New Algorithm and Processor for Obtaining Maritime Information from Sentinel-1 Radar Imagery for Near Real Time Services

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DLR, Maritime Safety and Security Lab Bremen
DLR, National Ground Segment, Neustrelitz

- Examples and concept
- Background
- Model Functions Tuning
- NRT implementation
- Outlook
The new empirical algorithm allows estimation of total integrated sea state parameters and also partial integrated parameters including:

- significant wave height $H_s$,
- first moment wave period $T_{m1}$,
- second moment period $T_{m2}$,
- mean period $T_m$,
- like swell (dominant and secondary) and windsea wave heights $S_{w1}$, $S_{w2}$, $S_{ww}$,
- windsea period $T_w$.

The algorithm allows processing of different S1 Synthetic Aperture Radar (SAR) modes with different resolution into sea state fields:

- For Sentinel-1 S1 Wave Mode (WV), acquires multiple vignettes with an extent of ~20km×20km and each displaced by 100 km along satellite tracks in open ocean (global) with relatively high spatial resolution of ~4 m wave height can be estimated with accuracy of ~35cm. This is comparable with the accuracy of satellite altimetry and a new achievement for SAR based techniques.

- For Sentinel-1 Interferometric Wide Swath Mode (IW) covers area-strips of thousand kilometres of earth and ocean surface in coastal areas with a resolution of ~20m by sequences of multiple images with an approximate size of 200km×250km the accuracy of ~70cm.

The algorithm has been integrated into a prototype processor for Sentinel-1 SAR imagery. The DLR Ground Station Neustrelitz applies this prototype as part of a near real-time demonstrator MSA service.
1. Concept and Examples

2. Background

3. Model Functions, Tuning

4. NRT implementation

5. Outlook
1.1. Sentinel 1A, 1B  IW and WV Modes

**Sentinel-1A - 2014**
**Sentinel-1B - 2016**

- flight 704 km
- ground speed 6.8 km/s
- C-Band Radar with wavelength of 5.6 cm

**IW - Interferometric Wide Swath Mode**
- Coastal areas
- ~200 km × 250 km, ~35 m resolution, 10 m pixel
- GRDH: level-1 Ground Range Detected High-resolution products

**WV - Wave Mode**
- Ocean
- ~20 km × 20 km vignette each 100 km, ~5 m pixel
- SLC: Single Look Complex products

**iw**: 0.2 – 2 GB
~80 imagettes

**wv**: 3 – 15 GB
~80 imagettes

Image LandSat / Copernicus image: ESA/CC
1.2. New sea state processor S1 IW and WV

New method allows estimating series of integrated sea state parameters for both S1 WV (tracks) and IW (fields).

<table>
<thead>
<tr>
<th></th>
<th>SwH</th>
<th>Tm0</th>
<th>Tm1</th>
<th>Tm2</th>
<th>Sw1</th>
<th>Sw2</th>
<th>Sww</th>
<th>Tw</th>
</tr>
</thead>
<tbody>
<tr>
<td>S1 IW</td>
<td>63cm</td>
<td>1.15 sec</td>
<td>0.95 sec</td>
<td>0.79 sec</td>
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</tr>
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~60 overflight per day

Total integrated partial integrated
1.3. Concept: maritime situation awareness (MSA) for safe navigation

Integrated Processor for MSA: Near Real Time services (NRT)

DLR Maritime safety and security Lab Bremen

- Algorithms and processor development
- Fast, full automatic raster processing
- Layer processing

Coupled processor

- SAR image
- Coastline
- Surface wind
- Sea state
- Ship detection
- Oil detection
- Ice classification

Information from different layers helps each other and improve accuracy.

DLR Ground Station Neustrelitz (NZ)
NRT chain

Operationally:
- Sea state
- Wind
- Ships
- Icebergs

FUSION with data from other sources:
+ Measurements
+ Forecast
+ Ship AIS

Map client, ftp, E-mail
1.4. Sea State Processor for Maritime Situation Awareness

**NRT services: SENTINEL-1 waves, wind, ships**

**Raster:** 6 km, **Subscenes:** 2.5kmx2.5km

Different product layers available on the GeoServer in NRT and displayed on the Maritime Security Web-mapping Client.

Screenshot of the NRT Service
Hurricane „Irma“ 2017 (S-1)

New techniques and algorithms allow observation and validation of forecast models worldwide.

ESA news: Sentinel-1 sees through hurricanes

“…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.”
1.6. Support of a research cruise in Arctic Seas – navigation and routing

Arctic Sea, 05.01.2017

Processed in NRT
And send to research vessel “Akademik Treshnikov” on Antarctic Circumnavigation
1.7. Following a storm in the Black Sea: 3 days (S-1)

Total Significant Wave Height | Black Sea storm 20-23.04.2017 | SENTINEL-1 SAR C-band IW mode | processing mesh 6km x 6km

Descending path ~03:00 UTC

2017-04-20

Modelled storm peak ~90 km northerly

2017-04-21

114-m long cargo vessel with 12 crew sinks

2017-04-22

Raging Black Sea storm splits cargo ship in half
1. Concept and Examples

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2.1. Background: Objective

1. Basic Research - Functions & Algorithms
   SAR Imaging Mechanism: Geophysical Model Function (GMF): development and adoption
   - mathematic investigations
   - for practical applications

2. Software Development - Prototype & NRT Processors
   - implementation of GMF into Processors (SSP) prototype
   - implementation of SSP into processing chain for NRT services,

3. Processing and Results Analysis - What do we learn?
   Forecasts improvement and geophysics
   - statistics, local distributions
   - extreme events
   - assessments, danger localization, follow up and validation of forecast models (e.g. DWD)
2.2. Satellite Radar Imagery

Imaging of sea surface by radar:
- Smooth surface: no radar echo
- Specular component: slightly rough
- Very diffuse scattering: very rough, strong radar echo

Active sensor:
- Radar
- Optic

Map showing Rottenest Island in Western Australia.
2.3. Sea surface by different sensors

<table>
<thead>
<tr>
<th>Hs ~ 0.5m</th>
<th>Hs ~ 4m</th>
<th>Hs ~ 7m</th>
</tr>
</thead>
<tbody>
<tr>
<td>calm (swell)</td>
<td>moderate</td>
<td>strong</td>
</tr>
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</table>

 SENTINEL S-1 IW VV 10m Pixel, C-band
 TerraSAR-X StripMap VV 1.25m Pixel, X-band

Principle wind and sea state estimation

- averaged value
- SAR subscene
- Local wind
- Local waves
- Compatibility

Variance, FFT, GLCM

DLR
2.4. Artefacts pre-filtering

Task №1 - removing artefacts before analysis
- Sand banks
- Wave breaking
- Ships, Buoys, Wind farms
- Current fronts, ship wakes

Without pre-filtering estimated $H_s$ can > 10 times overestimate real value

3 STEPS
- Removing before analysis
- Function correction terms
- Control results
1. Concept and Examples
2. Background
3. Model Functions, Tuning
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# 3.1. Empirical Function and Parameter (SAR features)

**Function:** linear regression

\[ p_i = \sum_{n=0}^{N} A_n S_n \]

**Solution:** quadratic minimization using SVD (singular value decomposition) – optimal solution for a linear system

<table>
<thead>
<tr>
<th>SAR features type</th>
<th>Parameters first order</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Subscene properties and statistics</td>
<td>NRCS, Norm.-variance, skewness, kurtosis, + 5 additional parameters (will be published later)</td>
</tr>
<tr>
<td>2. Geophysical</td>
<td>Wind</td>
</tr>
<tr>
<td>3. GLCM (grey level co-occurrence matrix)</td>
<td>GLCM-mean, variance, entropy, correlation, homogeneity, contrast, dissimilarity, energy</td>
</tr>
<tr>
<td>4. Spectral-A</td>
<td>using spectral bins for different wavelengths Goda-parameter, Longuet-Higgins-parameter, + 5 additional parameters (will be published later)</td>
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<tr>
<td>5. Spectral-B</td>
<td>20 parameter by using orthonormal functions, cutoff by ACF (autocorrelation function)</td>
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3.2. Model Function

Linear regression Empirical Model Function (EMF) bases on parameters
- Image spectral parameters (20 par.)
- Local wind information, variance
- GLCM (Grey Level Co-Currence Matrix) parameters (Entropy, Homogeneity, Contrast, Dissimilarity, etc.)

Model Function tuning – combination of spectral and Image feature analysis + filters
- tuning by minimizing root mean squared error RMSE
- number of used features improve results

Example for collocations of individual S1 IW images with measurement stations in the North Sea, Eastern Baltics and North Atlantics used for algorithm tuning and validation.
3.3. Model Function – example features estimation

Linear regression Empirical Model Function (EMF) bases on parameters
- Image spectral parameters (20 par.)
- Local wind information, variance
- GLCM (Grey Level Co-Currence Matrix) parameters (Entropy, Homogeneity, Contrast, Dissimilarity, etc.)

\[ W = a_0 + \sum_{i=1}^{n_a} a_i s_i \]
3.4. New sea state processor 2020: SWH improvement IW

New processor 2020

- New function with new parameters
- New S1 IW acquisition (~ 2000) + new validation data - CMEMS model results with ~5km resolution worldwide ([/WW3 ~30km resolution])
- New software

- Higher accuracy for SWH + additional parameters

SAINT Sea State Processor SSP for sea state fields estimation

SSP V1-2017 ~ 1000 S1-IW

Original SSP
- Created with ~ 1000 S1 IW and WWI model

SSP V1-2017 ~ 1000 S1-IW

SSP improved 2020

Hurricane Irma “eye” in WW3 model Hs~2.5m
3.5. Accuracy: new sea state processor S1 IW and WV

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Error distribution SWH S1 IW

Error distribution SWH S1 WV
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4.1. Sea State Processor for SENTINEL-1 and TerraSAR-X at Ground Station NZ

Sea State Functions

- Spectral parameters
- Local wind
- GLCM parameters

Sea State Processor

-step 1: TerraSAR-X/SENTINEL-1 IW image reading, calibrating
  - sub-image(s) selection
  - filtering outliers e.g. ships

-step 2: filtering surface films signatures, e.g. oil, ship wakes
  - Image structure analysis GLCM parameters
  - resampling, smoothing for SENTINEL-1 IW

-step 3: XMOD-2/CMOD local wind
  - signal intensity I
  - signal modulation $\alpha_s$
  - FFT, image spectra IS

-step 4: integrated energy $E_p$, spectra parameters, noise level, etc.
  - total of 24 parameters

-step 5: Function XWAVE_C / CWAVE_S1-IW

-step 6: control results
  - Results: total $H_s$, $T_p$, $T_g$

Outputs: data-files (lon, lat, values), graphs (gif, png), Google Earth (kmz), special points

NRT chain in Neustrelitz NZ
4.2. Acquisitions for a location S1 IW
Ground Station Neustrelitz, acquisition circle for Sentinel-1, 5 degree elevation. Inside of this area the data can be transferred from satellites to ground station directly after acquisition, without delay, for NRT processing.
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Example S1 IW (2): Atlantic - Storm

Sequences of 12 S1-IW images, North Atlantic with Hs of ~9 m coverage ~250 km × 2200 km, Raster 3 km (60 × 80 = 4800 subscenes/image).