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An oceanographic survey for oil spill monitoring and model forecasting validation using remote sensing and in situ data in the Mediterranean Sea

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ABSTRACT

A research cruise was organized on board the Italian National Research Council (CNR) R/V Urania to test the oil spill monitoring system developed during the PRogetto pilota Inquinamento Marino da Idrocarburi project (PRIMI, pilot project for marine oil pollution). For the first time, this system integrated in a modular way satellite oil spill detection (Observation Module) and oil spill displacement forecasting (Forecast Module) after detection. The Observation Module was based on both Synthetic Aperture RADAR (SAR) and optical satellite detection, namely SAR and Optical Modules, while the Forecast Module on Lagrangian numerical circulation models. The cruise (Aug. 6–Sep. 7, 2009) took place in the Mediterranean Sea, around Sicily, an area affected by heavy oil tanker traffic with frequent occurrence of oil spills resulting from illegal tank washing. The cruise plan was organized in order to have the ship within the SAR image frames selected for the cruise, at acquisition time. In this way, the ship could rapidly reach oil slicks detected in the images by the SAR Module, and/or eventually by the Optical Module, in order to carry out visual and instrumental inspection of the slicks. During the cruise, several oil spills were detected by the two Observation Modules and verified in situ, with the essential aid of the Forecasting Module which provided the slick position by the time the ship reached the area after the alert given by the SAR and/or optical imagery. Results confirm the good capability of oil spill SAR detection and indicate that also optical sensors are able to detect oil spills, ranging from thin films to slicks containing heavily polluted water. Also, results confirm the useful potential of oil spill forecasting models, but, on the other hand, that further work combining satellite, model and in situ data is necessary to refine the PRIMI system.

1. Introduction

Marine oil spill pollution poses a serious threat to the ecology of the world's oceans. Thousands of tons of oil are spilled into the oceans every year due to both anthropogenic causes, such as tanker accidents, rupture of rigs/pipelines or malfunctioning of oil extraction platforms, and natural events, such as natural seepage from seabed oil structures (Hu et al., 2009). However, the main contribution to oil pollution comes from illegal discharges of hydrocarbons intentionally released by ships cleaning their bilges underway to cut harbor costs. According to several marine oil pollution reports issued by the European Space Agency (ESA), the Regional Marine Pollution Emergency Response Center for the Mediterranean Sea (REMPEC) and other authors (ESA, 1998; Fingas, 2001; REMPEC, 2002; Huijer, 2005), it is estimated that about 45% of global oil pollution comes from such malpractice.

The Mediterranean basin, due to its strategic position, represents a major route for oil transportation. REMPEC (2015) has

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estimated that about 25% of the world's sea-borne oil traffic transits in the Mediterranean and up to some 600.000 t of oil are spilled in the Mediterranean Sea every year due to operational pollution, i.e. illegal tank-washing (REMPEC, 2002). As a further confirmation of this, observed oil spills correlate very well with the major Mediterranean shipping routes (LMIU, 2001; Ferraro et al., 2008). Therefore, the maritime transport of oil resources is an activity seriously endangering the Mediterranean marine environment and ecosystem, the latter being extremely vulnerable due to the long (80 years) water renewal cycle through the Strait of Gibraltar (e.g. Ross et al., 2000 and references therein).

In the last decades, a huge effort in oil spill monitoring at sea has been dedicated to satellite remote sensing and its exploitation in oil spill detection (Fingas et al., 1998; Brekke and Solberg, 2005; Fingas and Brown, 2014). Indeed, space-based observation can provide a regular, continuous, timely and synoptic oil spill monitoring. Satellite sensors can thus complement and support aerial and naval surveillance, which is generally adopted to counter maritime traffic and ocean pollution, by providing coverage of areas not easily surveyed with aircraft and ships, synoptic views of large areas and a more cost-effective approach to oil pollution monitoring.

The capability of satellite sensors in oil spill detection has been largely demonstrated (Wahl et al., 1994; Brown et al., 1998; Brown and Fingas, 2001; Brekke and Solberg, 2005; Fingas and Brown, 2014). Oil spill remote sensing techniques are based on visible, infrared, microwave and RADAR sensors. Among all satellite sensors, Synthetic Aperture RADAR (SAR) plays the main role as a means of observation, given the system's effectiveness in oil spill detection, the ability to observe the sea surface in all-weather and all-day conditions and its high spatial resolution (from $\sim$100 m to 1 m depending on sensor swath). For these reasons, SAR sensors are of primary use in oil spill detection and are part of the early warning monitoring systems currently used by several nations or international agencies, such as the SAR satellite-based monitoring system for marine oil spill detection and surveillance for the European Seas (CleanSeaNet, 2015). Optical oil spill detection, i.e. achieved by means of visible and near-infrared satellite sensors, is more recent with respect to SAR and has been investigated in recent years (Hu et al., 2003, 2009; Bulgarelli and Djavidnia, 2012; Zhao et al., 2014; Pisano et al., 2015). Indeed, the new generation of optical sensors, such as Moderate Resolution Imaging Spectroradiometer (MODIS) on board NASA's TERRA and AQUA platforms and Medium Resolution Imaging Spectrometer (MERIS) on board ESA's ENVISAT platform, have a sufficient spatial resolution (250–300 m) for oil spill detection.

The mechanism behind SAR and optical oil spill detection is very different. Indeed, SAR detection relies on the dampening effect of an oil film on the capillary waves generated by wind, which decreases the backscattering of the sea surface thus resulting in a dark area that contrasts the brightness of the surrounding spill-free sea. On the other hand, the visibility of an oil spill in an optical image is due to the optical contrast between the spill and surrounding water (Byfield and Boxall, 1999). Thus, the retrieval of spectral properties of oil films floating on the sea surface is essential for their detection with optical sensors.

Even though SAR results to be the best means for oil spill detection, it is affected by several limitations. Indeed, SAR oil spill detection is not applicable in weak wind conditions (<2 m/s), since the calm sea also appears as a dark patch. Also SAR detection is hindered by limited spatial coverage, due to SAR reduced swath width (i.e. 100–500 km), no routine acquisitions in that all images have to be requested to provide scenes of the desired site, and high costs. These limitations can be overcome by optical sensors, which provide wide swath (>1000 km), daily global coverage and are mostly free of charge. However, the presence of natural phenomena, such as local wind effects, natural films, phytoplankton, rain cells and fresh water slicks, can give false oil spill positives (look-alikes), a serious problem which affects both SAR and optical oil spill detection. Moreover, optical sensors are useless in cloudy conditions and at night. We feel that, even though optical oil spill detection is still prototypal, once consolidated, the combined use of SAR and optical satellite observations can enhance an oil spill detection system's effectiveness, in that the two types of sensor may compensate for each other's shortcomings.

Furthermore, in recent years a great effort has been put into oil spill displacement and transformation numerical forecast (Liu et al., 2011a, 2011b; De Dominicis et al., 2013a, 2013b), in the framework of operational oceanography, the relatively new branch of ocean science dedicated to the forecast of the marine environment. Oil spill forecasting provides the completion of an operational oil spill monitoring system, by giving information in near real time about slick position after detection. Consequently this allows one to assess the potential environmental risks represented e.g. by the presence of a slick in proximity of a coast, thus greatly aiding decision-making in remedy strategies. Several oil spill forecasting systems have been developed, e.g. in the framework of the Mediterranean Decision Support System for Marine Safety (MEDESS4MS, 2015) project (Zodiatis et al., 2016) to integrate well-established operational oil spill models in the Mediterranean Sea with the ocean data provided by the regional/sub-regional marine services and with the existing oil spill monitoring systems targeting the region, such as the European Maritime Safety Agency (EMSA) CleanSeaNet and REMPEC (regional center of IMO and UNEP/MAP for responding to oil pollution in the Mediterranean Sea).

One of the pioneering scientific and technical efforts in oil spill monitoring is the PRogetto pilota Inquinamento Marino da Idrocarburi (PRIMI/pilot project for marine oil pollution) project (2006–2009) funded by the Italian Space Agency (ASI, 2009; Nirchio et al., 2010). The main objective of PRIMI was to implement an observation and forecast system to monitor marine pollution from oil spills in the Italian seas. The system consists of four

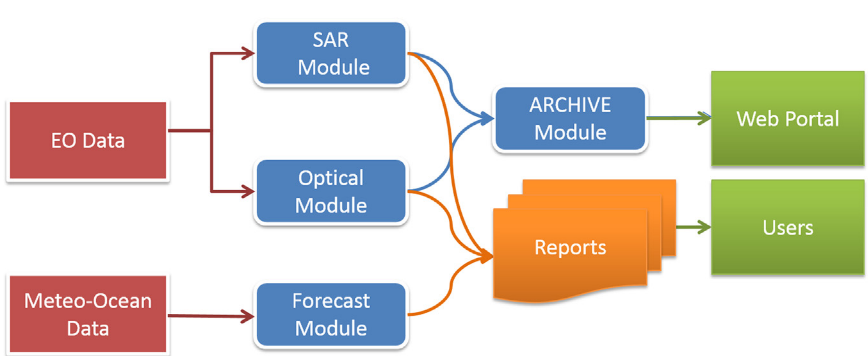

Fig. 1. The modular scheme of the PRIMI system.