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Earth Observation Opportunities to Enhance Maritime Safety

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ABSTRACT: In this paper, author presents capabilities of using satellite data, both radar and optical images, to enhance maritime safety. The concept of using satellite data includes a periodic data acquisition from the European satellite systems, both commercial and public. The aim of this paper is to show modern space technologies and the advantages of using them in the maritime domain. Advantages and disadvantages of earth observation are identified and described. Author outlines opportunities in maritime safety domain.

1 INTRODUCTION

Satellite Earth Observations (EO) for over 40 years are used in environmental monitoring. It is estimated that currently about 14% of satellite systems in orbit are designed to provide EO data, which gives about 225 systems in orbit [15]. Each year, new systems with various parameters and functions are placed in orbit. The vast quantity of earth observation data brings enormous opportunities, but also challenges in terms of choosing and using the most appropriate data. For purposes related to the marine domain, the benefits of EO data do not only result from the volume of data available, but from the intelligent use of data in a targeted manner.

As the ocean covers approximately 360 million sq. km. of the Earth's surface, it is highly important having a tool which provide information from all around the world. This is a favourable time for satellite monitoring of both oceans and lands, thanks to the Copernicus Program, a European Union flagship initiative. Copernicus is coordinated and managed by the European Commission. This long term program aims to provide an operational satellite monitoring capability and related services for the environment and security. The information services provided are freely and openly accessible to its users.

Changes in the oceans affect not only everyday weather and local changes in fisheries, but also have global effects in the form of large-scale atmospheric circulation, climate change and marine ecosystems. Typical EO products gives data on ocean parameters, such as sea surface temperature, sea ice, chlorophyll-a concentration (phytoplankton's photosynthetic pigment) and photo synthetically active radiation (sunlight effective for the photosynthesis of plants), based on various observation data sets. The continued advancement of satellite technology is expanding the range of ocean parameters which can be monitored, but also gives opportunity to detect and identify objects at sea, like oil spill detection or ship movement in harbours.

2 SATELLITE SYSTEMS

The basic parameters characterizing satellite images are: the number of spectral bands in which the recording was made, the range and resolution of each band, as well as the spatial and temporal resolution. Due to the type of registered electromagnetic radiation, satellites can be divided into optical and microwave systems [12]. Another division, due to the resolution of the obtained image, allows to distinguish very high resolution (VHR) systems with a pixel size smaller than 1 m, high resolution systems from 1 to 4 m pixel, medium resolution from 4 to 12 m, rather low resolution from 12 to 50 m and low resolution above 50 m [5].

2.1 *Copernicus data*

Copernicus gives a unique set of observations from Sentinel satellites, which provide unmatched spatial and temporal coverage with different sensors and resolutions.

The Sentinel missions support marine monitoring by providing timely, continuous and independent data on the behaviour, use, and health of the oceans and the associated coastal zones. Each Sentinel mission is based on a constellation of more than one satellite, to fulfil revisit and coverage requirements and has specific features, like a certain resolution, revisit time and sensors.

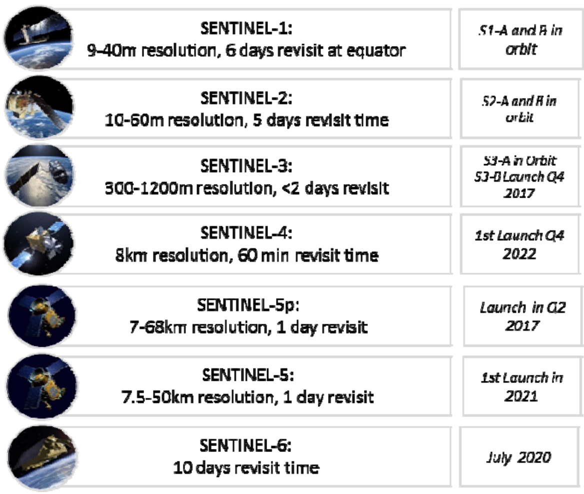

Figure 1. Sentinel mission and status *(source: [4])*

Sentinels provide datasets for Copernicus Services:

- Sentinel-1 is a Synthetic Aperture Radar (SAR) with the prime objectives of Land and Ocean monitoring. The goal of the mission is to provide C-Band all-weather, day-and-night radar data continuity following the end of the ERS-2 and Envisat mission. Its data is very valuable for the observation and study of: management and monitoring of the European marine environment, sea ice measurement, surface winds and waves, oil spills detection, land surface movements, etc.
- Sentinel-2 is a Multi Spectral Imager (MSI) whose data benefits in marine applications, among others the observation and study of coastal conditions.
- Sentinel-3 includes three main instruments: a radar altimeter, an Ocean and Land Colour Instrument (OLCI) and a Sea and Land Surface Temperature Radiometer (SLSTR). Its main mission is to provide a multi-instrument capability to support the accurate parameterization of such topics as Ocean Colour (OC), Sea Surface Height (SSH) and Sea Surface Temperature (SST). Its data products address almost all domains of Earth Sciences, including Oceanography.
- Sentinel-4 and Sentinel-5 are in preparation and will be missions dedicated to the atmosphere composition.

2.2 *Third party mission data*

Around 30 from ESA, their Member States, Eumetsat and other European and international third party mission operators make some of their data available for Copernicus Services. In majority, these data are characterized by higher spatial resolution but also smaller scene size. This means, that those high resolution satellite data cannot be so easily used for big area monitoring, but rather to confines studies to individual sites.

2.2.1 *Radar satellites*

TerraSAR-X satellite is the most accurate, commercial satellite for radar observations of the Earth built in a public-private partnership: German Space Agency, DLR and EADS Astrium (currently Airbus Defense & Space). TerraSAR-X uses radar with active antenna working in frequency 9.65 GHz (X band, wavelength 3.1 cm) [1]. It is the length of the emitted wave and excellent knowledge of the location allow, among others, extremely accurate detect objects on sea surface.

Table 1. TerraSAR-X available modes characteristic (*source: [1]*)

Mode	Coverage Azimuth x Range (km^2)	Resolution Class (m)
ScanSAR Wide (SCW)	200 x (194–266)	40
ScanSAR (SC)	150 x 100	18
StripMap (SM)	50 x 30	3
Spotlight (SL)	10 x 10	1.7 - 3.5
High-Resolution Spotlight (HS)	5 x 10	1.4 - 3.5
300 MHz High- Resolution Spotlight (HS 300)	5 x (5-10)	1.1 - 1.8
Staring Spotlight (ST)	(2.5 – 2.8) x ~ 6	0.24 azimuth, 1.0 range

Different modes give opportunity to acquire data with smaller resolution for large area monitoring, detect shoreline and recognize and identify objects and infrastructure with very high resolution. Wide ScanSAR mode with a large coverage (up to 270 x 200 km^2) and a spatial resolution of 40 m is a unique ratio between coverage and resolution, offering a unique potential.

2.2.2 *Optical satellites*

For better understanding of radar images, it is helpful to use optical data for photointerpretation. Some very high resolution optical satellites with main parameters are presented below.

Table 2. Very high resolution optical satellites systems

Satellite/ Sensor	From	To	Spatial resolution [m]		Number of bands	Swath [km]
IKONOS	1999	2015	0,82 (PAN)	3,28 (MS)	PAN + 4 MS	11
QUICKBIRD	2001	2015	0,61 (PAN)	2,44 (MS)	PAN + 4 MS	16,5
GEOEYE-1	2008		0,41 (PAN)	1,65 (MS)	PAN + 4 MS	15,2
WORLDVIEW-2	2009		0,5 (PAN)	2 (MS)	PAN + 8 MS	16,4
WORLDVIEW-3/4	2014/2016		0,31 (PAN)	1,24/3,7 (MS)	PAN + 8 MS + 8 SWIR	13,1
PLEIADES-1A/-1B	2011		0,5 (PAN)	2 (MS)	PAN + 4 MS	20

Spatial resolution indicates the size of the smallest object that can be detected in the image. Comparing these systems with Sentinel data, the trend is clearly visible, the better the resolution, the smaller the size of the scene.

The Pléiades satellite system is a constellation of very high definition satellites and at the same time the first European system of this class. The Pléiades system is in fact a constellation of the two twin satellites Pléiades-1A and Pléiades-1B. The first of these was placed in orbit on December 17, 2011, and the second on December 4, 2012. The constellation belongs to Airbus Defense & Space - the largest European space technology company. The Pléiades satellites are equipped with multispectral sensors R, G, B, NIR with a pixel of 2.0 m and panchromatic with a pixel of 0.5 m.

What distinguishes the Pléiades system from other VHR systems is a strong sensitization to the blue range. Sensitization of the sensor starts from 430 nm, while usually it is only 450 nm. The positive effect of this is the increase in possibilities of studying water bodies. In addition, images are recorded in 12-bit what gives a very large tonal distinction between objects. This feature allows you to analyse objects in shadows and low contrast background in detail. No other system currently registers 12-bit images.

3 MONITORING

As it was well recognized in [10], marine transport development causes the increase of the intensity of ships traffic and ships dimensions. The navigational risk increase requires more sophisticated methods of its assessment.

The European Maritime Safety Agency (EMSA) is the Entrusted Entity responsible for implementing the Copernicus Maritime Surveillance (CMS) service. The CMS service is available for European Union (EU), European Free Trade Association (EFTA) national administrations with responsibilities at sea, and relevant EU bodies and institutions [3]. The CMS service supports monitoring of human activity at sea for a range of functions, including: maritime safety and security, marine pollution monitoring and law enforcement. It supports authorities by value added products extracting particularly valuable information from the basic image data, analysis of objects, features or activities at sea and allowing them to undertake more quickly and efficiently activities and decisions.

Through CleanSeaNet Service, EMSA provides an oil spill monitoring service. CleanSeaNet supplements existing surveillance systems at national or regional level, strengthens member state responses to illegal discharges, and supports response operations to accidental spills [6]. The service is based on radar images obtained from synthetic aperture radar (SAR) satellites. Operators evaluate the satellite images, together with supporting meteorological, oceanographic and other available data. Aim is to detect and identify possible sea pollutions, or to assess the probability of the presence of oil on the sea surface, help identify the source of contamination and model the oil drift. When a spill is detected, a pollution alert is sent to national authorities.

4 OPPORTUNITIES

The value added products based on satellite data for marine safety include:

- vessel detection,
- oil spill detection,
- activity detection,
- SAR wind and SAR wave.

Optical sensors provide a variety of information in different spectral bands. Images provide easier image interpretation due to the colour combination of red, green, blue (RGB) bands. Optical radiometers cannot acquire images during the night or in cloud cover conditions.

Synthetic-aperture radar sensors use microwave frequencies to retrieve backscatter measurements from the detected surface, including sea surface. The images can be acquired independent of the weather condition and cloud cover, at any time of day or night. SAR images of the ocean greatly depend on surface roughness caused by wind stress at the sea surface. By measuring the roughness of the sea surface, resulting images display features which stand out against the background.

4.1 *Vessel detection*

SAR images results of vessel detection analysis, and vessel traffic information and other man-made structures appear as bright spots.

On Figure 2 ship detection is made based on TerraSAR-X very high resolution data. In vessel detection higher resolution SAR images are more efficient. Key benefits are:

- Quick availability through
  - cloud and day-light independence
  - (semi-)automatic processing
  - near real-time delivery
- High sensitivity to also smaller ships
- High geolocation accuracy
- High monitoring frequency

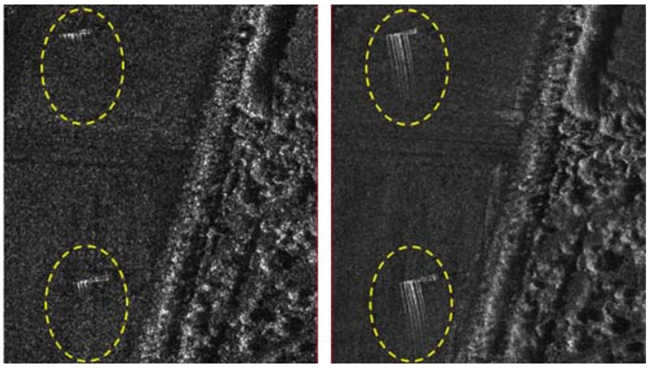

Figure 2. TerraSAR-X Staring Spotlight ship detection (*source: Airbus DS*)

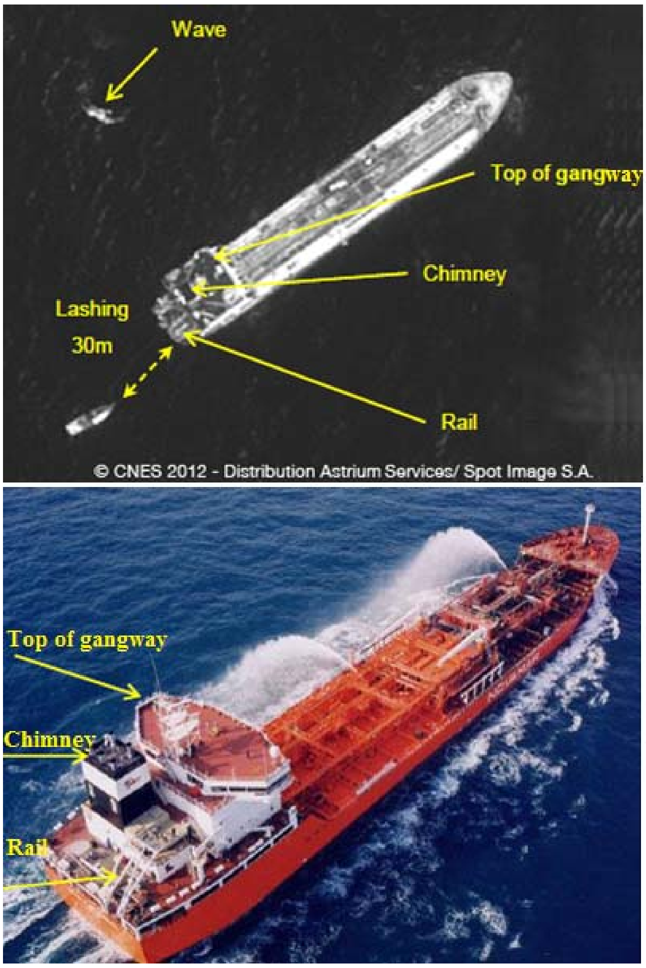

Figure 3. Pleiades ship detection and identification *(source: Airbus DS)*

Ship detection results can be used to further utilize also optical satellite sensors in order to identify ships detected using SAR data. Example of Pleiades image interpretation is presented on Figure 3. With 0.5 m spatial resolution, it is possible to recognize vessel's elements like chimney, top of gangway, rail, etc. and measure the exact dimension of this elements from image. Having those detailed information it is possible to identify the ship model and even name of the vessel.

What's more, the ship's accurate position is also identifiable. On the picture Enrico Iveoli is presented. Its coordinates and metric information:

- Latitude: 07°13′29″ N
- Longitude 049°35′11″ E
- Length 138 m
- Width 22 m
- Oriented 053°

Radar and optical data complement each other very well. However, the optical data is dependent on weather conditions, therefore their availability is somewhat limited.

4.2 *Oil spill detection*

In the case of oil spills or areas with very low wind appear as dark shapes. The surface roughness of the sea has a large impact on the detection of oil spots on the basis of SAR images. This impact is much greater than when detecting bright objects.

On Figure 4 the example of oil spill recognition during different weather conditions is presented. Picture shows oil spill detection based on TerraSAR-X radar data. On the first image, on the top, it is not possible to detect oil spills. Weather conditions are defined as rough weather. On the second one seeps are also not visible. Because of calm weather the seeps are indistinguishable. Last picture present the perfect weather conditions and oil is clearly visible, by dark shape.

The ideal weather conditions means:

- Wind speed: between 6 to 16 knots,
- A stable wind direction,
- Swell height: < 1.5 m,
- Wave height: < 1.0 m.

Figure 4. Oil spill detection depending on surface roughness (*source: Airbus DS*)

4.3 *Daily monitoring*

Daily revisit of Pleiades satellites gives opportunity for frequent monitoring the traffic in the harbour. On Figure 5 changes in the Suez Harbour are visible.

Figure 5. Daily monitoring based on Pleiades images, Suez harbor, Egypt, 2013, February 20 (upper) and February 21 (bottom) (*source: Airbus DS*)

Especially for shipowners it can be an interesting source of information about the current situation in the port, and on the sea.

5 CONCLUSION

Mixing radar and optical satellite data gives more opportunity in monitoring and detecting objects. Radar can see where optical sensors cannot. On the other hand optical sensors can detect smaller objects. Example of combining radar data for detection and optical for identification was presented in this paper. Another advantage is the more frequent leveraging all sensors to afford daily and even intra-daily revisit.

Moreover combining freely available Copernicus data with available on request commercial data allows to increase capabilities its usage in maritime domain. Copernicus has full free and open policy for data and information and provide continuous environmental information. Detection and identification might be done using commercial images with higher resolution.

The advancement of the satellite based technology and the ability to monitor ocean salinity, temperature and many other factors will shape the development of future satellite sensors. These satellite observations, used in conjunction with in situ measurements and models, will become a key element in understanding and assessing oceans. While important for advancing ocean monitoring capabilities, satellite Earth observation will by no means replace in situ observations as they are needed to evaluate satellite data.

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