Sea State Retrieval from Sentinel-1 Imagery as Support of Maritime Situation Awareness

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Abstract

From Synthetic Aperture Radar (SAR) imagery various types of maritime information are extractable, including surface winds, waves, oil slicks, waterline changes, changes of seabed morphology in shallow waters, wakes of ships, etc. The algorithms recently developed for this purpose are integrated into a prototype processor for Sentinel-1 (S-1) imagery. The DLR Ground Station Neustrelitz applies this prototype as part of a near real-time demonstrator service for support of Maritime Situation Awareness. The presented scientific service involves daily provision of surface wind and sea state parameters estimated fully automatic from S-1 Interferometric Wide Swath (IW) images for North and Baltic Sea.

1. Introduction

The rapid development of the satellite technology, SAR sensors, SAR processors, information extraction algorithms and ground infrastructures made possible a series of oceanographic applications in near real-time (NRT) during the last years [1]. Several minutes after acquisition, the processed data can be transferred to the weather services for validation of the forecasting models [2]. The data of different kind such as wave height, surface wind speed, ice coverage, oil spills etc. can be processed in parallel for the same image and combined to support Maritime Situation Awareness (MSA). For example, "information about the sea state can help to assess how destructive a hurricane is and can predict its path respectively time and location on which it will make landfall" [3]. **Figure 1** shows sea state parameters estimated for the case of hurricane Irma in 2017 acquired by Sentinel-1 (S-1) Interferometric Wide Swath mode (IW) using the Sea Sate Processor (SSP) developed at DLR [4].

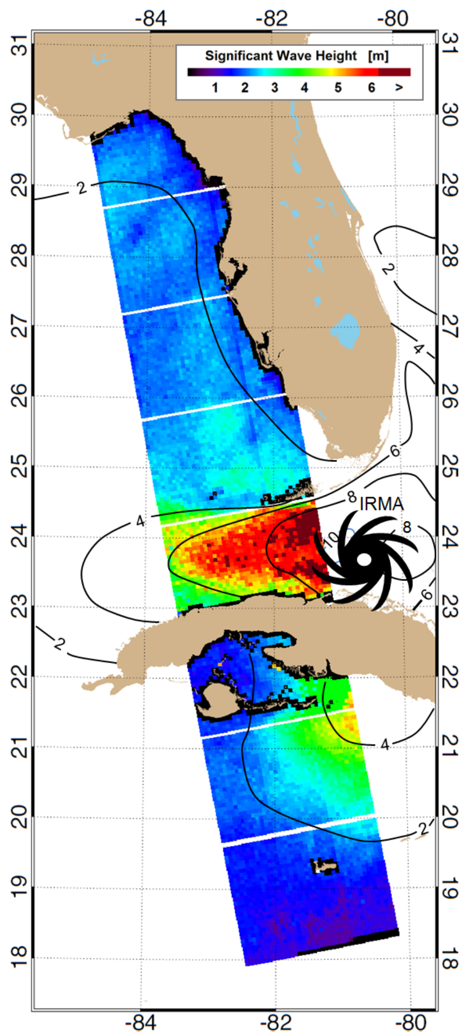

Figure 1: Total significant wave height H_S estimated from a Sentinel-1 IW images acquired over Cuba and Florida on 09.09.2017 at 23:33 UTC during hurricane Irma was moving towards Golf of Mexico. The isolines present the WWIII model results for H_S.

Running the different processors in parallel helps to stay within a NRT time frame and ensures that all extracted information is instantly available to the other information extraction processes. For example, in coastal zones, kilometer-wide areas can fall dry or become flooded depending on weather and tidal conditions. As most processors benefit from a reliable land mask, the dynamic land-water line estimation has priority and is used as input to other value adding processors. Another example is the so called "white capping" (crashing of upper wave crest part by a wind speed higher than ~10 m/s) and wave breaking in shallows produce turbulence at the sea surface causing a high radar backscatter that can be falsely detected as a ship. An optimal ship detector for this situation should maximize the probability of an actual detection while minimizing the probability of false alarm. This tradeoff can be controlled (e.g. by thresholds by the other information extracted from the image. In this manner by sharing information between the processor modules the overall performance of the processor is increased. The fusion of data from multiple data sources increases the benefit for MSA e.g. a better spatial and temporal coverage and resolution. **Figure 2** shows an overview of the concept developed at DLR and realized in a prototype version for NRT service validation at DLR's Ground Station in Neustrelitz. The service runs daily for Southern North Sea and Western Baltics on S-1 IW imagery since February 2017 and provides sea state and wind parameters on a 6 kmx6 km raster and ship detection results. An example of the demonstrator GUI, developed for the product dissemination is shown in **Figure 3**.

2. Sea State form Sentinel-1 IW for NRT services

The Sea State Processor developed for X-Band TerraSAR-X imagery [2],[5] has been extended by the CWAVE_S1-IW model function and the surface wind CMOD-5 function and validated by buoy measurements . However, simple application of CWAVE_S1-IW is insufficient for an operational service. A series of additional operations is required to enable a robust and reliable raster processing of any acquisition within NRT. The most common occasions are image disturbances generated by man-made features like ships and offshore structures and natural features like rain cells and slicks. All these incidents produce signals not connected to sea state.

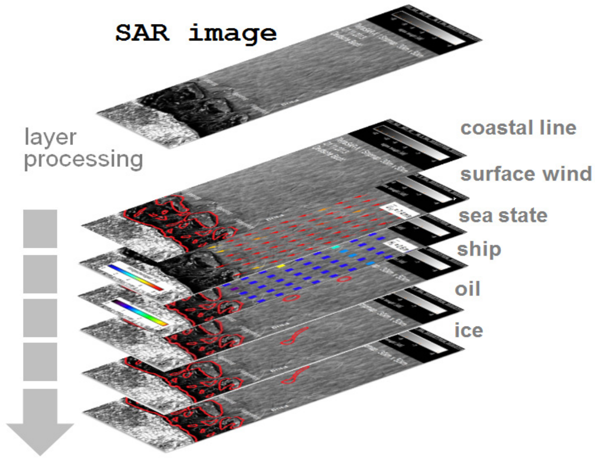

Figure 2: Processing of a SAR image for maritime situation awareness. Information from different layers are shared to each other to improve the product accuracy.

For example, in the German Bight a series of locations are continuously occupied by intensive ship traffic and offshore windfarms. A direct application of any model function without pre-filtering of these structures in such locations leads to a total overestimation of the wave height in the order of several meters. Therefore the model function needs also a term tuned for compensation of the unfiltered signal in a pre-filtering procedure.

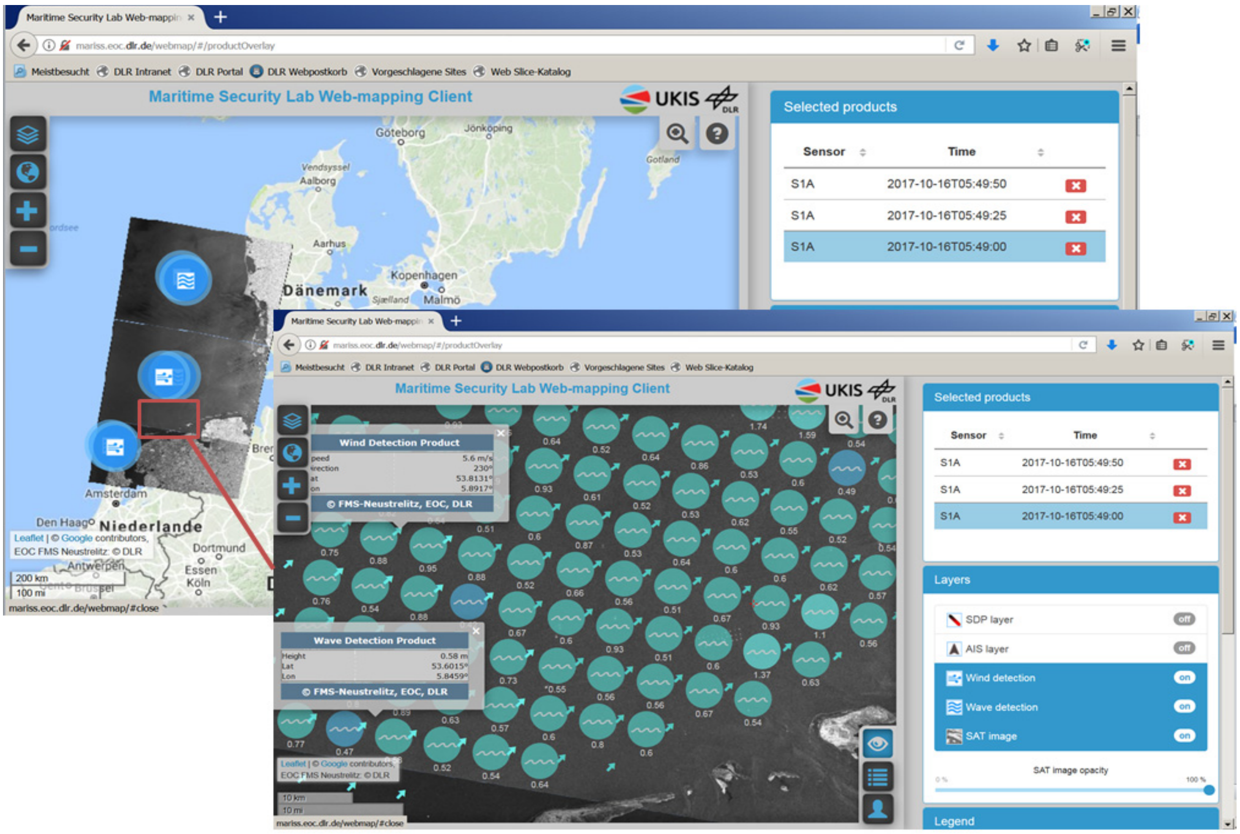

Figure 3: Screenshot of the SAR wind and wave product on Web Mapping Server at Ground Station Neustrelitz. The developed algorithms are included into an integrated processor and implemented into the NRT server chain. The maritime environment: wind (arrows) and sea state (circles) and ship detection products are combined in layers. The demonstrator runs daily for Sentinel-1 IW in Southern North Sea and Western Baltic Sea.

As shown by validation, the artefacts can be divided into two classes (**Figure 4**): radar echo much stronger than the background backscatter (e.g. ships) and radar echo much weaker than the background backscatter (e.g. slicks of different origin are typical for the Baltic Sea). A pre-filtering procedure recognizes and removes the influence of signals not produced by sea state, e.g. dry sandbars, nonlinear SAR image distortions produced by short wind waves or wave breaking, image artefacts like ships, seamarks, buoys, offshore constructions and slicks (wind, oil). The subscene is analysed using a 200 m× 200 m sliding window (sub-subscene), where the outlier pixels are replaced by the mean value of the subscene. All these were adapted for S-1 IW imagery.

3. Sea state from Sentinel-1 IW for storm observations.

Sentinel-1 IW covers the area-strips of thousand kilometres of earth and ocean surface with 10m pixel spacing by sequences of multiple individual IW images each with an approximate size of 200km×250km. The worldwide acquisitions with high frequency are free for common use and allow nowadays unprecedented opportunities for the observation of ocean processes and natural features. “Since understanding and predicting these powerful weather systems is essential to saving lives and property, scientists have been looking into how the Copernicus Sentinel-1 radar mission can help” [3]. **Figure 5** depicts the three days of storm in the Black Sea covered by S-1 IW acquisitions. The HZG (Helmholtz Center Geesthacht) forecast spectral model running for Black Sea [6] reproduced the storm peak near to the S-1 data. However, the storm peak estimated from S-1 data is shifted 80 km south in comparison to the model simulations (**Figure 5**).

4. Conclusion

The implementation of a model function for the estimation of meteo-marine parameters from SAR imagery into a NRT service is highly demanding and needs besides scientific effort an extensive validation of both, the accuracy and robustness of the methods applied. Multiple techniques have been included to allow robust and reliable automatic raster processing of arbitrary S-1 IW images. In summary these techniques include: data preparation, design of the data filtering framework, false alarm analysis, error compensation and quality flagging as well as organisation of data transfer.

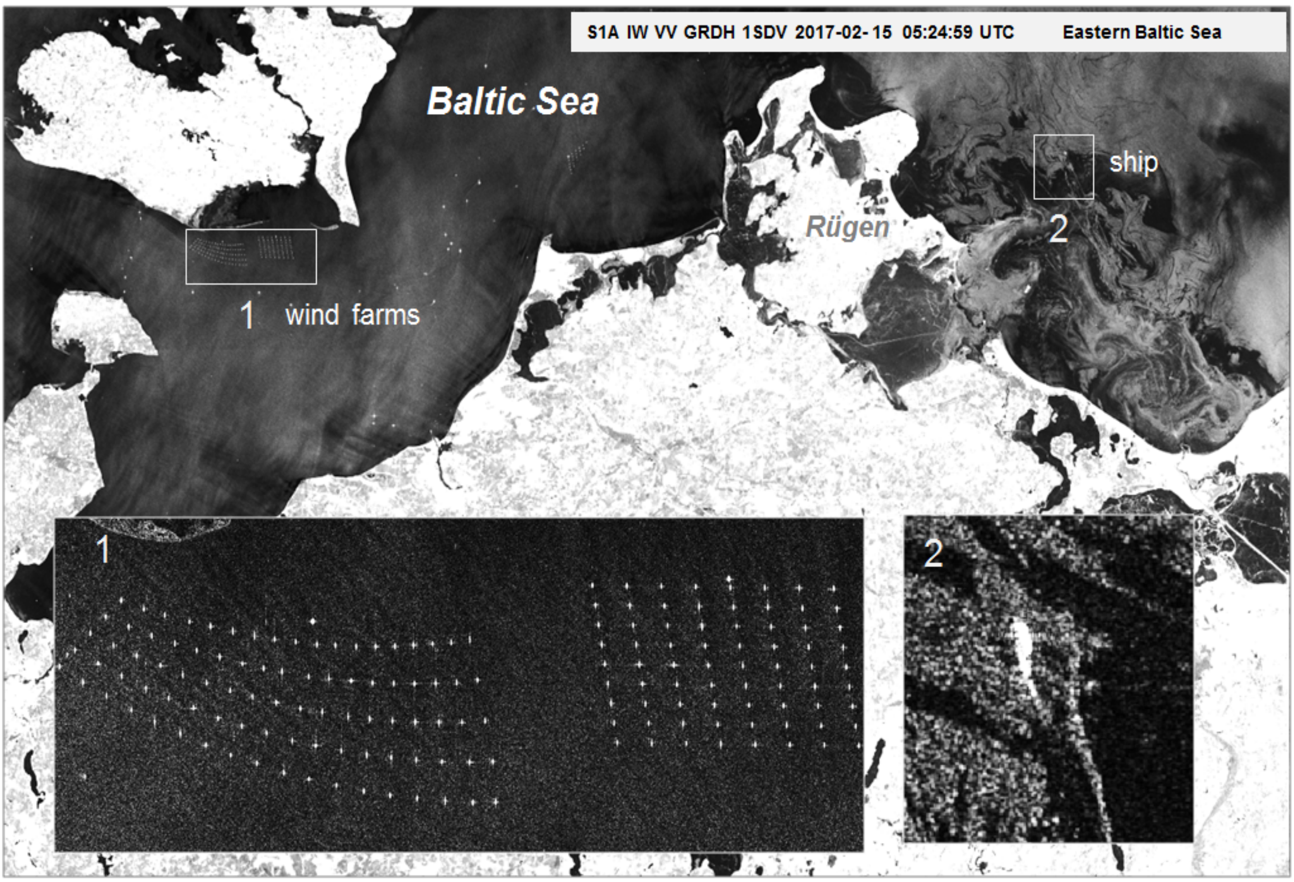

Figure 4: S-1 IW in VV polarization acquired over Eastern Baltic Sea. Artefacts of both kinds are present: very high radar echo from ships and weak radar echo by surface slicks. The edges of such films produce also contribution for spectrum energy. Relatively narrow slicks like ship wakes can be misinterpreted as long surface wave.

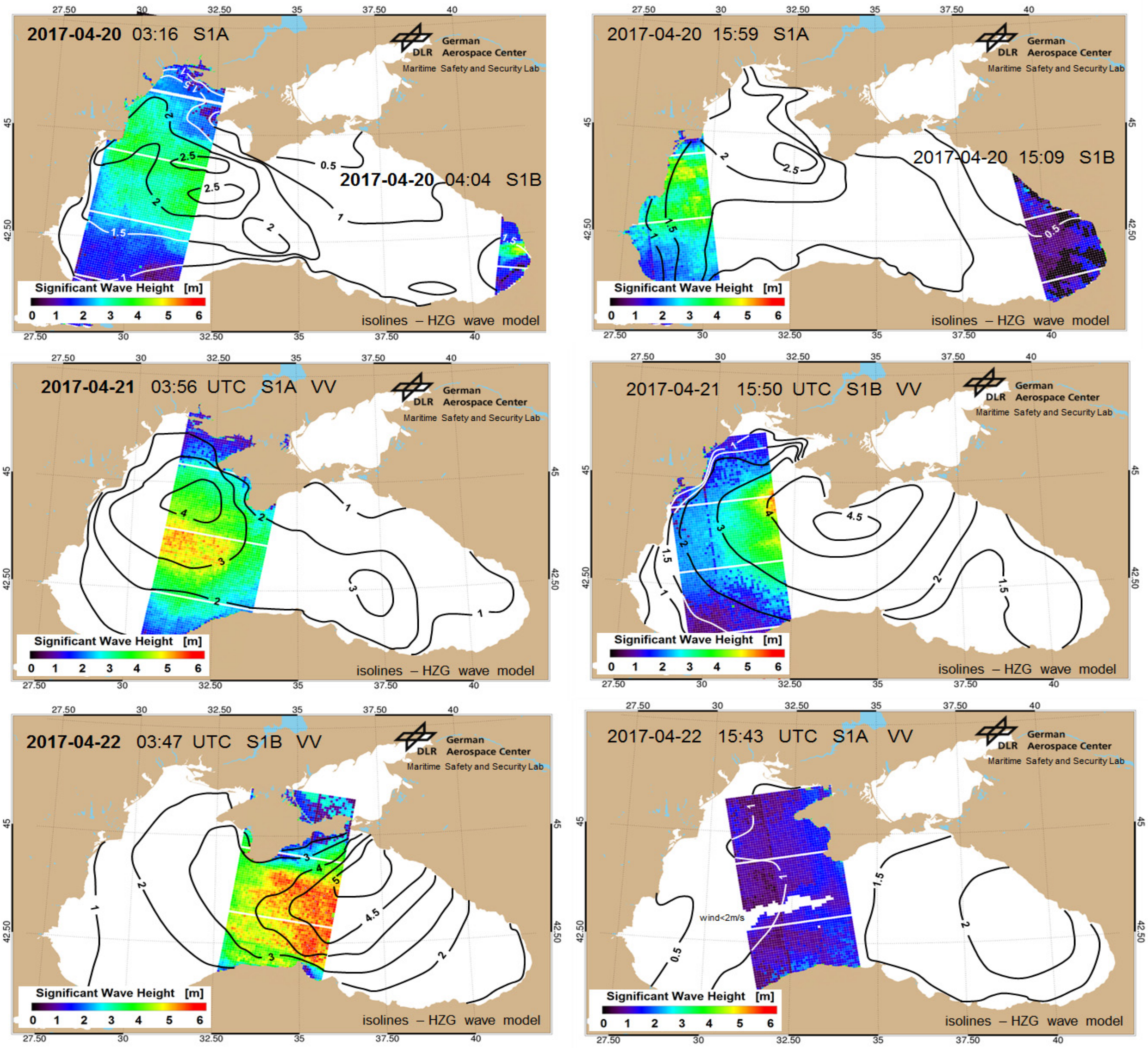

Figure 5: Sea state estimated from Sentinel-1 IW imagery in Black Sea. A storm in April 2017 is tracked during three days. The isolines show the results of forecast numerical wave model developed and run by HZG [6]. The storm peak estimated from S-1 is shifted 80km to the south in comparison to the model simulations (21.04.2017 03:56, descending pass). During this storm, a cargo ship was capsized. Only one of the 12 people aboard has been rescued so far. The ship was carrying grain from southern Russia to Turkey when it capsized near the Kerch Strait, according to the Associated Press.

5. Literature

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