COASTAL ZONE MONITORING USING SENTINEL-1 SAR POLARIMETRY DATA

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In recent years the role of the surveillance and security of Polish boundaries has significantly increased. Polish coastal zone monitoring requires various approaches using various technological means in order to ensure the protection of Polish boundaries. In this paper, the authors discuss and present alternatives to underwater surveillance methods of coastal area analysis and monitoring using data retrieved from the newly developed and operational Synthetic Aperture Radar (SAR) Sentinel-1 (ESA S-1) satellite. The authors discuss whether the proposed data source is a valid and reliable source of data that can be utilized in the current Polish coastline monitoring strategy and increase the safety of the country. A description of the various parameters concerning the data for the sea surface, sea objects and technical infrastructure are also discussed and presented.

INTRODUCTION

In recent years the increasing role of the safety and security measures for marine infrastructures such as ports, shipyards and economically important technical infrastructures (e.g. the LNG terminal in Świnoujście), has resulted in an intensified set of activities related to the development of the various methods of monitoring of the aforementioned places. New threats demand the use of innovative methodologies and technologies by government authorities in order to ensure this safety and security. Nowadays, this situation requires NRT (Nearly Real-Time) observation data to be delivered to decision stakeholders in order to ensure optimal cooperation between institutions, as well as between technologies and response procedures to a variety of threats, not only human-induced ones [1].

In this context, many remote observation methods constitute several problems applying them to operational continuous NRT manner, which include:

- observation continuity,
- sensitivity to weather conditions,

- high telecommunications network availability,
- need for a high computational environment and amongst others.

As an alternative to the currently applied methods of coastline observation, i.e. *in situ* observations, hydroacoustic systems and on-land surveillance, the authors present a methodology that utilizes data delivered by the newly launched ESA Sentinel-1 (S-1) satellite. Unlike passive observing satellite systems that use radiation in visible, near-infrared or thermal channels, S-1 is an active C-band radar, which makes it particularly important in the context of threats monitored independently from weather conditions (clouds, atmosphere fluctuations, etc.). The usefulness of S-1 for ship detection, harbour infrastructure monitoring and in the observation of other on-water objects is analyzed in the paper. The presented methodology is based on the use of raw S-1 data which can be delivered to data centres in semi-real-time mode.

1. ESA SENTINEL-1 SATELLITE

The European Earth observation programme Copernicus [2], previously known as GMES (Global Monitoring for Environment and Security), is a European Space Agency set of activities for monitoring the Earth [3]. Basically, the Copernicus is a set of systems that collects, stores, processes and disseminates data from multiple sources, such as satellites, in situ measurements such as ground stations, as well as airborne and sea-borne sensors. As a result, data is provided to the users with reliable and up-to-date information through a set of services related to environmental and security issues.

The application of Copernicus can be divided into six groups (Fig. 1):

- land,
- marine,
- atmosphere,
- climate change,
- emergency management
- security

Products retrieved from Copernicus and other Earth observation systems can be also utilized in environmental protection, management of urban areas, regional and local planning, agriculture, forestry, fisheries, health, transport, climate change, sustainable development, civil protection and tourism [4] [5].

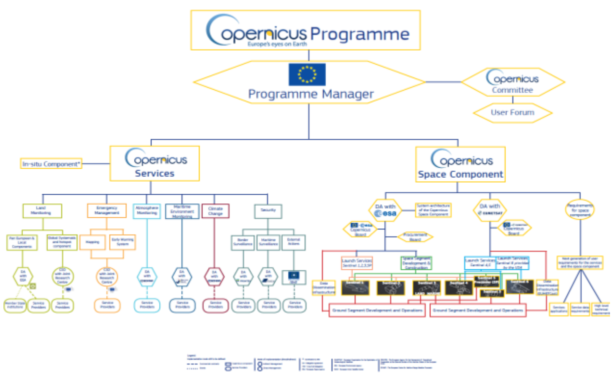


Fig. 1. Copernicus programme overview, source: ESA.

In this context, NRT services can bring valuable information to operational critical decisions in the event of an emergency, such as a natural disaster or a humanitarian crisis. Copernicus is coordinated and managed by the European Commission. The development of the observation infrastructure is performed under the aegis of the European Space Agency for the space component and of the European Environment Agency and the Member States for the in situ component.

The Sentinel-1 is the first satellite system to have been used within Copernicus [6] [7]. It carries an advanced radar instrument to provide independent data on weather conditions and day-night imagery of Earth's surface. In fact, S-1 is the system of satellites that will comprise two orbiting units, 180° apart, and whose mission will ensure the whole globe is revisited every six days. Currently the revisit time is 12 days, because only the first unit (Sentinel-1A) is in orbit, the second unit (1B) will be launched in 2016.

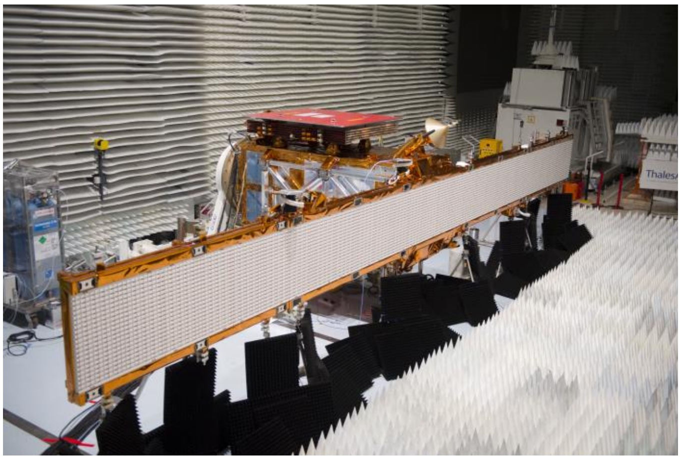


Fig. 2. Sentinel-1 satellite during radio frequency tests: Credit: ESA–S. Corvaja, 2014.

2. S-1 DATA

The conducted study described in the paper was focused on the area of the Gulf of Gdansk, localized in the Pomeranian (Pomorskie) Voivodeship, Poland, on the southern shores of the Baltic Sea. Data for the study was retrieved from the ESA Sentinel-1 download site [8] that provides free open-access to the S-1 rolling archive.

The S-1 data delivered is in the form of monochromatic images that contain information about the reflectance value of the given area. This image can be enriched with additional information using various advanced processing methods, including images acquired with different polarizations of the antenna or interferometric techniques.

The S-1 satellites are equipped with a C-SAR sensor, which offers medium and high resolution images regardless of weather conditions. The C-SAR sensor is also capable of delivering night imagery and detecting small movement on the ground or water (e.g. ships), which makes it useful for coastline and land monitoring.

The data is obtained using the Synthetic Aperture Radar (SAR) technique, which is a method of microwave imaging. The basic advantage of the method is the possibility of narrowing beams in order to acquire better resolution data than with classic radars, as the size of the antenna is virtually increased. In SAR, better resolution is achieved by the transmitting and receiving of the active beam from a mobile platform. Registered signals are combined together in the way they would be received by a substantially bigger sensor (the "virtual" increase of the antenna's size). The theoretical resolution of the SAR data in the direction of the platform's movement, airplane or satellite, is equal to the size of the sensor (also in the direction of movement), decreasing the antenna in this case results in SAR sensor better resolution.

Another important aspect of S-1 data is the polarization type which enables the retrieval from resulting images of information about the type of the surface reflecting the beam. Typical SAR sensors send beams with vertical (V) and horizontal (H) polarization. When both signals are reflected and acquired by the sensor, 4 different datasets, in relation to the polarization, can be generated, i.e. VV, HH, VH and HV.

Apart from the physical aspects of data retrieval, Sentinel-1 offers various data products divided by levels and modes depending on intended purpose of the data, its parameters and analysed area size. Level-0 data is in raw (unprocessed) format, which is compressed and unfocused. This is the basis for all other higher-level products. Level-1 (L-1) products are intended for most users and applications. This contains focused data, which has been initially processed. The first type of L-1 data is Ground Range Detected (GRD) images, which are multi-looked and projected to ground range with an Earth ellipsoid model. The second type is Single Look Complex (SLC) data, which has been additionally georeferenced with a satellite's orbit data and is provided in slant-range geometry. Level-2 data is utilized in order to create ocean products for wave, wind and current measurements.

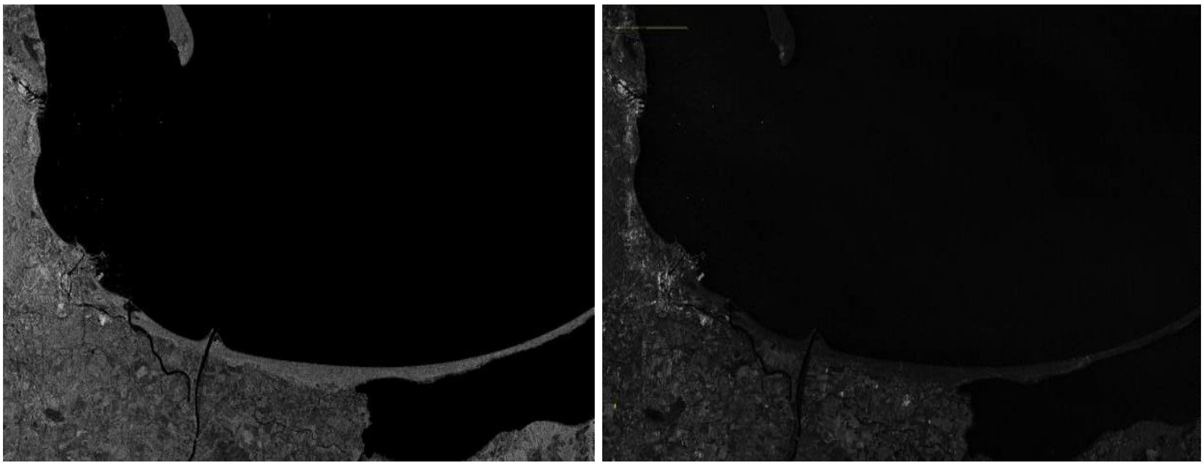
S-1 also provides four modes for data acquisition. The first mode, strip map, is intended only for specific cases, i.e. emergencies or disasters. It has a 80km swath width and a 5m x 5m spatial resolution. It is acquired with a continuous sequence of signal pulses, the antenna is pointed to a fixed azimuth angle and the images have a constant image quality at the incidence angle. Interferometric Wide Swath (IW) is intended as a main acquisition mode, which satisfies the majority of service requirements. It gathers data in a 250km width swath with a 5m x 20m resolution and is acquired using Terrain Observation with Progressive Scans SAR (TOPSAR) technique [9]. The beam is steered back and forth in the azimuth direction for each burst, which ensures that the scalloping effect is reduced and this results in homogeneous image quality. The SNR (Signal-to-Noise Ratio) and DTAR (Distributed Target Ambiguity Ratio) is constant throughout the swath. Extra Wide Swath (EW) is similar to IW, but it acquires data over a wider area (400km swath with 20m x 40m resolution) and includes more sub-swathes (five instead of three as in IW). The last mode, Wave, is used in ocean data analysis. It is characterised by a distinctive "leap-frog" acquisition pattern, 100km image intervals and 5m x 5m resolution.

3. RESULTS

In this section, results of S-1 data analysis are presented. The authors of the paper described several use-cases in order to verify if S-1 data can be utilized for the particular applications presented below. The focus area of the study was the Gulf of Gdańsk.

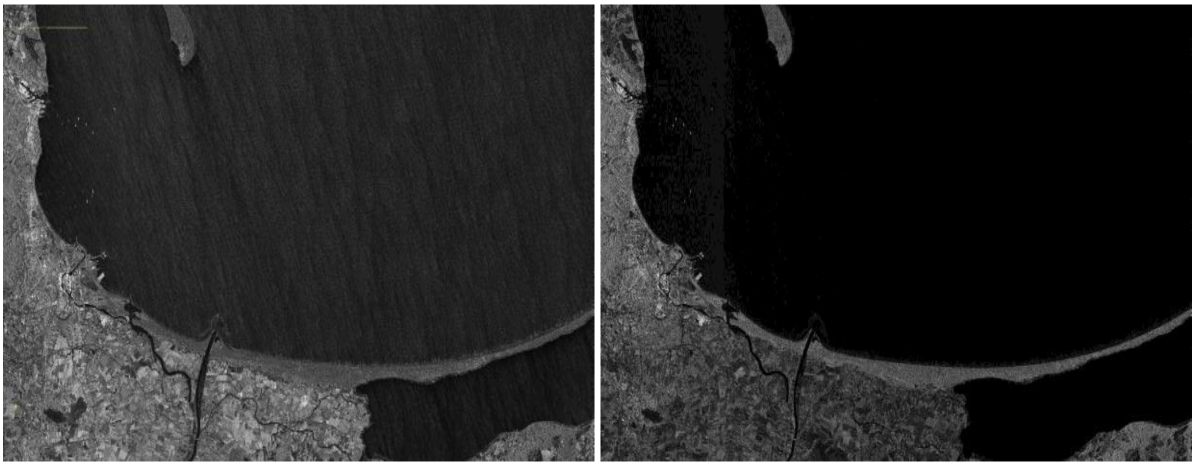
3.1 GULF OF GDAŃSK

The first case presents the S-1 data acquired on 23rd December, 2014 in VH (Fig. 3a) and VV polarization (Fig. 3b). The same area was also observed by the pass on 4th January, 2015 (Fig. 4a, 4b). During research, spatial analysis of the presented data was performed. The methodology of the analysis was as follows: firstly, a mask dividing sea and land areas was generated using the S-1 Toolbox [10], secondly spatial analysis for land and sea areas were performed in order to obtain basic statistical parameters: mean value, standard deviation, and minimum and maximum values - presented as 3rd and 97th percentile of the data, in order to avoid singular deviations. The results show that polarization type influences data statistics for both land and marine areas. This means that any spatial analysis of polarimetry data must take various polarisations into consideration if such data is available.



(a) (b)

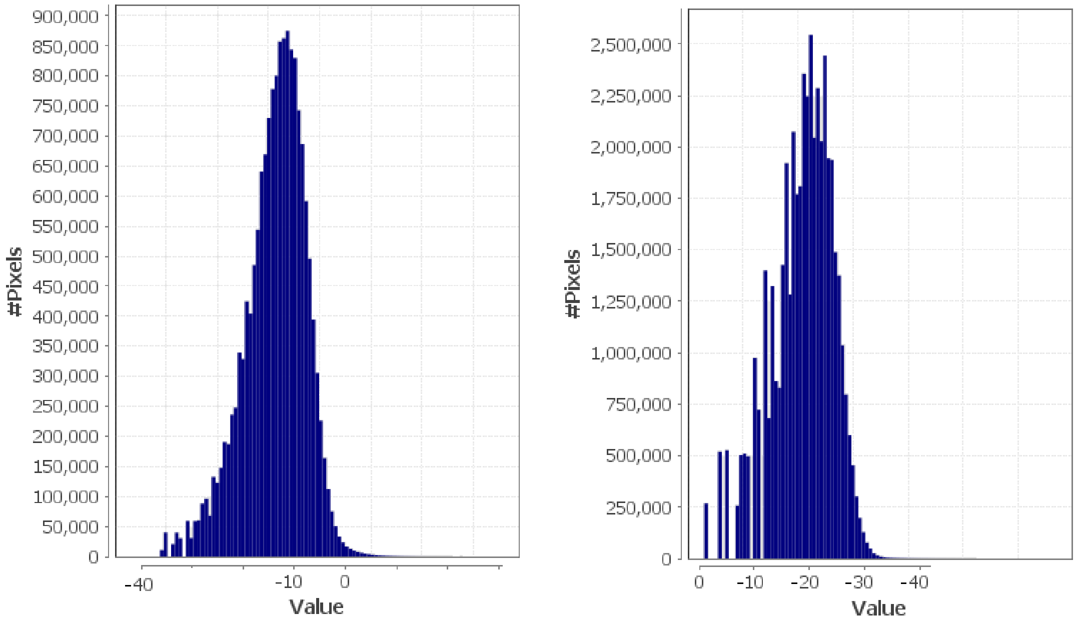
Fig. 3. Study area 1 – Gulf of Gdańsk (23.12.2014), VH polarization (a) and VV polarization (b).



(a) (b)

Fig. 4. Study area 3 – Gulf of Gdańsk (04.01.2015), VH polarization (a) and VV polarization (b).

In addition to the spatial analysis of S-1 data, histogram analysis for data acquired on 4th January, 2015 was also performed. The plots, as can be seen on the histograms, for VH polarization (Fig. 5a) and for VV polarization (Fig. 5b) are clearly distinguishable and value distribution for land and for marine areas differ not only in mean value but also in value distribution.



(a) (b)

Fig. 5. Value distribution of study area for 04.01.2015) for land in VH polarization (a) and for sea in VH polarization (b).

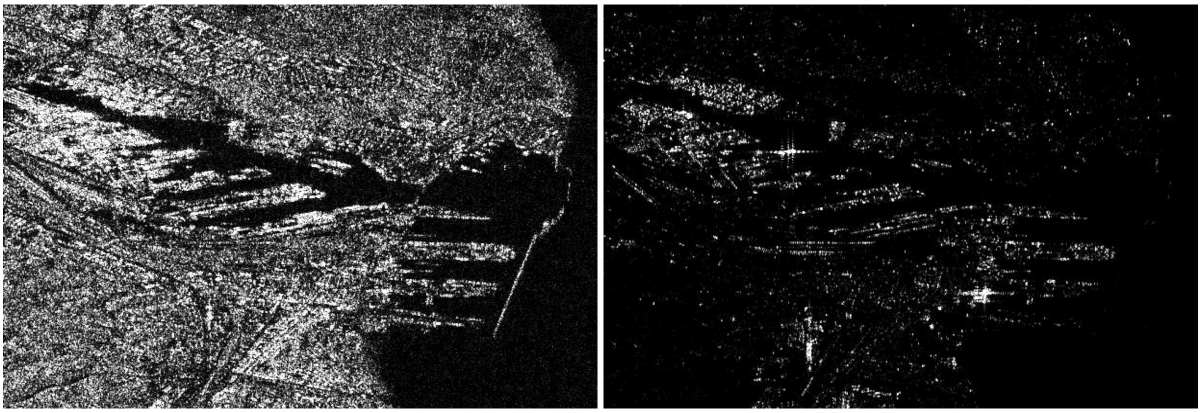
Additionally, table 1 presents the analytical cumulative results of both passes presented in Fig. 3 and Fig. 4. Similarly to spatial analysis, these results also show that the mean intensity of pixels representing marine areas is significantly lower than for land; this phenomena can also be observed for minimum and maximum values represented as 3rd and 97th percentile of the data. As expected, standard deviation for marine area is also significantly smaller than for land. This phenomenom can be explained by the fact that land, specifically for the Gulf of Gdansk, is of significantly higher diversity than sea [11].

Tab. 1. Statistics for study for Gulf of Gdansk area.

image	**intensity mean value [dB]**	**standard deviation**	**Percentile 3% [dB]**	**Percentile 97% [dB]**
23.12.2014, land, VH	-9.84	1.14	-23.64	-2.4
23.12.2014, land, VV	-17.86	1.07	-30.57	-9.35
23.12.2014, sea, VH	-20.11	0.21	-22.58	-1.8
23.12.2014, sea, VV	-28.16	0.10	-30.56	-9.46
04.01.2015, land, VH	-9.51	0.95	-23.57	-2.69
04.01.2015, land, VV	-2.88	0.74	-16.45	-0.74
04.01.2015, sea, VH	-17.69	0.23	-30.57	-11.68
04.01.2015, sea, VV	-8.15	0.47	-20.35	-0.84

3.2 PORTS IN GDYNIA AND GDAŃSK

In accordance with the overall analysis presented in Fig. 3-6, the authors of the paper also verified whether the accuracy and spatial resolution of the S-1 allows for the analysis of the critical infrastructure related to marine economy. In this case, the Port of Gdynia was presented as a complex spatial construction and is good example data to verify the usefulness of S-1 data. As can be seen on Fig. 6, details of the port's infrastructure are clearly visible in the SAR images. In this context, S-1 can be used to monitor the current state of the infrastructure, detect changes or damages in infrastructure (for instance in breakwaters), docks or other objects related to the marine infrastructure.

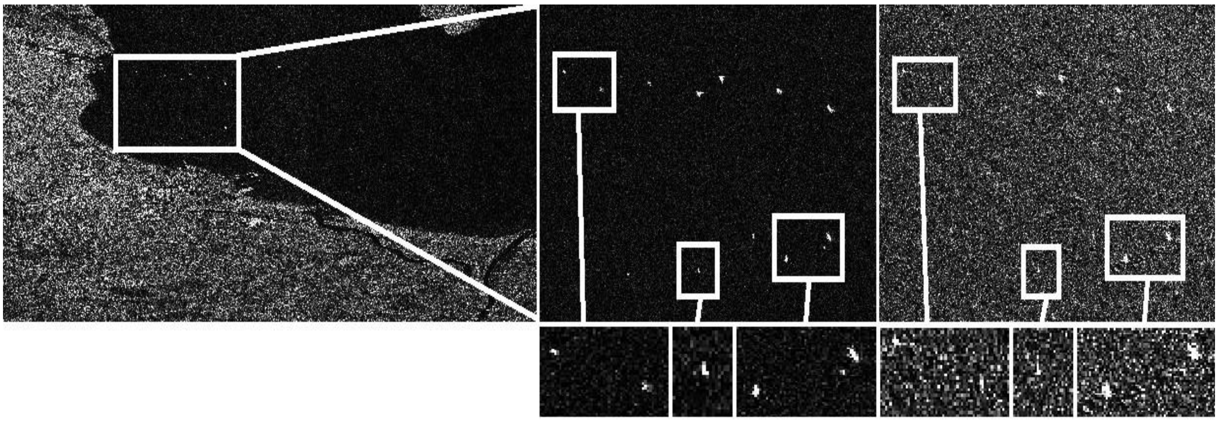


(a) (b)

Fig. 6. Study area 5 – Port in Gdynia (23.12.2015), VH polarization (a) and VV polarization (b).

3.3 SHIPS NEAR PORT IN GDYNIA

The last presented application of S-1 data is ship detection performed for the Gulf of Gdansk area on 4th January, 2015. As can be seen in the case presented in Fig. 7, the VH polarization image is better suited for ship detection than VV polarization, as the resulting contrast between sea-water and ships is significantly better. It is also worth noticing that this application of S-1 data can bring additional information to already operational systems including ARPA [12], AIS [13] and others.



(a) (b)

Fig. 7. Ship detection near port in Gdynia (04.01.2015), VH polarization (a) and VV polarization (b).

4. CONCLUSIONS

Sentinel-1 is a new, very promising source of microwave imaging that gives new opportunities in various applications related to the monitoring of marine environment. In the paper, the authors discuss its usefulness in the context of marine infrastructure monitoring for safety and security applications. In order to verify if the phenomena that take place on the surface of marine areas can be observed by S-1, the visualization and basic spatial analysis of the presented data were performed. Future work will focus on detailed applications of S-1, related to coastline change-detection, land type change-detection as well as others.

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