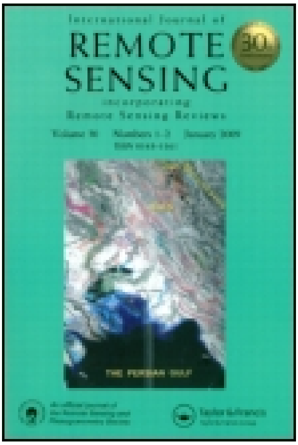

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Cover: Detection of oil spills near offshore installations using synthetic aperture radar (SAR)

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Cover

Detection of oil spills near offshore installations using synthetic aperture radar (SAR)

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Oil spills in marine environments are of great public, political and scientific concern, since such pollution may have a lethal effect on fragile marine and coastal ecosystems. Large oil tanker or platform accidents are sporadic and account only for a small amount of the marine oil pollution. On the other hand, operational oil releases from ships in transit (i.e. when cleaning tanks), are estimated to account for over 20% of the pollution (Lean and Hinrichsen, 1992). Moreover, produced water containing small amounts of oil, is released on a regular basis from offshore oil installations (Furnes, 1994). As long as there is a global reliance on petroleum products, oil spills will continue to occur. To limit and/or prevent such pollution, several limitations on operational spilling (e.g. when cleaning tanks) have been agreeed upon. In addition to international regulations there is a need to monitor and verify that regulations are followed. Here, ship observations and aircraft surveillance, using Side Looking Airborne Radar (SLAR), Infrared (IR) and Ultraviolet (UV) scanners, have proven useful, but they are of limited coverage and high operational cost. Therefore, pollution control authorities in various countries have looked to satellite Synthetic Aperture Radar (SAR) for their oil spill detection systems.

Since the launch of SEASAT in 1978, remote sensing using SAR has become a field of rapid growth. Today, three spaceborne SAR systems are operating, one is approved, while three more are proposed. The large amount of data generated by spaceborne SAR systems provides an unique opportunity for global scale oil spill detection, compared to scattered ship observations or aircraft surveillance in limited areas. Unlike other remote sensing sensors, it has been documented that the SAR is capable of detecting oil spills at high spatial resolution, independent of daylight and cloud conditions.

The cover image (figure 1) from 30 October 1994 illustrates how the satellite SAR identifies spills, possibly containing oil, in connection with British and Norwegian offshore installations. The winds are ideal for slick detection, 5 m s^{-1} from south-east. Seven platforms have been identified (bright spots), and dark areas (slicks) are connected to six of them (see the Murchison platform located at N61°23′ E01°44′). In addition, a large dark slick co-located with a sea bottom ridge, and several supply vessels (one connected to a slick) can be seen. The SAR senses capillary and short gravity waves (7.3 cm sea surface waves using ERS C-band SAR). Under

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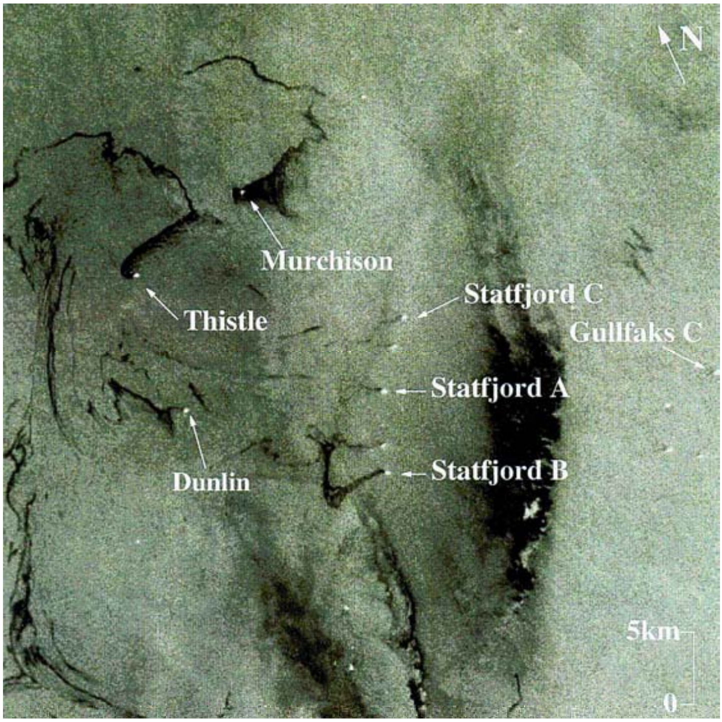

Figure 1 (and cover). ERS-1 SAR image from 30 October 1994. The image identifies several spills, possibly containing oil, in connection with British and Norwegian offshore installations. Original data ©ESA/TSS. Image analysis NERSC.

moderate weather conditions, an oil spill will dampen these waves. No signal is returned to the radar, and the spill will appear as a dark slick in a SAR or SLAR (Side-Looking Airborne Radar) image. This effect has been used for decades in aircraft-based oil spill monitoring systems, especially in the North Sea. The radar satellite ERS-1 was launched in July 1991. Following three years of experiments, demonstrations and testing, a routine satellite-based oil spill monitoring service was established in Norwegian waters in June 1994 (Wahl *et al.* 1994, 1996). This service makes use of fast processing and visual interpretation of ERS-1/2 (and soon also RADARSAT) SAR images at Tromsø Satellite Station (TSS), where a crew of operators on duty 24 hours a day have been trained in the basic elements of SAR image analysis and feature extraction. The service started out covering the Norwegian sector of the North Sea, and has later expanded into other areas of the North Sea, the Norwegian Sea and the Baltic Sea (Pedersen *et al.* 1996). The North Sea is populated with rigs and platforms engaged in the exploration and production of oil and natural gas. These are possible sources for oil pollution, but harmless slicks caused, for example, by run-off water, cleaning operations or wind sheltering may also be expected under certain conditions. Also, several natural phenomena may appear as dark slicks in SAR images. Figure 2 shows an example of an oil spill and three look-alikes (natural film, a current shear zone and rain cells). Therefore, in parallel with the routine operations at TSS, further research work has been conducted by the Nansen Environmental and Remote Sensing Center (NERSC) in Norway on decision criteria for distinguishing true oil spills from harmless natural or man-made

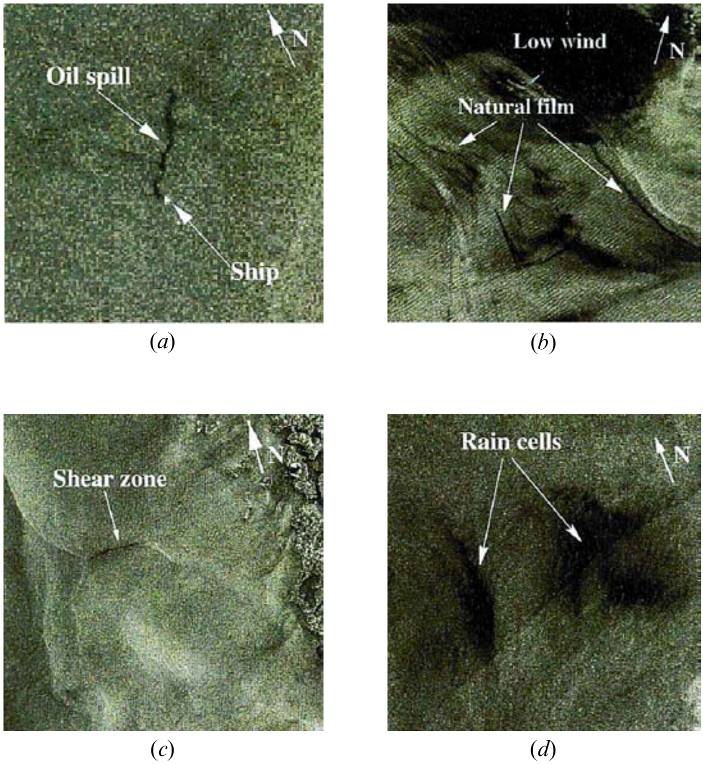

Figure 2. (a) An ERS-1 SAR image of an ship spilling oil 60 km off the coast of Sogn in western Norway. Image size is 12.5 × 12.5 km. (b) ERS-1 SAR image of natural film aligned parallel with a bright current shear or convergence zone. Image size is 25 × 25 km. (c) Shear zone in ERS-2 SAR image. Image size is 50 km × 50 km. (d) A cluster of rain cells in ERS-1 SAR image . The cell centres have a very low backscatter value and are surrounded by squall lines with a higher backscatter. Image size is 25 km × 25 km. Original data ©ESA/TSS. Image analysis NERSC.

slicks (Espedal *et al.* 1995, 1996, 1998, Espedal and Wahl 1999, Espedal 1998a, 1998b). A supervised slick discrimination algorithm has been developed, and it contains the following main steps:

- **Initial processing of the SAR image:** includes range normalization, linear scaling from 16 to 8 bits pixels, resampling to square 100 m pixels and absolute calibration.
- **A direct analysis.** For each slick the following parameters are extracted: slick source (if seen), shape, size and dimensions, texture (mean, standard deviation, maximum and minimum, skewness and kurtosis), damping and gradients.
- **A contextual analysis.** The slicks are studied together with information on instantaneous wind and wind history (to determine slick age). Then information on possible slick sources are extracted from a 'hot-spot' data base. Pollution sources may be displayed on a map, or overlayed directly on the SAR image. Rain, temperature/season and sea bottom topography are also studied to rule out rain cells, grease ice and sea bottom topography as the cause of the slick.
- **Model studies.** If a slick in a SAR image has been through the direct and contextual analysis and has not been identified, modeling the behaviour of

spills and their typical SAR characteristics may help in the discrimination process. This modeling must be based on the relevant environmental conditions for the slick being studied. A numerical oil drift model (Furnes, 1994) and the ERIM SAR Ocean Model (Tanis *et al.* 1989) have therefore been tested for implementation in the algorithm.

- **Drawing conclusions based on the combined results:** Even though all the phenomena that create dark slicks in the SAR imagery are potential oil spill look-alikes, it does not automatically follow that they are difficult to distinguish from oil slicks. Most of the look-alikes have very characteristic shapes and configurations, or depend on weather conditions (Espedal 1998a and b). The algorithm has been tested on 124 slicks in SAR imagery.

Details of the supervised slick discrimination algorithm are described in (Espedal 1998b). The algorithm supplies a standard procedure to be followed, and ensures the same criteria are applied, each time a slick is analyzed. Using wind history and an oil drift model from the contextual analysis, the slick from the Murchison platform (cover image and figure 1) was estimated to be at least 3–4 days old. A spill having survived that long on the ocean surface is very likely to contain oil.

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