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Original Article

News of Marine Surveillance in Cuba with SAR technology from the e-GEOS_INSMET collaboration

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Novedades de la Vigilancia Marina en Cuba con tecnología SAR a partir de la colaboración e-GEOS_INSMET

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ABSTRACT: This article shows the contribution of the Italy-Cuba collaboration and technology transfer project: "Strengthening the Cuban marine meteorological system" (Marine Surveillance) in the application of SAR technology in the surveillance of the seas around Cuba from the acquisition of SAR images from the CosmoSky-MED satellite constellation for 9 months; and training for digital processing through the IT tools of the SEonSE platform. With these new tools, 2,550 SAR images were processed with the SEonSE Engine computer tool, with statistics of the vessels and oil slicks found in the same period using the SEonSE Portal software. During this period, a significant number of oil slicks were found in the seas surrounding Cuba, which evidenced the existence of inappropriate conduct of dumping of hydrocarbons into the sea, and the importance of monitoring these bad practices in the future to combat them. These new features constitute a new approach in marine surveillance and an impact on the early warning system for marine oil pollution, since the system is capable of detecting slicks and sending notification to end users.

Keywords: marine surveillance, SAR images, COSMOSky-MED, SEonSE.

RESUMEN: Este artículo muestra la contribución del proyecto de colaboración y transferencia tecnológica Italia-Cuba: "Fortalecimiento del sistema meteorológico marino cubano" (Vigilancia Marina) en la aplicación de la tecnología SAR en la vigilancia de los mares alrededor de Cuba a partir de la adquisición de imágenes SAR de la constelación de satélites CosmoSky-MED durante 9 meses; y la capacitación para el procesamiento digital a través de las herramientas informáticas de la plataforma SEonSE. Con estas nuevas herramientas, se procesaron 2550 imágenes SAR con la herramienta informática SEonSE Engine, teniendo las estadísticas de los buques y las manchas de petróleo encontradas en el mismo período mediante el software SEonSE Portal. Se encontraron en este período un número importante de manchas de petróleo en los mares circundantes a Cuba, lo cual evidenció la existencia de conductas inapropiadas de vertimiento de hidrocarburos al mar, y la importancia del monitoreo de estas malas prácticas en el futuro para combatida. Estas nuevas prestaciones constituyen un nuevo enfoque en la vigilancia marina y un impacto en el sistema de alerta temprana de contaminación marina por petróleo, ya que el sistema es capaz de detectar las manchas, y enviar la notificación a los usuarios finales.

Palabras clave: vigilancia marina, imágenes SAR, CosmoSky-MED, SEonSE.

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INTRODUCTION

It is known that the shipping industry is one of the main contributors to marine oil pollution, given the large volumes of hydrocarbons that can be released in a spill event. Spills from supertanker accidents represent only 8% of the total oil that enters the oceans; however, both large spills (Perdomo et al., 2021) and small spills constitute the main focus of attention. In this sense, remote sensing has been used, in recent decades, to search for and monitor oil spills drifting into the sea. For this, the use of remote satellite sensors has been attempted on numerous occasions (Polinov et al., 2021).

As examples of the use of optical satellites, we have the IXTOC I oil drilling rig accident in Mexico, using GOES (Geostationary Operational Environmental Satellite); and the AVHRR (Advanced Very High Resolution Radiometer) on the Landsat satellite (Gutierres et al., 2016). Other examples are the EXXON VALDEZ accident and the HAVEN spill near Italy. In all these cases, the processing of the information took a long time, evidencing the dependence on optical satellites on clear skies and daylight hours to carry out monitoring. This was the trend in the EXXON VALDEZ spill, which covered extensive areas of the ocean for more than a month, and there was only one sunny morning that coincided with the passage of the satellite (Chaturvedi et al., 2020a).

However, it has been shown that remote sensing with synthetic aperture radar (SAR) is the most effective tool to detect and analyze oil slicks on the marine surface. As an example of this, since 1978, oil slicks were detected with SAR images in southern California offshore with the Seasat mission (Ivanov & Morović, 2020); therefore, tools and methods have been developed to detect oil contamination, to estimate its distribution and extent, and even to identify the sources of spills (Perkovic et al., 2018).

Modern SAR instruments on board satellites such as Radarsat-2, TerraSAR X, COSMO-SkyMed and Sentinel-1A provide good performance for monitoring oil spills with adequate spatial coverage and temporal resolution (Ivanov & Morović, 2020). Organizations such as the Regional Marine Pollution Emergency Response Center for the Mediterranean Sea (REMPEC), the International Tanker Owners Pollution Federation Limited (ITOPF) are increasing their spill databases and have been collecting data since 1977 and 1970 respectively (Alexopoulos & Dounias, 2003; ITOPF, 2023). Furthermore, the European Maritime Safety Agency (EMSA) has provided an observation service for the detection of oil spills by satellite since 2007; although it is only available to EU member states (Carpenter, 2018).

The EMSA advanced monitoring combines satellite monitoring with aerial surveillance (Vidmar & Perkovič, 2018) 24 hours a day throughout the year allowing oil spills to be identified (Fingas & Brown, 2014), with an accuracy between 80% and 92% in the detection and classification of oil spills (Polinov et al., 2021). This service is completed with the fate forecast of oil slicks through numerical modeling based on satellite data (Lardner & Zodiatis, 2016).

Starting in 2022, with the international Italy-Cuba collaboration project: "Strengthening the Cuban marine system" (Marine Surveillance), and the e-GEOS company and the Cuban Institute of Meteorology (INSMET) as main executors of both parties, 3 very important milestones were achieved in Cuba: the training of personnel, a technological transfer and the acquisition of SAR images of the COSMO-SkyMed (CSK) satellite constellation continuously for 9 months, and with full coverage of the territorial seas of the archipelago Cuban every 48 hours.

In the training, courses were held on Introduction to Synthetic Aperture Radar (SAR), Detection of hydrocarbon slicks and other environmental processes, among others. After carrying out the technological transfer agreed upon in the collaboration, the SEonSE (Smart Eyes on the Seas - http://www.e-GEOS.it/SEonSE/) Platform was installed on the INSMET servers, with a training course to exploit the aforementioned tool. (Cancio & Rodriguez, 2022b, 2022a).

During the collaboration period, in a process completely unprecedented in Cuba, INSMET had SAR information available from the download of satellite images from the e-GEOS ftp site. These SAR images were processed by INSMET researchers, using the SEonSE Engine and SEonSE Portal Applications (Oddone et al., 2021), acquired under the project contract.

This article aims to summarize the results of the processing of the images acquired during this collaboration, in order to highlight the importance of marine surveillance of the seas around the Cuban archipelago with SAR technology. Following the Introduction, section 2 briefly describes SAR technology applied to marine meteorology, the features of oil slick SAR detection, the COSMO-SkyMed satellite constellation, the Sentinel 1 satellite, and the SEonSE SAR image processing tools, received in the technology transfer. In Section 3, outputs from SAR image processing with SEonSE Engine and statistics from the SEonSE portal. Finally, conclusions and recommendations are presented in Section 4.

METHODS AND MATERIALS

2.1 SAR technology applied to marine meteorology

SAR radars are capable of observing the ocean surface in high spatial resolution in all weather conditions. In recent years, the potential of SAR images to detect oil slicks and wave parameters such as wave direction, period and height has been demonstrated (Nieto et al., 2006). SAR images at sea provide evidence of a large set of geophysical phenomena in addition to oceanographic features related to waves and ocean currents (Li et al., 2022).

With its day-night acquisitions not dependent on weather, SAR is currently experiencing tremendous growth. In addition to operating at different frequencies, they are characterized by the availability of different operating modes, which provides the possibility of balancing resolution and coverage (Zamparelli et al., 2016).

Natural disasters such as floods take place all over the world and can be analyzed using SAR technology (Abreu Del Sol & Rodriguez, 2023). The effects of these include urban areas, coasts and agricultural areas; one of its main causes being extreme weather phenomena (Pelich et al., 2022). The well-known inSAR techniques can be used for the evaluation of disasters and also to verify the outputs of forecast models.

In Cuba, coastal flooding is caused by tropical cyclones, cold fronts and southern winds associated with extratropical lows. These phenomena generate the most intense winds in the region with a significant increase in sea level in the coastal area (Mitrani, 2017). The most severe floods in Cuba are generated by tropical cyclones where the storm surge effect also appears (Perez et al., 2019).

2.2 SAR technology in the detection of oil slicks in the sea

Oil particles are described in SAR images by long dark tails protruding from the sea surface. The operability of SAR for oil slick discovery is restricted by wind speed. Low wind speeds (less than 3 m/s) do not reflect the complexity of the marine environment contaminated by the absence of waves; while, in conditions of intense wind (more than 12 m/s), the roughness on the surface of the contaminant decreases due to the increase in waves and emulsification (Gee et al., 2016).

As the ocean is a non-static mass of water, the fate of oil on the sea surface depends on: the quantity, the physical properties of the hydrocarbon and the environmental conditions. The different physical-chemical-oceanographic processes in the spilled oil have a long time scale and impact the perceptibility in SAR images (Chaturvedi et al., 2020b).

The Sentinel-1, TerraSAR X and COSMOSkyMed satellites operate in the X band, this being the best band for remote sensing of oil slicks with regard to Bragg scattering. Each of these SAR satellites has polarimetric imaging modes that may have application for remote sensing of oil spills(Lohberger et al., 2018).

2.3 The COSMO-SkyMED satellite constellation

The COSMO-SkyMed (CSK) program, developed by the Italian Space Agency (ASI), is a constellation of four (currently three satellites are fully operational and one was deorbited and substituted by two satellites of new generation) medium-sized satellites in low Earth sun-synchronous polar orbit, located in the same orbital plane and each equipped with a high-resolution multimode SAR that operates in X-band. The four satellites have been arranged in a one-day interferometric configuration between both the second and third satellites, while the first and fourth satellites are positioned with a 90 degree offset to optimize the temporal performance of the overall constellation. The CSK constellation can operate in different mission configurations with specific orbital geometry that directly characterizes the system's capabilities and performance (Battagliere et al., 2012; Daraio et al., 2016).

The constellation is capable of acquiring images of the entire world in all atmospheric conditions, day and night, without latitude limitations. The SAR payload has been designed to acquire data in different modes depending on the image area and the resolution that can be obtained. The following table describes the main characteristics of the different sensor modes available (Battagliere et al., 2019).

In this way, the e-GEOS ftp site e-GEOSwas enabled to download from Cuba the SAR images of the CSK constellation of the ScanSAR Huge mode, comprising an area per image of 200 x 200 km with 100 m spatial resolution, covering 350,000,00 km^2 of the area of interest in 48 hours, and reaching 80% coverage. This results in 15 coverages of each area per month.

2.4 Availability of Sentinel 1 SAR Satellite

Sentinel-1 operations are based on a series of closely coordinated activities involving satellites and

Table 1. COSMO-SkyMed sensor mode features

Sensor mode	Swat Extension (km km)	Geometric resolution (mxm)
Enhanced Spotlight	10x10	1x1
StripMap HIMAGE	40x40	5x5
StripMap Ping Pong	30x30	20x20
ScanSAR WIDE	100x100	30x30
ScanSAR HUGE	200x200	100x100

the ground segment. The satellites are routinely monitored and controlled by the Flight Operations Segment (FOS) managed by ESA-ESOC. The FOS ensures the overall security of the satellite; Routine tasks include executing all platform activities and commanding payload programs (Potin et al., 2019).

Strict orbit maintenance control for the Sentinel-1 satellite results in small baselines for SAR interferometry and is of primary importance for most InSAR applications. The Terrain Progressive Scan (TOPS) technique has been implemented in the main default SAR imaging mode over land, the interferometric wide swath (IW) mode (as well as in the extra wide swath, EW, mode used mainly at sea for sea ice monitoring and maritime surveillance) (Potin et al., 2017).

Systematic availability of Level 0 Products and GRD Level 1 products is also guaranteed for all data acquired in SM, IW and EW instrument modes (high speed modes) within 24 hours of detection and the 3 hours NRT from detection. It also includes the systematic availability of OCN Level-2 products for all data acquired in WV mode. As of November 2017, OCN level-2 products of systematic generation (IW, EW, SM), have been extended to all seas and oceans (Potin et al., 2017).

Within the framework of Sentinel's free and open data policy, the opening of the data flow to all users took place on October 3, 2014 for Sentinel-1A. The open data access service is based on a high-capacity broadcast network that exceeds 20 Gbps. Statistics for the last 24 hours are available in real time on the Data Hub home page: https://scihub.copernicus.eu (Torres et al., 2012).

2.5 Computer tools received in technology transfer

Important tools for SAR image processing were installed at the Center for Marine Meteorology (CMM) of INSMET: SEonSE Platform *(SEonSE Engine and SEonSE Portal)*, able to provide near real-time maritime situational awareness and operational maritime services 24 hours a day, 7 days (Oddone et al., 2021).

SEonSE Engine

SEonSE Engine is an application that allows you to detect and characterize ships and oil spills in SAR images acquired by satellite. It has a client-server architecture and uses a relational database to write and read data. The application uses a Graphical User Interface (GUI), implemented as a QGIS plugin, dedicated to helping the user of the software to perform the necessary steps in processing information (Oddone et al., 2021).

SEonSE Engine can work with the following SAR images: RADARSAT2, COSMO-SkyMed and Sentinel-1. No preprocessing is required because the products are read in native format.

Being an application that focuses on marine surveillance, it has a built-in mask for land areas. The ground mask is always the first task executed in the software and is mandatory for all subsequent processing tasks. The next Load Cooperative Data task is responsible for loading into the application the tracks and details of the ships provided by the Satellite AIS (Automatic Identification System) tracking systems. This task runs automatically after completing the LandMasking task, but it is also possible to start it manually. SEonSE Engine then offers the capability to derive, by the processing of input SAR images, supervised ship detections, fused with AIS for assigning well-knowing identification codes to each satellite detection, oil spill detection, wind and wave measurements. The detection of vessels close to detected oil spills is very important for marking potential polluters for each detected spill. With the GUI, oil spill and offending vessel reports can be created in different formats: shapefile, KML, and HTML. Using the Meteo Reports plugin, meteorological data reports are created that provide meteorological information on the detection of oil slicks. It uses wind and wave field reports, which can also be created in netCDF format.

SEonSE Portal

SEonSE Portal is a web application in which all available features can be viewed by customers for security, intelligence, law enforcement, border control, critical infrastructure monitoring, marine resource management, environmental protection and emergency response analysis applications. In addition to these services, it also provides actionable information, including ship and oil spill detection reports, tracking analysis, anomaly detection, wind and wave fields extracted from SAR images, and maritime life pattern extraction (Oddone et al., 2021).

RESULTS

3.1 Digital processing of SAR images received from e-GEOS

The SAR images agreed upon in the international collaboration were downloaded by INSMET researchers in the period from October 1, 2022 to June 30, 2023. The SEonSE Engine application was used for digital processing, and the reports were displayed through the SEonSE Portal. Table 2 shows the number of acquisitions in the 9 months of SAR image downloads by INSMET from e-GEOS.

Each of these images was processed with digital processing tools to search for oil slicks and possible vessels violating hydrocarbon spills. Throughout this

Table 2. Total number of images received at INSMET.

Year	Month	INSMET-Quantity
2022	October	298
2022	November	287
2022	December	290
2023	January	308
2023	February	275
2023	March	280
2023	April	271
2023	May	291
2023	June	250
	Total	**2550**

period, minor oil slicks were found in the area of interest, evidencing in some cases that vessels carrying out illegal practices at sea transit through the area. An example of this can be seen in figure 1.

All polygons of the detected spots were exported in different format files (.json, .tiff, .shape), which can be loaded with the different geographic information tools; and also, through program coded in different languages and applications such as the Lagrangian model of oil spills PETROMAR-3D that offer a forecast of the pollutant motion in the sea (Calzada et al., 2021).

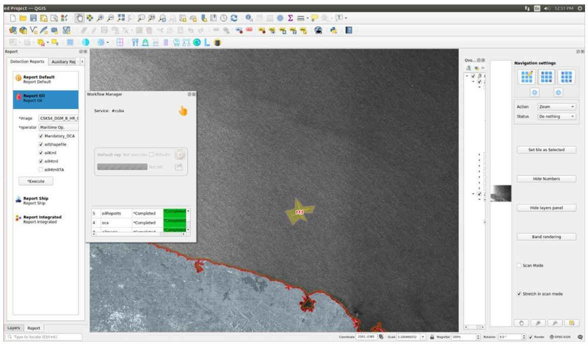

Figure 1. View of digital SAR image processing with SEonSE Engine showing an oil slick processed by the software operator.

3.2 SEonSE Portal Statistics

Once the digital processing of the images was carried out using the SEonSE Engine application, the outputs were assimilated by the SEonSE Portal. This web application showed the maps with the distribution of vessels and oil slicks in the EEZ of Cuba, as can be seen in figure 2, all the vessels that crossed the seas of Cuba between October 1, 2022 and on June 30, 2023. At first glance you can see the greater density of vessels towards the western portion of the Cuban archipelago, with a significant number of class A vessels (more than 100 m in length) mainly in the area of the Strait of Florida. Likewise, the oil slicks detected, which are represented as red or light green drops, depending on the case. They were most abundant in the western area, although they can also be seen in the central south and south east respectively.

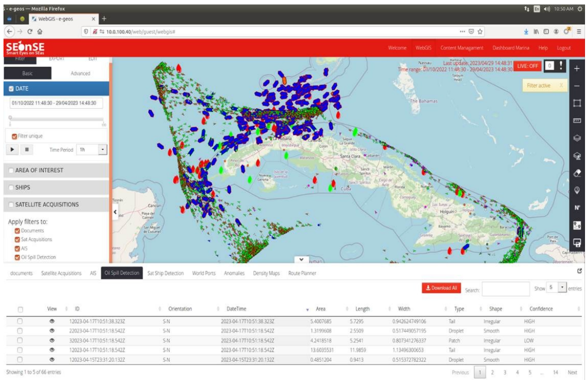

Figure 2. View of the SEonSE Portal showing the vessels (arrows and hexagons), and the oil slicks (tears) between October 1, 2022 and June 30, 2023.

Figure 3 shows a graphic report from the SEonSE Portal, referring to the types of vessels and oil slicks detected in the period indicated above. A total of 315 class A and 2 class B vessels (lengths between 50 and 100 m) can be seen, as well as a total of 66 oil slicks detected, 49 of them processed with high reliability.

In this way, there were 66 oil spills detected in the period between October 1, 2022 and June 30, 2023. Judging by the proximity to the coast of the oil slicks detected, the size, the duration hours and distance to the oil basins around Cuba; it could be suspected that a large part of the oil spills found could be discharged due to inappropriate behavior by the crew of some vessels, which violate international agreements to combat marine pollution. These assumptions would reinforce the need for constant monitoring of the waters surrounding the Cuban archipelago, especially when based on the surveillance and monitoring of these indisciplines with the technologies applied in this project, in many cases the offenders are also detected.

With the application of these technologies in Cuba through this collaboration, the efforts of the governments of Italy and Cuba materialize to comply with the Paris agreements and the Rio de Janeiro Agenda, referring to adaptation and mitigation to climate change, with a contribution to the care of the environment and coastal ecosystems, as well as the fight against pollution of the seas.

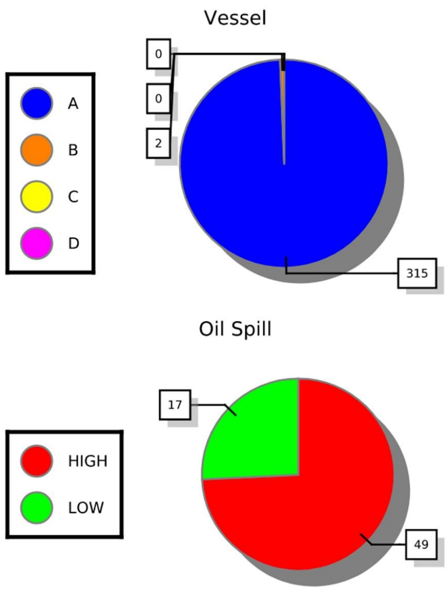

Figure 3. Graphical output from the SEonSE Portal web application showing the number and types of vessels and the number of oil spills.

CONCLUSION

By providing, within the framework of the Italian-Cuban collaboration through the Marine Surveillance project, access to the SAR images of the CSK satellite constellation for 9 months, it can be seen that:

1. A total of 2,550 SAR images were downloaded and digital processing of each one was carried out using the SEonSE technology transfer computer tool.
2. A statistical summary of the behavior of maritime navigation and oil spills in the seas of the EEZ of Cuba was shown with the SEonSE Portal tool.
3. By finding 66 oil spills in the seas surrounding Cuba during the collaboration period, the existence of sources of marine pollution became evident. This fact speaks for itself of the need for support from the high levels involved in the preservation of ecosystems and adaptation to climate change to maintain marine surveillance and combat damage to ecosystems and hydrocarbons dumped into the sea.

RECOMMENDATIONS

1. Work to achieve the sustainability of this service by incorporating optical satellite images and their respective digital processing techniques to detect oil slicks.
2. Continue working on the promotion of this service, as well as environmental education to preserve the marine environment.

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