising in the Arabian Gulf is estimated to be around 8 million metric tons per year, representing 60 % of the total pollution in the area. Oil of 15.5 million barrels per day is transported through the strait of Hormuz. Contamination influx is mainly from tankers releasing ballast, tank cleaning leakage from drilling rigs and production platforms, and ship accidents.

3.2 Data set

Ers-1/2 C-band SAR data has been used for the great majority of oil spill detection. However, other satellites images even optical sensor images have shown good capabilities for this purpose. Therefore, we searched all available image data archives and selected more than one hundred of images derived from different platforms that covered the most of the offshore water of the UAE. We conducted a search of ERS-1/2 data archive to compile a list of all images acquired over the study area. To evaluate their suitability for slick detection, historical wind conditions for corresponding SAR images were obtained. For each date of acquisition, surface wind speed histories were reconstructed using historical records. Because radar backscatter from the sea surfaces are strongly affected by surface wind patterns, the wind speed histories were used to rate the suitability of each image for oil slick detection.

A total of more than 300 frames of ERS-1/2, Landsat-7 ETM, JERS-1 SAR, Terra ASTER, RADARSAR, and Space Shuttle photographs were used. The images were acquired within the period between mid 1980's and early 2001. These images were used. The images were not uniformly distributed over the study area. The frequency of coverage ranges was maximum 5 scenes per frame. the following are the satellite imagery used in his project:

1. ERS-1 SAR (Japan), 64 scenes
2. Shuttle Imaging Radar C/X-SAR (US), 37 segments
3. ERS-1/2 AMI (EU), 15 scenes
4. Radarsat SAR (Canada), 3 scenes
5. Envisat ASAR (EU), 7 scenes

6. Hexagon KH-9 (US), 12 scenes
7. Landsat-7 ETM+ (US), 15 scenes
8. JERS-1 OPS (Japan), 92 scenes
9. Terra ASTER (Japan/US), 95 scenes
10. Shuttle Handheld Camera Photographs, 50photos

3.3 Image Analysis and oil Slick detection

Briefly summarizing the characteristics of each satellite-borne imaging sensor in oil slick detection, in the visible and near-infrared region, the absorption and reflection of solar illumination determines the characteristics of the oil by means of spectral reflectance of electromagnetic energy. Crude oils show different colours, that is spectral reflectance varies depending upon chemical composition of crude oil. Sea surface roughness changes the direction of solar illumination reflected from water, due to randomly scattered sun glint from wave facets oriented at the specular angle, as does the presence of sea surface condition(berry, 1995). As a results, reflectance contrast between clear water and oily water varies with sea state at any given wavelength in the visible and near-infrared region.

By looking at the thermal infrared region, the water surface temperature can be calculated. Brightness temperature is calculated with respect to function of both emissivity and kinetic temperature. A film of oil on water has the same kinetic temperature as the water since they are in direct contact. The difference of emissivity 0.02 between Seawater and crude oil makes an apparent difference of 1.2oC in brightness temperature in the wavelength region of Landsat TM band 6 at room temperature (Salisbury et al., 1993). Generally an oil slicked surface shows a lower temperature than the surrounding clear water surface (Figure 2.). The image data observed in night time is more reliable to avoid the influence of solar illumination difference between seawater and oil slicks.

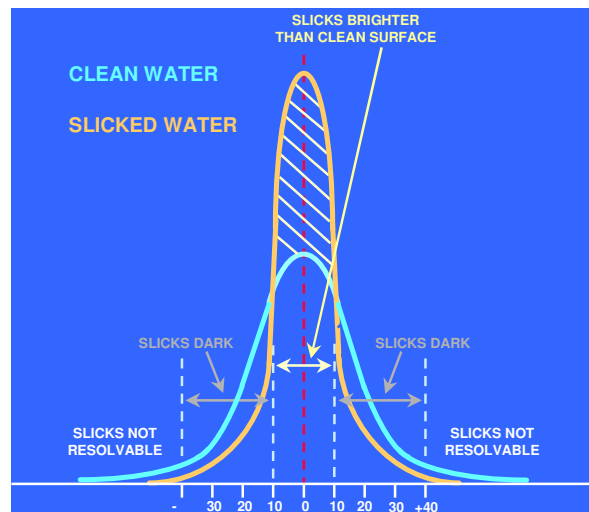


Figure 2. water surface temperature of clear water and of slicked water.

In the microwave region, the brightness of the sea surface is measure of backscatter of the sea surface roughness. As smooth sea surface appears dark and the brightness increases as the sea surface becomes rougher. Oil films damp wind-generated gravity capillary waves on the sea surface. Hence they appear dark against brighter surrounding areas in a SAR image.

A large archive of historical satellite radar imagery exists for the Arabian Gulf region stretching back to 1984. However, not necessarily all of these images are useful for showing oil slicks. The suitability of radar imagery for slick detection is largely a function of the local weather and sea-state conditions at the time of image acquisition. Detection hinges on a significant difference in sea-surface texture between the area covered by oil and the surrounding clean water. This occurs when a uniform wind of sufficient strength blows across the surface, raising small capillary wavelets in the absence of oil. However, if the wind blows too strongly it overwhelms the surface-tension effects of a film of oil, and the oil covered area becomes as rough as the surrounding seas. Precipitation can also break apart or obscure thin oil slicks.

The image data were geographically transformed to fit the base map image using corner point locations provided with the images. Images brightness and contrast were manipulated to optimise the discrimination of slicks. After the radiometric range correction and the georeferencing of each image, the procedure starts with the definition of a target area. For each ERS SAR image, we obtained handcart wind speed data every 6 hours interval spanning the 24-hour prior to the time of satellite's overpass. Wind speed at the time of image acquisition was between 3 and 5 metres per second. Ideal condition were considered to be a wind speed of 3-4 metres per second at acquisition time, with a maximum speed well below 10 metres per second and average speed well below 5 meters per second during the prior 24 hours. As a minimum, several hours of fair conditions are required for new slick to accumulate to a detectable size. If at most likely have been dispersal. If the wind speed exceeded 5 meters per second during the previous 24 hours, it will most likely have prevented the formation of a thin oil slick. The ERS-1/2 images used in this study were observed during suitable wind condition for slick analysis.

Analytical efforts were focused on overall assessments of image quality and suitability for slick detection, identification of possible oil slicks in the area, and comparison of slick patterns between the different dates of imagery and also different types of sensors. The interpretation results indicate that certain coastal areas of the UAE face frequent oil spills.

Satellite images show striking examples, one offshore Fujairah (centred at the coordinates 25°30' N/56°25' E). Considerable spill concentrations were found within successive JERS-1 OPS, Landsat-7 ETM+ images and ERS-1/2 SAR browse images. Other 'eventful' but less critically affected regions appear to be the congested waterway approaches, such as the Strait of Hormuz, and zones with major oil production and transport routes offshore Dubai, Sharjah, and Ajman. The images indicate that the areas in the offshore Fujairah, the coast line of the Gulf of Oman, face a higher incidence of oil spills than the other of areas. Here considerable spill concentrations were found within the continuously observed JERS-1 OPS, Landsat-7 ETM+ images and ERS-1/2 SAR browse images. The heavily polluted regions lie off the coast between Fujairah and Khor Fakkan associated with anchorage of tankers prior to entering the Arabian Gulf. The pollution in this area is probably due to deliberate discharges of ballast water containing oil from ships. Oil discharging from both anchored and moving vessels can be observed in each image. Immediately after discharging flush ballast water, the shimmering water surface can be seen as bright silver to gray colour patches on the surrounding water. Based on the size of the image pixel, most of vessels are super tankers

whose size of hull is more than 300 m in length. Although sequential sampling of the ERS-1/2 SAR browse images can be considered, some first conclusions can already be drawn about this potential threat to the Gulf of Oman environment, such as the generally higher abundance of spills along the coast of Fujairah.

Shipping routes with relatively frequent incidences of oil spills are the offshore area running parallel to the coast of Abu Dhabi, Dubai, Sharjah and Ajman where intensive oil production activities exist, and the routes through the Strait of Hormuz. This study is probably the first time that spatial distribution of oil pollution is mapped over a quite wide sea area in the region using high spatial resolution satellite images. Attention was focused on the area of the offshore from Abu Dhabi to Ajman with analysis using seven ERS-1/2 SAR images including 2 tandem mode 24-hour interval image observed on 24 April, 29, May and 30 May 1996 (Figure 3). Numerous small oil slicks caused by oil spilled from ships leaked from oil platforms, and natural seeps from the seafloor are visible throughout the images.

A partial problem is the effect of extensive dark, low wind areas across the north-eastern parts of the 29 and 30 May images. This weather pattern is not uncommon in the Arabian Gulf region. Scattered oil spill are marked by dark patches with a variety of sizes and shapes on the sea surface. Despite these localized problems, both images were acquired under generally acceptable conditions for slick detection. It is seen clearly that there are two polluted regions, one in the west side of the image and one in the southwest corner of the image. If we put this map over the layer representing the oil fields and the shipping routes, a close relationship between spills and both oil fields and the shipping routes can be found visually.

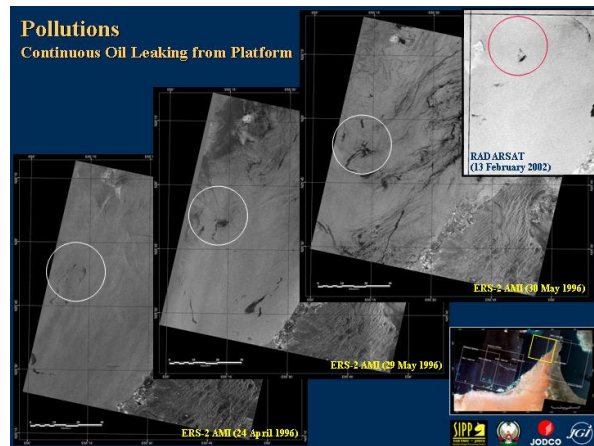


Figure 3. ERS-1/2 SAR images including 2 tandem mode 24-hour interval image observed on 24 April, 29, May and 30 May 1996.

Near the oil field north-western quadrant of the image in many distinct elongated and dog-leg slicks appear with very similar morphology to natural seepage slicks. Hence very bright spots can be seen at one end of the slicks as origin points. Observed slicks and bright spots in the 3 images acquired on different dates are confirmed as leakage oil slicks from same oil production platforms. In addition, known well location correspond to the leaking points as well. The clear discrimination of these slicks on these images provides strong evidence that

imaging conditions were well within bounds for reliable oil slick detection.

One additional feature of interest appears on the 29 May image. The platform is obviously trailing a small, wind-driven slick that extends 10 kilometres to the southwest and the bend nearly perpendicular to ESE. This bend seems to be due to a change of surface current. Oil platforms and vessels appear as bright spots, generally indistinguishable unless the well locations are superimposed on the images. A few vessels can be distinguished by the presence of short, faint lines that indicates a trailing ship wake. The size of the longest slick detected was 25 km. The characteristics suggest that the slicks are ephemeral surface events from a moving source, probably oil spills from a passing vessel moving down from north to south.

3.4. Field Observation in Offshore Fujairah (Feb 2003)

A Sea surface observations with a synchronized data acquisition of SPOT-5, in Fujairah Offshore Anchoring Area (FOAA) (Figure 4). Space borne observations were carried out on 1st & 2nd February 2003 with the cooperation of UAE Coast Guard. Observation points were located by both a GPS system on board and portable GPS receivers. Spilled oil and seafloor sediments were sampled for chemical analysis. Water temperature was measured by both thermal infrared thermometer and contact thermometer.

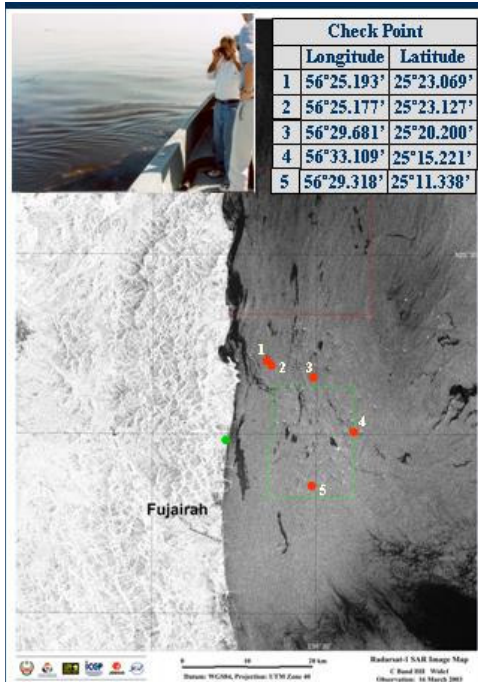


Figure 4. Field Observation in Offshore Fujairah (Feb 2003)

5. CONCLUSION

We focused on discriminating between direct hydrocarbon pollution such as big spills by tanker accidents, discharged oil caused by routine maintenance, and leaking oil from offshore exploration and development operations by means of satellite imagery. Satellite-borne sensors have different electromagnetic characteristics with varying limitations for detecting marine surface features, therefore a combination of sensors is required to monitor marine oil pollution effectively. This case study

indicates that most oil spills are found along the major shipping routes and in anchorage area as well as in such areas with intensive large-scale oil production activities with leakage or tank-washing discharges. The results will help in locating potentially vulnerable areas, and serve as a reference in future routine monitoring. Oil spills can occur both in the open sea and along the coasts.

Operational monitoring system for oil pollution using satellite images of the Arabian Gulf is recognised as a regional priority, this could be achieved only with the cooperation of all concerned organizations at national and regional level. This will be based on an integrated GIS focusing on delivering real-time information on coastal marine environments (Figure 5).

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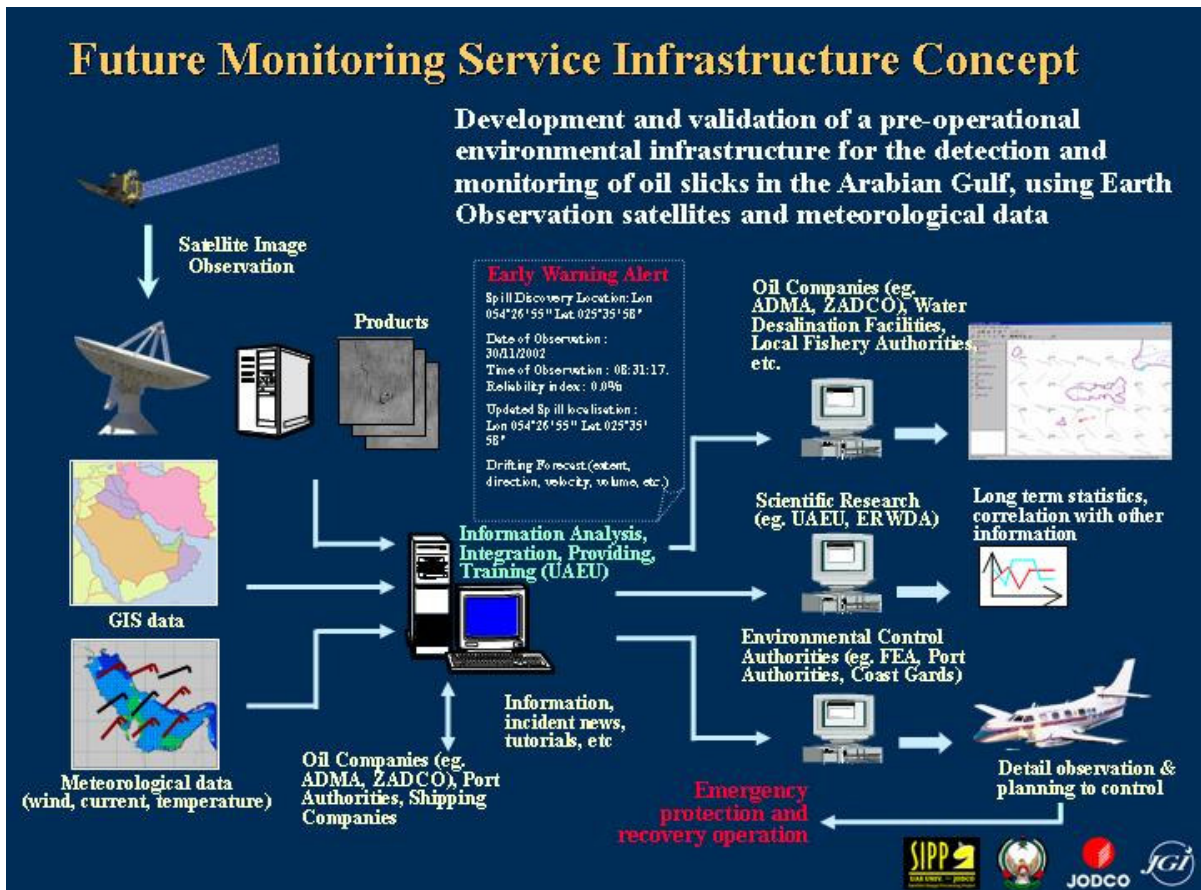


Figure 5. Operational monitoring system for oil pollution using satellite images of the Arabian Gulf

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