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Sentinel-1 near real-time application for maritime situational awareness

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Abstract
In the context of the project real-time services for maritime security (Echtzeitdienste für die Maritime Sicherheit—security), an experimental research platform for validation of maritime products derived from remote sensing data, was developed. This article describes the work carried out to derive ship-, wind-, and wave detection products out of Sentinel-1 remote-sensing data by DLR's Maritime Safety and Security Lab in Neustrelitz, part of the German Remote Data Center DFD. The activity aims to the fulfilment of project requirements, primarily to support the need for near real-time performance up to 15 min, as those in maritime situational awareness. The development and implementation cover the task of level 0 processing, based on DLR's front end processor, the implementation of the framework for real-time processing up to level 2 (value adding), as well as the development of a hardware-independent virtual-processing platform.

Keywords Near Real time · Maritime · Ship · Wind · Wave · SAR

1 Introduction

1.1 Project real-time services for maritime security—EMSec

Supported by the Research for Civil Protection program undertaken by the German Federal Ministry for Education and Research (BMBF) the EMSec project was composed as a joint project, interconnecting a variety of data sets and sensors to demonstrate new capabilities for Maritime Situational Awareness. The objective is to initiate a coordinated service network to provide integrated maritime services in near real time (NRT). Under the leadership of the German Aerospace Center (DLR) Programme Coordination for Security, the project team is composed by six institutes from DLR (Maritime Security Lab in Neustrelitz, part of the German Remote Data Center DFD, Maritime Security Lab in Bremen, part of the Remote Sensing Technology Institute IMF, Institute for Flight Guidance FL, Institute of Space Systems RY, Institute of Communications and Navigation IKN, Institute of Optical Sensor Systems OS). Partners from industry were: ATLAS ELEKTRONIK, Airbus DS, Airbus DS Airborne Solutions, the Civil Protection Organisation, the University of Rostock and other associated partners. The project includes the following users: the German Federal Maritime Police, the Waterways Police in the coastal regions and the German Maritime Search and Rescue Service.

In the frame of EMSec, the Maritime Security Lab in Neustrelitz is responsible to provide and maintain the experimental environment for generation and validation of value-added information derived from remote-sensing data. The new development for the Copernicus Mission Sentinel-1 described here is one of the remote-sensing sensors beside TerraSAR-X and Radarsat-2 provided in the EMSec context. The image data from the Sentinel-1 Synthetic Aperture Radar (SAR) mission are directly received and processed in Neustrelitz and serves as one of the primary input data for deriving value added information products. The main task of the work packages, carried out at DFD was the development of functionalities for:

- an user request handling interface
- an automated ground station reception planning system, handling the user requests
- real time data reception

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- near real time data processing, product generation and dissemination

1.2 Copernicus mission Sentinel-1

Sentinel-1A was launched at 3rd April 2014 followed by Sentinel-1B at the 25th April in 2016. Both satellites are twins equipped with a Synthetic Aperture Radar (SAR) in C-band. The near-polar, sun-synchronous orbit of 679 km provides a 6-day repeat cycle taking both units into account. The instrument follows the missions ERS-1, ERS-2 and later ENVISAT ASAR and acquires comparable radar images. All Sentinel-1 products are available free of charge for scientific and commercial use. The Sentinel-1 SAR instrument payload is operated on a global scale in four exclusive acquisition modes, enabling imaging for a wide range of applications. The resolutions and swath widths are shown in Table 1 [2].

The instrument operation mode is planned for specific regions in advance with respect to the mission objectives of the user community and ends up in an observation scenario. The mission acquisition plan, known as high level operations plan, controls the observation scenario and is static for a certain period.

Generally, the interferometric wide swath (IW) mode with dual polarization VVVH is used over Europe. Dual polarization products are useful for ship detection as well as oil spill detection and can also be adapted to extract wind and wave information out of the ocean surface. All payload data are downlinked to one of the three ESA core ground stations (CGS) Svalbard, Maspalomas, and Matera, which are part of the Sentinel Core Ground Segment, as part of the payload data ground segment (PDG). For processing and archiving the data are stored in level 0 products and pushed to the processing and archiving facility (PAF). All level 0 products are systematically processed to level 1 (L1) products and published on the data hub operated by ESA and on different national mirrors, e.g., CODE-DE in Germany.

Additional to the CGSs, reception of data takes can be done by the so-called local ground stations (LGS). They are operated in listening mode and receive image data acquired over Europe which are transmitted in direct downlink (PassThrough) mode. In addition, NRT acquisitions can be placed by ESA especially for one LGS (Fig.1)

Table 1 Sentinel-1 acquisition modes and characteristics

Mode	Swath (km)	Spatial resolution (m)
Extra-wide swath (EW)	400	25×100
Interferometric wide swath (IW)	250	20×5
Strip map mode (SM)	80	5×5
Wave	20	5×20

2 Ground station Neustrelitz

2.1 National ground segment

For more than 25 years acquisition, processing and archiving of payload data from remote sensing and small-satellite science missions are performed by the National Ground Segment Department in Neustrelitz as part of the DFD. The station is located north of Berlin at 53°19.779′N, 13°4.247′°,

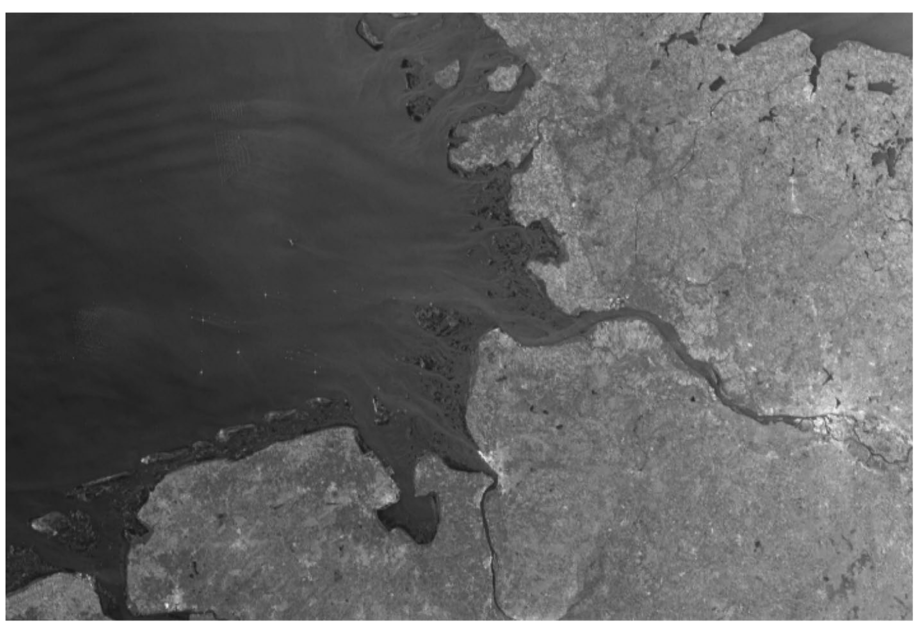

Fig. 1 Sentinel-1B image (IW) German Bight (15.03.2017 05:40)

which is an ideal location for achieving maximal coverage of Europe. The ground station consists of one 11.5 m S/X/Ka-band antenna and three 7.3 m S/X-band-antenna systems which fulfils the requirements for all elevations > 5° in case of X-band reception. Currently, the station supports more than 20 national and international missions and cooperates closely with a multitude of science and commercial partners and public authorities. The whole station is highly automated and all antennas are integrated to a multi-mission reception system.

2.2 Copernicus local ground station

Already in 2013, as an answer to the ESA activity "Collaborative Ground Segment", DFD launched the extension of the Neustrelitz ground station to develop the local ground station (LGS) as part of the DLR Copernicus Collaborative Ground Segment [1]. Located in the middle of Europe and also within the reception area of the Sentinel-1 core ground stations, Neustrelitz is very suitable for receiving Sentinel-1 data in direct downlink (PassThrough) mode. Figure 2 shows the 5° observation mask of Neustrelitz which represents the area of possible acquisitions.

In the parallel project real-time services for maritime safety and security (EMS), a new 11.5-m antenna system has been build up and the Sentinel 1 level 0 front end processor for data pre-processing was developed. This work was co-financed by the Federal Ministry of Economic Affairs and Energy and the State of Mecklenburg-Western Pomerania. Since the L0 processing is one of the main processing steps and a pre-condition to apply higher level processing, the functionality is described in Sect. 3.2 in more detail.

3 Planning and data reception

3.1 Reception planning

The downlink reception planning for regions within the ground station acquisition zone is fully automated based on the incoming user request and the Station Downlink Plan provided by the ESA for the LGS. The Station Downlink Plan contains only datatakes planned for direct downlink within the ground station horizon mask as shown in Fig. 2. The ground station planning is done once per week, 1 week in advance for each of the satellites Sentinel-1A and Sentienl-1B. Figure 3 shows the reception plan for week 10 2017 for the region of interest (ROI) EMSec (white polygon). The orange boxes are datatakes intersecting the ROI, a minimum of coverage, e.g., 20% can be defined to filter out scenes located at the borders of the ROIs.

Datatakes suitable for more than one user request are merged automatically. In this way, the reception schedule is optimized and contains the relevant reception times only. In addition, a priority can be defined to allow displacement by higher prioritized downlinks of other missions. Table 2 shows the reception plan holding planning information of three user requests, "EMSec", "ZKI flood test" and "Ground Motion".

3.2 Data reception and level 0 product generation

The EOC operates the Neustrelitz ground station (NSG) which is used as main ground station for the X-band data reception of high rate data stream. The Sentinel-1 data

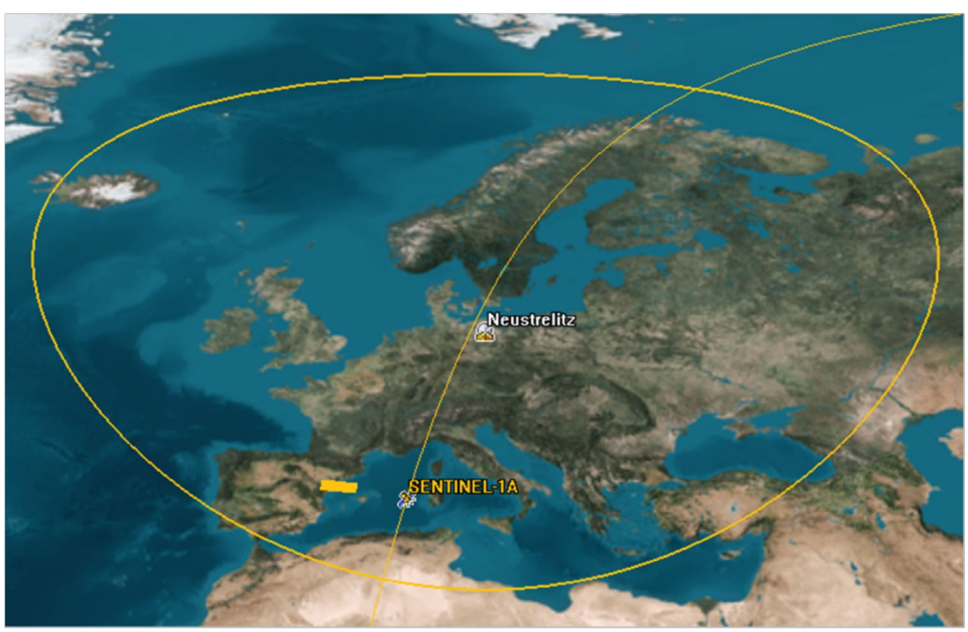

Fig. 2 Ground station Neustrelitz, acquisition circle for Sentinel-1, 5° elevation

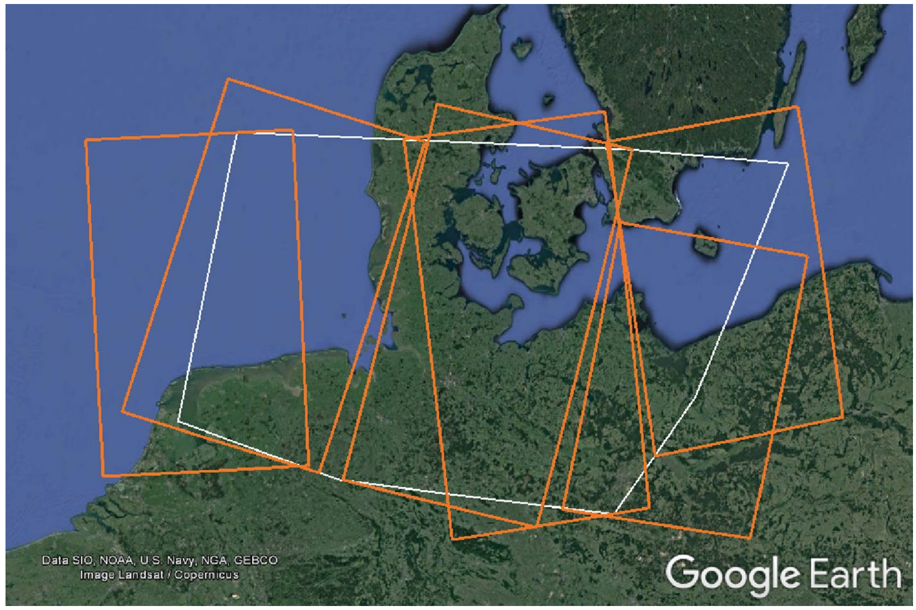

Fig. 3 Reception planning KML, Sentinel 1B for week 10 2017, ROI EMSec

Table 2 Reception plan, Sentinel 1B for week 10 2017

Date	SAT	STN	AOS	LOS	PRIO	COMMENT
17 03 07	S1B	NSG	16:15:11	16:15:29	MEDIUM	ZKI flood test
17 03 08	S1B	NSG	04:13:39	04:13:59	MEDIUM	ZKI flood test
17 03 08	S1B	NSG	05:48:09	05:49:20	HIGH	EMSec
17 03 08	S1B	NSG	16:59:33	17:00:53	HIGH	EMSec, ground motion
17 03 09	S1B	NSG	06:30:20	06:30:42	MEDIUM	ZKI flood test
17 03 10	S1B	NSG	05:31:41	05:33:05	HIGH	EMSec, ground motion
17 03 10	S1B	NSG	16:43:19	16:44:25	HIGH	EMSec
17 03 11	S1B	NSG	06:13:57	06:14:24	MEDIUM	ZKI flood test
17 03 11	S1B	NSG	17:24:20	17:25:26	HIGH	EMSec
17 03 12	S1B	NSG	05:15:35	05:16:39	HIGH	EMSec

reception is integrated in the Neustrelitz ground station multi-mission reception system, which currently consists of four antenna systems, redundant CORTEX high data reception (HDR) receivers, and redundant front end processor (FEP) [2] systems. All LAN interconnects between station elements (CORTEX HDR XXL, FEPs) and the processing chain is realized with a Gigabit-LAN. Figure 4 shows a structural view of the FEP system, which consist of a number of ingest units, a number of telemetry (TM) processing units, a unique FEP monitoring and control (M&C) component and a distribution unit. All of them are designed to support several missions such as Landsat-8, Landsat-7, TerraSAR-X, AQUA/TERRA, and a number of scientific missions using S-band and in accordance with CCSDS standards [3].

For Sentinel-1 reception, the system is configured to consider only PassThrough (VC37–VC44) and NRT (VC4–VC19) data packages. For further analysis or redistribution of products, data are stored temporary for a couple of days.

The real-time telemetry stream processing of the FEP system starts at the CORTEX interface with two ingestion units, which simply store the RS corrected and annotated channel access data unit (CADU) streams. Simultaneously at the begin of storing, the TM processing unit starts to reconstruct the instrument source packets (ISP), which is connected with an extraction of a wide variety of meta information, and the separation of noise, annotation and calibration packets. These steps are combined within one process for both received data streams in parallel. The flow of ISP reconstruction includes also the handling of overlaps needed for level 0 product slices, by copying specific parts of the ISP streams to the individual slices. For the purpose of generation dual pole products, one unit is designed as master, which incorporates the respective slice components on the fly and combines them to one final SAFE SAR L0 standard product [4]. In case of multi-slice processing, the FEP system generates global SAFE annotation, noise and calibration products at the end of the datatake or at lose of signal (LOS).

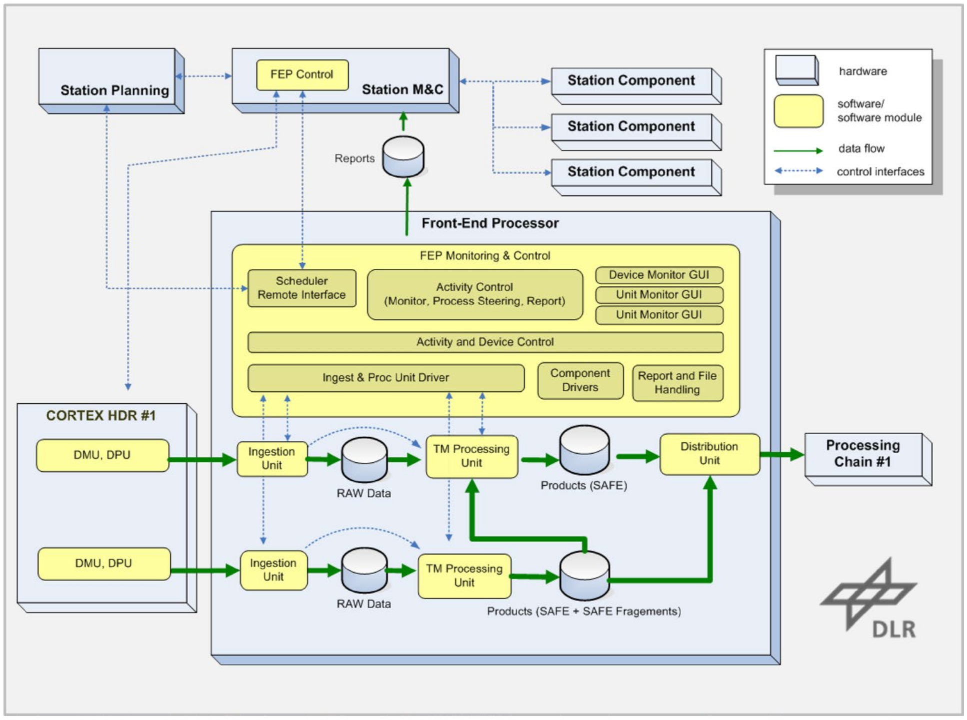

Fig. 4 Sentinel-1 front end processor for L0 generation

Once a SAFE SAR L0 slice product is completed, the TM Proc unit generates a transfer request for the distribution unit, which immediately starts a transmission with nearly wire speed to the processing chain, using the FDT protocol. Table 3 shows the timing achieved from arrival of satellite (AOS) until the availability of the product at the processing storage node.

The following SAFE products have been implemented and verified according to [2, 3]: SAR L0 standard, L0 noise, L0 Cal, and L0 annotations. All these products are available for single or dual polarization and for the modes SM, IW, EW.

4 Data processing and dissemination

4.1 Processing environment

During the EMSec project, an experimental platform was designed and build-up to facilitate the delivery of Sentinel-1 L1 products as well as the DLR value added L2 information products within the near real time requirement of 15 min after data reception. Furthermore, the usability of multi mission hardware should be validated. Therefore, the focus during the platform arrangement was on:

- Hardware setup and configuration
- Virtual vs. native
- Shared file systems

Table 3 Performance results of the data reception chain until level 0 processing

Orbit	S1A 15,728, 2017-03-17	S1A 15,735, 2017-03-17
AOS	06:14:34	17:24:56
LOS	06:15:19	17:26:22
Mode	IW_RAW__0SDV	IW_RAW__0SDV
Products	2 L0 slices, 3 global A, N, C	2 L0 slices, 3 global A, N, C
DatatakeID	0×019e38	0×019e70
Distribution started	06:15:22	17:26:23
L0 process readiness	06:16:46	17:29:12
Duration	00:02:12	00:04:16

For testing the overall performance of the different solutions, a SAR image processing test suite based on TerraSAR-X data sets was established. TerraSAR-X data were used because of the missing L1 instrument processing facility (IPF) for Sentinel-1 at project start time and the already existing comparative performance tables for TerraSAR-X on comparable hardware in operational use.

First hardware performance tests on AMD Opteron(tm) Processor 6380 with installed VMware ESXi 5.5 and guest operating system Centos 7 reconfirmed the literal research results, whereas AMD does not perform well enough to fulfil our processing requirements. Additional tests on Intel(R) Xeon(R) CPU E5-4650 0; 32 CPUs × 2.70 GHz and Intel(R) Xeon(R) E7-4870 v2; 60 CPUs × 2.30 GHz showed that the E5 processor clocked with 2.70 GHz achieved the best SAR image processing performance.

Following this, for the reason of multi mission usage of the hardware, a test case was composed to check out the performance of native hosted Centos 7 machines vs. virtualized Centos 7 on VMware ESXi 5.5. The SAR image processing tests did not show any significant throughput differences. Therefore, the final experimental platform was build-up based on VMware ESXi 5.5 to fulfil the multi mission task.

The processing system management (PSM) software (DLR/Werum framework), widely in use at DFD requires a shared file system to support parallel processing, needed to reach the project aim of NRT specification. First and only test was done with Global File System GFS-2 which is part of the Centos-7 distribution and fulfils all requirements.

Future tests with the MDA Sentinel 1 L1 SAR image processor (S1 IPF) confirmed those tests based on TerraSAR-X data sets. Only for special arrangements during the L1 processing of Sentinel 1 data sets enforces a local ram disk use.

Finally, the platform was assembled by additional Intel(R) Xeon(R) E5 processors with high clocked CPUs, VMware ESXi 5.5 with virtualized Centos-7 configured with a clustered shared file system GFS-2.

4.2 SAR image processing

The Level-1 product generation based on the Sentinel-1 L0 products is driven by the original ESA payload data ground segment (PDGS) instrument processing facility (IPF). This core processor S1 IPF is developed, licensed and supported directly by MacDonald, Dettwiler and Associates Ltd. (MDA), Canada on behalf of ESA. The following products are supported by our system:

- Level-1 Single Look Complex: Focused data, geo-referenced using orbit and attitude data from the satellite, and provided in slant-range geometry.
- Level-1 Ground Range Detected: focused data that has been detected, multi-looked and projected to ground range using an Earth ellipsoid model (used for further processing of Level-2 value-added marine products).

The standard processing depends on level 0 product slices generated by the FEP at Neustrelitz LGS or as provided by ESA datahub. The slice algorithm needs to be identical to the implementation of the S1 IPF delivered by MDA, which is described in the Sentinel-1 Instrument Processing Facility Interface Control Document [8]. Following the documentation, the L1 slice processing depends on the datatake sensing start- and stop time taken from the annotation product manifest, the self-calculated slice number and the total number of slices composing the whole datatake. The S1 IPF processes and cuts automatically the given L1 slice out of the L0 data, fitting to the surrounding slices without overlaps.

The S1 IPF has to be interfaced by the so-called Joborder defined in the ESA Generic ICD and its Tasktables describing the processing steps to be done. This is implemented based on PSM framework which enables a systematic parallel processing. Figure 5 shows the design of this instance.

The SAR image processing starts automatically as soon as the L0 product slices becomes available at the FEP delivery point. Afterwards all scene slices are being processed in parallel on different processing nodes, followed by the customizer driven value adding processing and dissemination. Table 4 shows the processing times during the EMSec campaign and a reprocessing run on optimized hardware and software configuration.

4.3 Value-adding processing

While the development at the Maritime Security Lab in Bremen aims to the estimation of wind and sea state conditions from SAR images in addition to the vessel detection, the Maritime Security Lab Neustrelitz developed the SAR Image Transformer, AIS Fetcher, the Ship Detection Value Adder (SDVA [7]) and the processing frame work which takes care of the product generation and dissemination in near real time.

The image processor "SAR image transformer" generates the geo-projected L1 image and adjusts the histogram. The processor produces several outputs such as the full resolution L1b geotiff image in different projections, e.g., UTM and EPSG:4326, the quicklook product in PNG complemented by world and projection files, which enables GIS application use.

The SAR target detection intermediate product generated by the SAR AIS NRT Integrated Toolbox (SAINT) [6] is the basis for further production. Detected targets could be vessels and stationary objects such as windfarms, oil and gas platforms or buoys on the open sea. The positions of the generally known stationary objects are stored in a filter database. In SDVA, these filters are

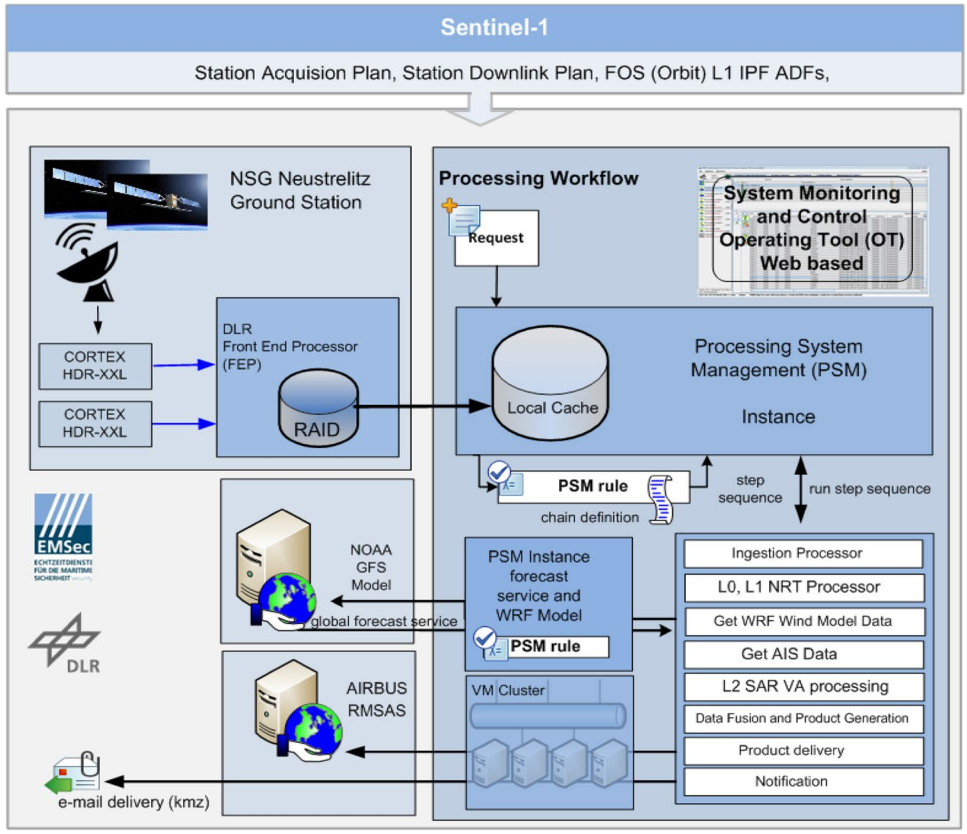

Fig. 5 Overview Sentinel-1 processing system developed by DLR

Table 4 L1 processing durations EMSec campaign and optimized reprocessing

	2016-09-08T17:09:00 – 2016-09-08T17:09:32	2016-09-08T17:09:25 – 2016-09-08T17:09:50	2016-09-10T05:40:45 – 2016-09-10T05:41:17	2016-09-10T05:41:10 – 2016-09-10T05:41:32
S1A-L1 processing (EMSec campaign)	00:07:53	00:12:47	00:07:25	00:13:40
S1A-L1 processing optimized (reprocessed 24.03.2017)	00:06:53	00:05:53	00:06:27	00:05:17
Total time from acquisition: best	00:02:12 + 00:06:53 = 00:09:05	00:02:12 + 00:05:53 = 00:08:05	00:02:12 + 00: 06:27 = 00:08:39	00:02:12 + 00: 05:17 = 00:07:29
Total time from acquisition: worst	00:04:16 + 00:07:53 = 00:12:09	00:04:16 + 00:12:47 = 00:17:03	00:04:16 + 00:07:25 = 00:11:41	00:04:16 + 00:13:40 = 00:17:56

used to deselect those objects. Afterwards data fusion between SAR-detected objects and automatic identification system (AIS) reported information is applied. AIS data are acquired for the requested imaging time and coverage via the AIS Fetcher, a real-time web interface based on HTTP protocol, which has been developed by DLR and JAKOTA Cruise Systems. After extracting AIS reports at imaging time and projecting the vessel positions according to the estimated Doppler shift a merging step between AIS reports and SAR detections takes place before generating the final product.

The fully automated derivation of wind direction from wind streaks on the ocean surface is currently task of research. As part of the SAINT toolbox SAR, this kind of product can be calculated using the CMOD5 algorithm. Beside the SAR image, a main wind direction is needed as an additional input parameter to avoid ambiguities. For this reason, a WRF model is used to provide a forecast especially for the scene region and acquisition time. The WRF model is calculated in advance using the reception planning information. Finally, SAINT produces the SAR derived wind product containing the wind direction and intensity (WD10).

The CWAVE algorithm adapted for Sentinel-1, also part of the SAINT toolbox, is applied to derive the significant wave height directly out of the SAR image. Although the processing chain supports the automated wave product generation, the content validation is still ongoing.

Table 5 shows the value-adding processing times during the EMSec campaign and a partly reprocessing on optimized hardware and software configuration. The implemented solution supports processing of all L2 products in parallel. The steps SAR image transformer, SAINT and in the vessel detection scenario the AISFetcher were executed in parallel followed by SDVA.

4.4 Dissemination

For dissemination, standard delivery methods FTP, SFTP as well as fast delivery via e-mail or web-mapping server are available. Within the EMSec project, the SFTP protocol was used to push the products to the real-time maritime situation awareness system (RMSAS), developed by AIRBUS. RMSAS uses an OGC web-mapping server solution to distribute the products to the human machine interface (HMI) developed by ATLAS.

As an example, Fig. 6 shows the different product layers available on the DLR web-mapping server which is comparable to RMSAS within the DLR maritime security web-mapping client.

The delivery to RMSAS via SFTP was not optimized; Table 6 shows the EMSec campaign results. Comparable deliveries to other servers showed a much better performance due to a better network performance on client/server site.

Table 5 Vessel detection durations EMSec campaign and partly optimized reprocessing

	2016-09-08T17:09:00–2016-09-08T17:09:32	2016-09-08T17:09:25–2016-09-08T17:09:50	2016-09-10T05:40:45–2016-09-10T05:41:17	2016-09-10T05:41:10–2016-09-10T05:41:32
SAR image transformer (EMSec campaign)	00:03:34	00:03:10	00:03:42	00:03:48
SAR image transformer (reprocessed 24.03.2017)	00:01:25	00:01:14	00:01:25	00:00:43
SAINT	00:00:34	00:00:32	00:00:36	00:00:46
AISFetcher	00:04:29	00:01:45	00:02:54	00:04:42
SDVA	00:08:11	00:02:12	00:03:35	00:04:59
Total time from acquisition: best	00:09:05 + 00:04:29 + 00:08:11 = 00:21:45	00:08:05 + 00:01:45 + 00:02:12 = 00:12:02	00:08:39 + 00:03:42 + 00:03:35 = 00:15:56	00:07:29 + 00:04:42 + 00:04:59 = 00:17:10
Total time from acquisition: worst	00:12:09 + 00:04:29 + 00:08:11 = 00:24:49	00:17:03 + 00:03:10 + 00:02:12 = 00:22:25	00:11:41 + 00:03:42 + 00:03:35 = 00:18:58	00:17:56 + 00:04:42 + 00:04:59 = 00:27:37

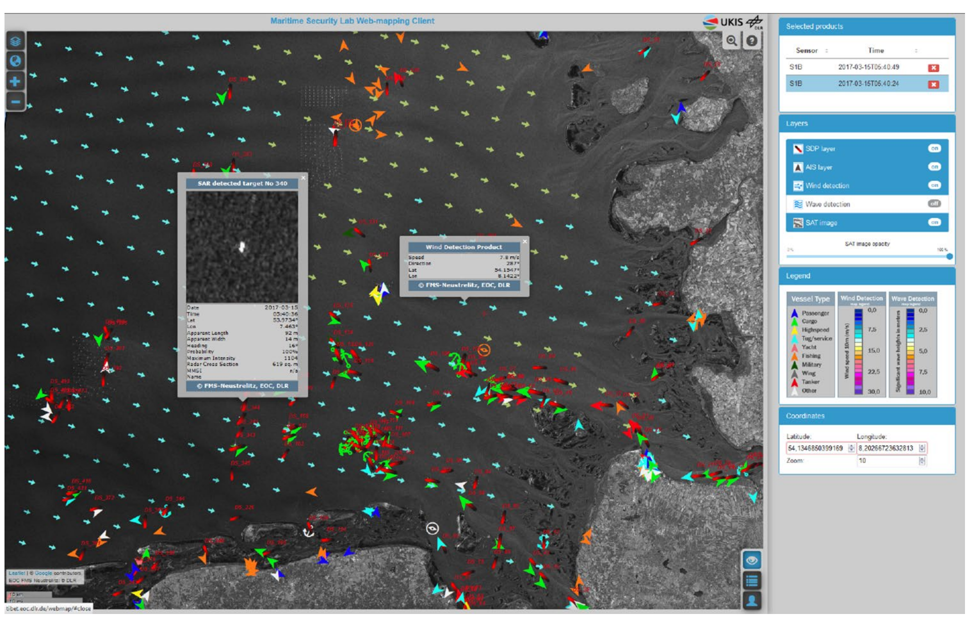

Fig. 6 Maritime security lab web-mapping client developed by DLR

Table 6 Value-adding durations EMSec campaign and partly optimized reprocessing

	S1A slice 2016-09-08T17:09:00–2016-09-08T17:09:32	S1A slice 2016-09-08T17:09:25–2016-09-08T17:09:50	S1A slice 2016-09-10T05:40:45–2016-09-10T05:41:17	S1A slice 2016-09-10T05:41:10–2016-09-10T05:41:32
SFTP upload	00:12:55	00:04:59	00:00:03	00:00:03
Total time from acquisition: best	00:21:45 + 00:12:55 = 00:34:40	00:12:02 + 00:04:59 = 00:17:01	00:15:56 + 00:00:03 = 00:15:56	00: 17:10 + 00:00:03 = 00:17:13
Total time from acquisition: worst	00:24:49 + 00:12:55 = 00:37:44	00:22:25 + 00:04:59 = 00:27:24	00:18:58 + 00:00:03 = 00:19:01	00:27:37 + 00:00:03 = 00:27:40

5 Conclusion

This paper discusses the development and the environmental setup of the reception and processing chain for the generation and validation of maritime information products derived from Sentinel-1 images. The implemented solution of reception chain generates ESA conform level 0 products in near real time. The proposed configuration of the experimental platform represents a fully automated Sentinel-1 SAR image processing chain supplemented by the value-adding processing for ship, wind and wave detection developed at DLR. In addition, the concept of hardware virtualization for multi mission support could be successfully demonstrated.

The NRT requirement of delivering the products within 15 min could not be reached at this time. The total time from acquisition until delivery showed a high variability reaching from 15 min 56 s up to 37 min 44 s in the worst case. Further research and development is needed to fulfil those requirements in an operational manner. First optimizations could already improve processing performance, nevertheless, the delivery component and the AIS fetching have to be redesigned.

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