

Sea State Parameters from Sentinel-1 SAR

Andrey Pleskachevsky
Björn Tings

German Aerospace Center (DLR)
Maritime Safety and Security Lab, Bremen

1. Overview
2. Actual progress
3. Storing results – *.txt / *.nc
4. Sea State processor and Methodology
5. Ground Truth, Training/Validation/Cross-Validation
6. Summary

Progress since last meeting:

- SWH S1 wv accuracy improved 36 cm > 26 cm
- S1 wv archive processed 2014-2020 (~450 TB)
- Results stored using CCI format *.nc

1. Overview

2. Actual progress

3. Storing results – *.txt / *.nc

4. Sea State processor and Methodology

5. Ground Truth, Training/Validation/Cross-Validation

6. Summary

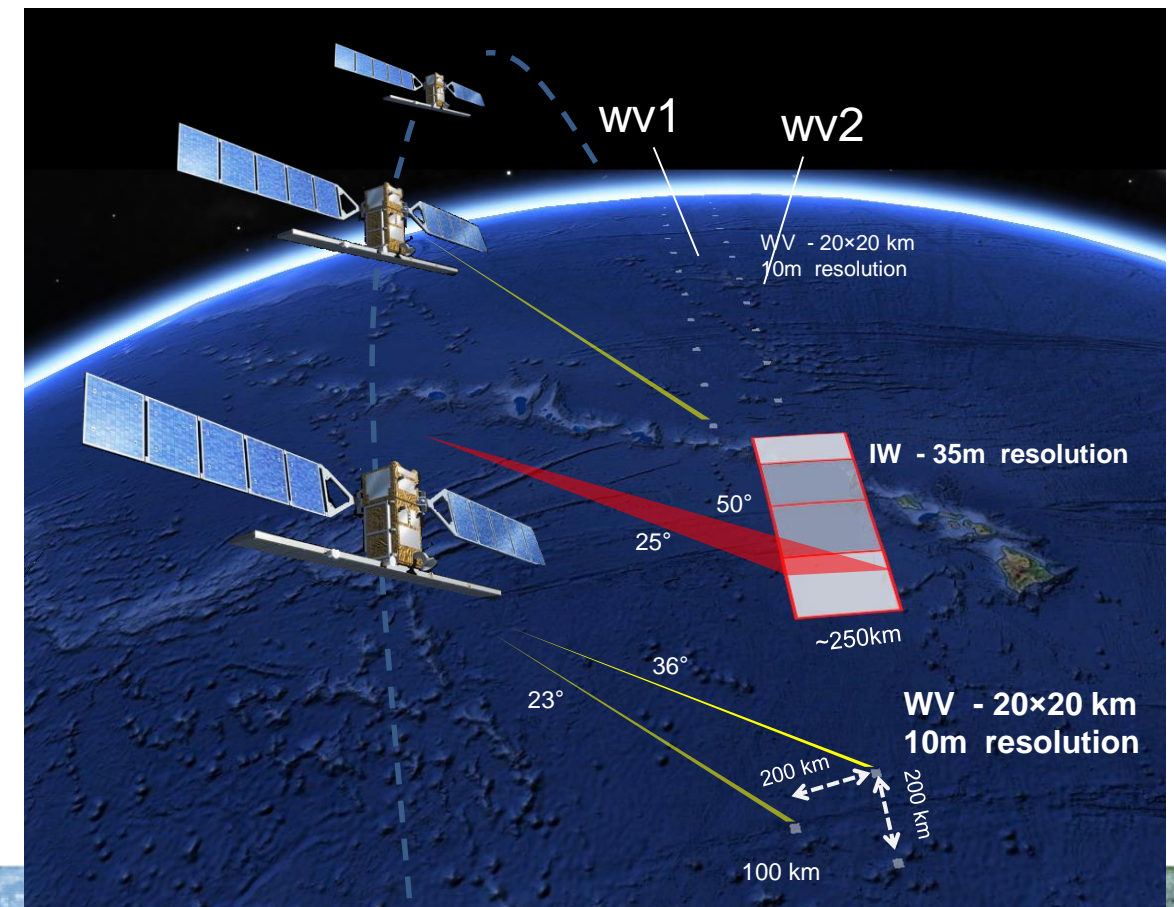
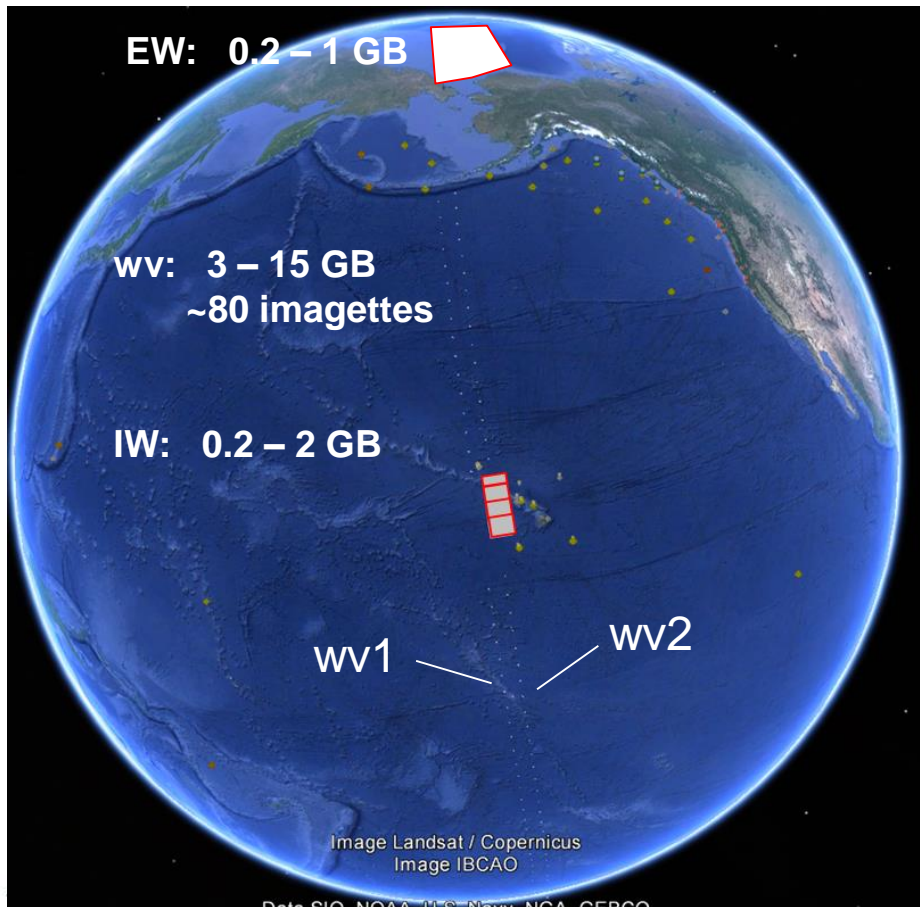
1.1. Sentinel 1A, 1B IW, WV, EW

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

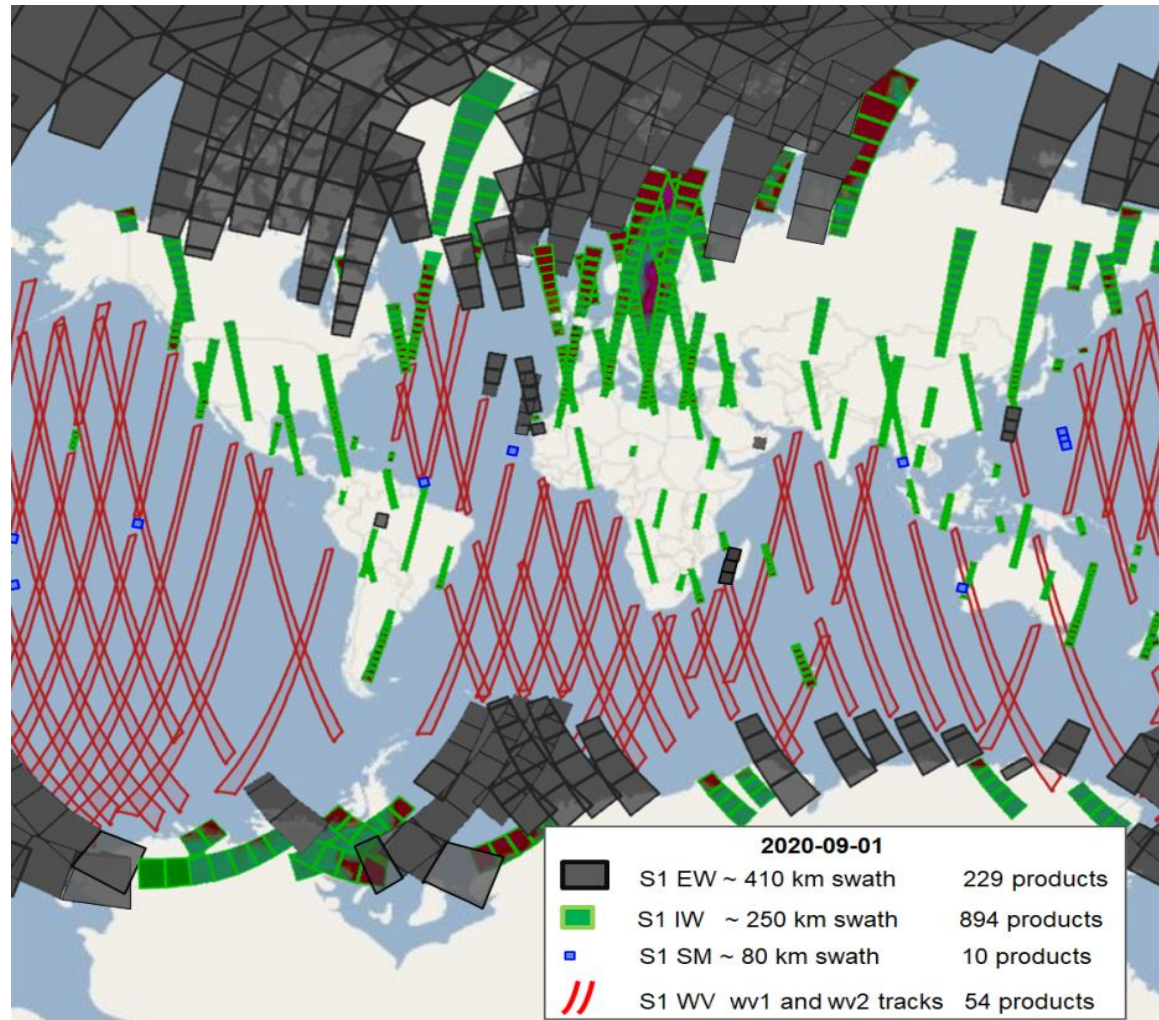
- ▶ flight 704 km
- ▶ ground speed 6.8 km/s
- ▶ C-Band SAR wavelength of 5.6 cm

CCI SeaState

- ▶ **WV** - Wave Mode - **Ocean**
~ 20 km × 20 km vignette each 100 km, ~ 5m pixel SLC: Single Look Complex products
- ▶ **IW** - Interferometric Wide Swath Mode - **Coastal areas**
~ 200 km × 250 km, ~ 10m pixel GRDH: level-1 Ground Range Detected High-resolution products
- ▶ **EW** - Extra Wide - **Ocean, Polar regions**
~ 400 km × 400 km, ~40m pixel GRDH



1.2. Sentinel-1 acquisitions during one day and archive processing



Products value

wv (ID)	~ 5 GB (~250 GB/day, ~7.5 TB/month)
IW	~ 0.6 GB
EW	~ 0.4 GB

CCI wv processing workflow

- 1. Archive transfer and unzip** : Level-1 SLC >
 - ~ 3 days for a month ~ 7.5 TB
 - ~ 5 months for all 2014-2020
- 2. Processing** > SAR features and first guess swh
 - ~ 2 days for a month (30 processors á 3GHz)
- 3. Reprocessing** using machine learning technique (support vector machine (SVM))
 - ~ 2 days for all (30 processors á 3GHz)

Results wv

- > SWH RMSE (CMEMS) 24cm / 27cm (wv1/wv2)
- > *.txt and *.nc formats
- > ~ 1.5 GB all 2014-2020 archive

1. Overview

2. Actual progress – parameters / rmse

3. Storing results – *.txt / *.nc

4. Sea State processor and Methodology

5. Ground Truth, Training/Validation/Cross-Validation

6. Summary

2.1. Sea State Processor RMSE

SAR products, output and total **RMSE** (all sea state conditions) for **8 sea state parameters**

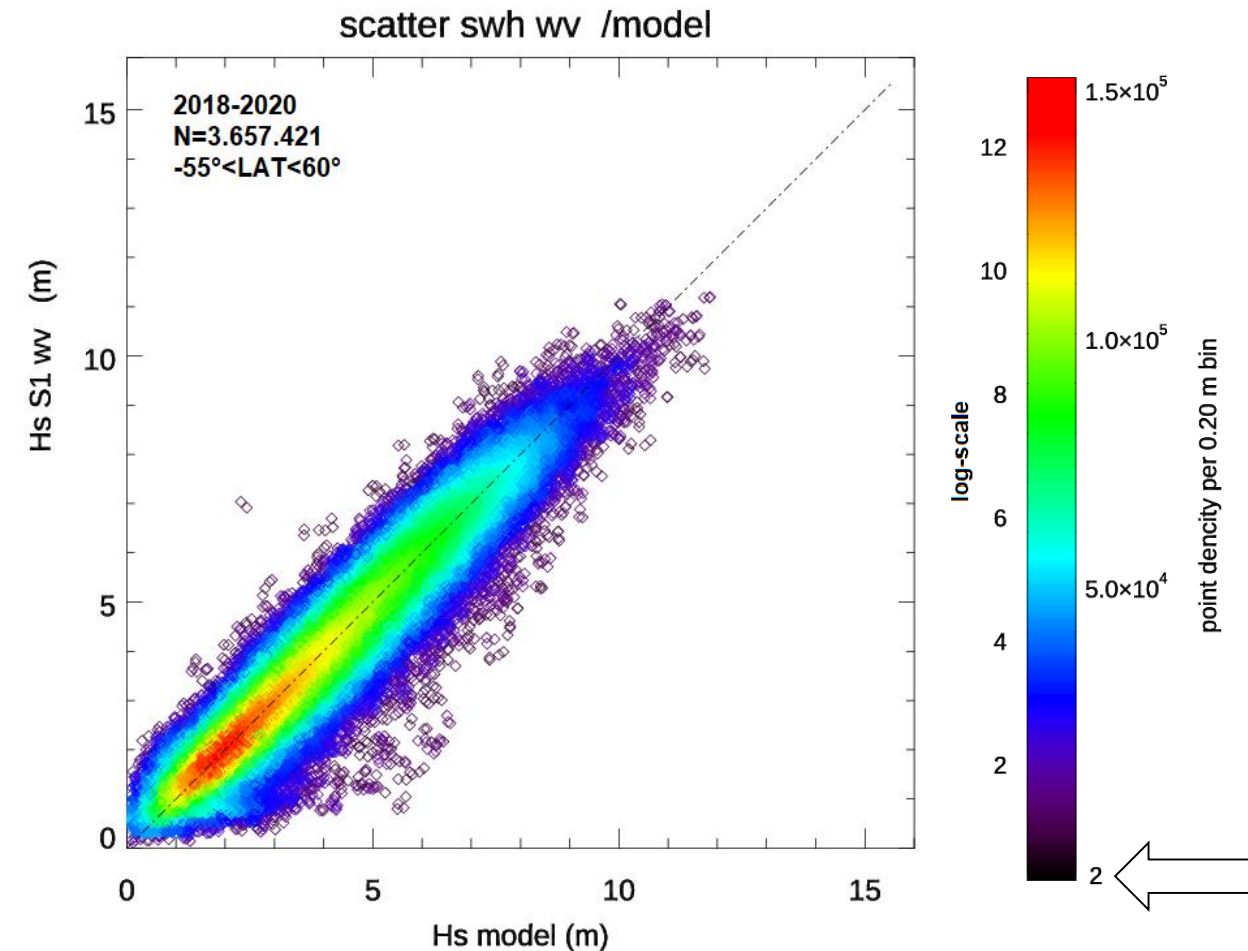
Sea State Parameter	Description	S1 WV
	products used >	SLC
	output type>	Along track (imagettes 20km×20km each 100 km)
SWH (m)	Total significant wave height	0.26 m
T_{m0} (s)	Mean wave period	0.62 m
T_{m1} (s)	First moment period	0.52 sec
T_{m2} (s)	Second moment period	0.45 sec
SW1 (m)	Dominant swell wave height	0.46 m
SW2 (m)	Secondary swell wave height	0.35 m
SWW (m)	Windsea wave height	0.41 m
T_{mw} (s)	Windsea wave period	0.62 sec

2018-2020 Validation CMEMS

~3.5 Mio collocations

RMSE wv1=0.245 m

RMSE sw1=0.273 m



2.2. SWH results

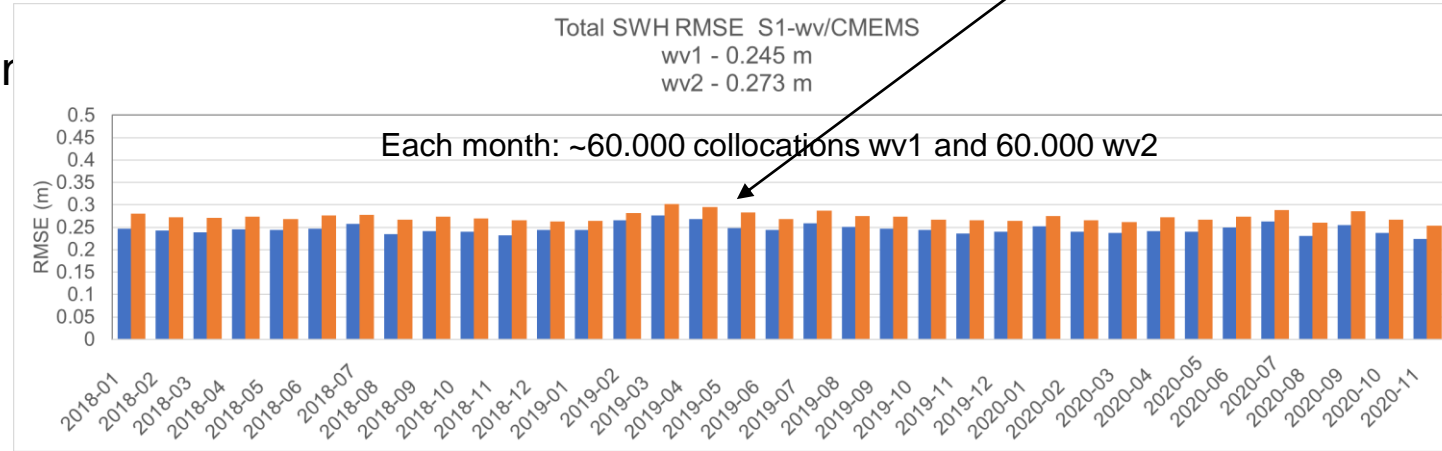
S1-wv archive 2014-2020 completely processed

2018-2020 Validation CMEMS (2016-2017 training)

3.8 Mio collocations
(-55° < LAT < 60°, 30km from land)

wv1: RMSE=0.245 m BIAS= -0.01cm
wv2: RMSE=0.273 m BIAS= -0.01cm

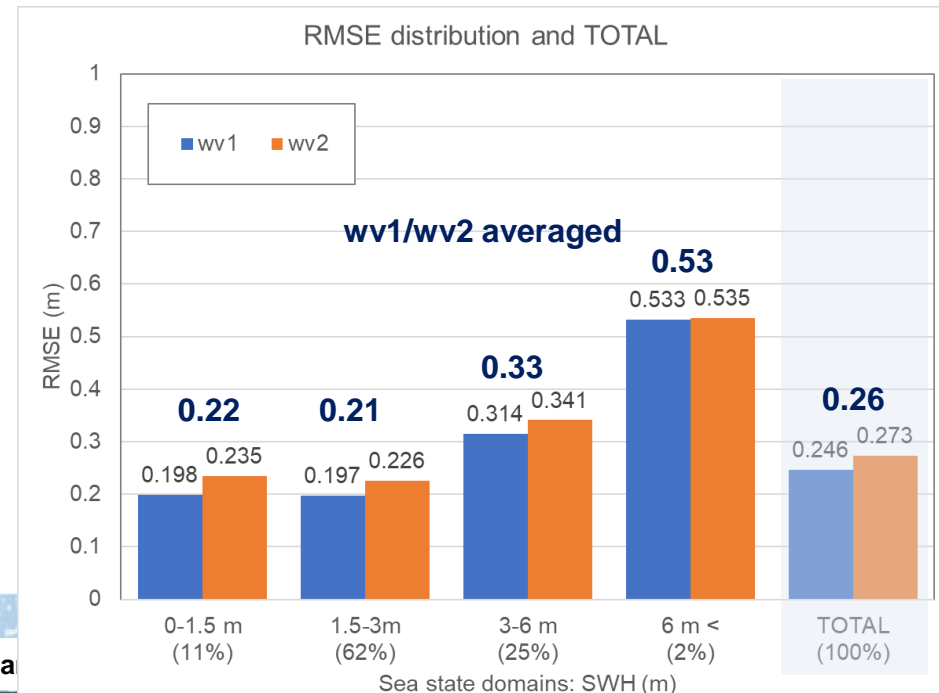
more storms with SWH>6m with rmse~53cm
SWH RMSE monthly



TABLES CCI N = 3806761 total data

wv-1	SWH (m)	RMSE(m)	no-seastate(%)	outliers(%)	BIAS(m)	N(model)	N(active)	SEA STATE(%)
0.0 - 1.5		0.19827	2.88504	0.90218	-0.10534	205058	199142	10.839
1.5 - 3.0		0.19708	0.55503	0.88519	-0.01802	1137603	1131289	60.131
3.0 - 6.0		0.31444	0.07190	0.94616	0.02326	507633	507268	26.832
6.0 <		0.53275	0.06494	1.11592	0.07605	41580	41553	2.198
TOTAL		0.24599	0.66717	0.90846	-0.01405	1891874	1879252	100.000

wv-2	SWH (m)	RMSE(m)	no-seastate(%)	outliers(%)	BIAS(m)	N(model)	N(active)	SEA STATE(%)
0.0 - 1.5		0.23474	5.02344	1.01722	-0.12596	207527	197102	10.838
1.5 - 3.0		0.22592	1.27410	0.89729	-0.00257	1151246	1136578	60.121
3.0 - 6.0		0.34105	0.21915	0.87699	0.04186	514258	513131	26.856
6.0 <		0.53523	0.08123	1.12768	0.06156	41856	41822	2.186
TOTAL		0.27279	1.37105	0.90987	-0.00196	1914887	1888633	100.000



1. Overview
2. Actual progress – parameters / rmse
- 3. Storing results – *.txt / *.nc**
4. Processed data
5. Sea State processor and Methodology
6. Ground Truth, Training/Validation/Cross-Validation

3.2. Results: PRODUCT_ID.txt and PRODUCT_ID.nc

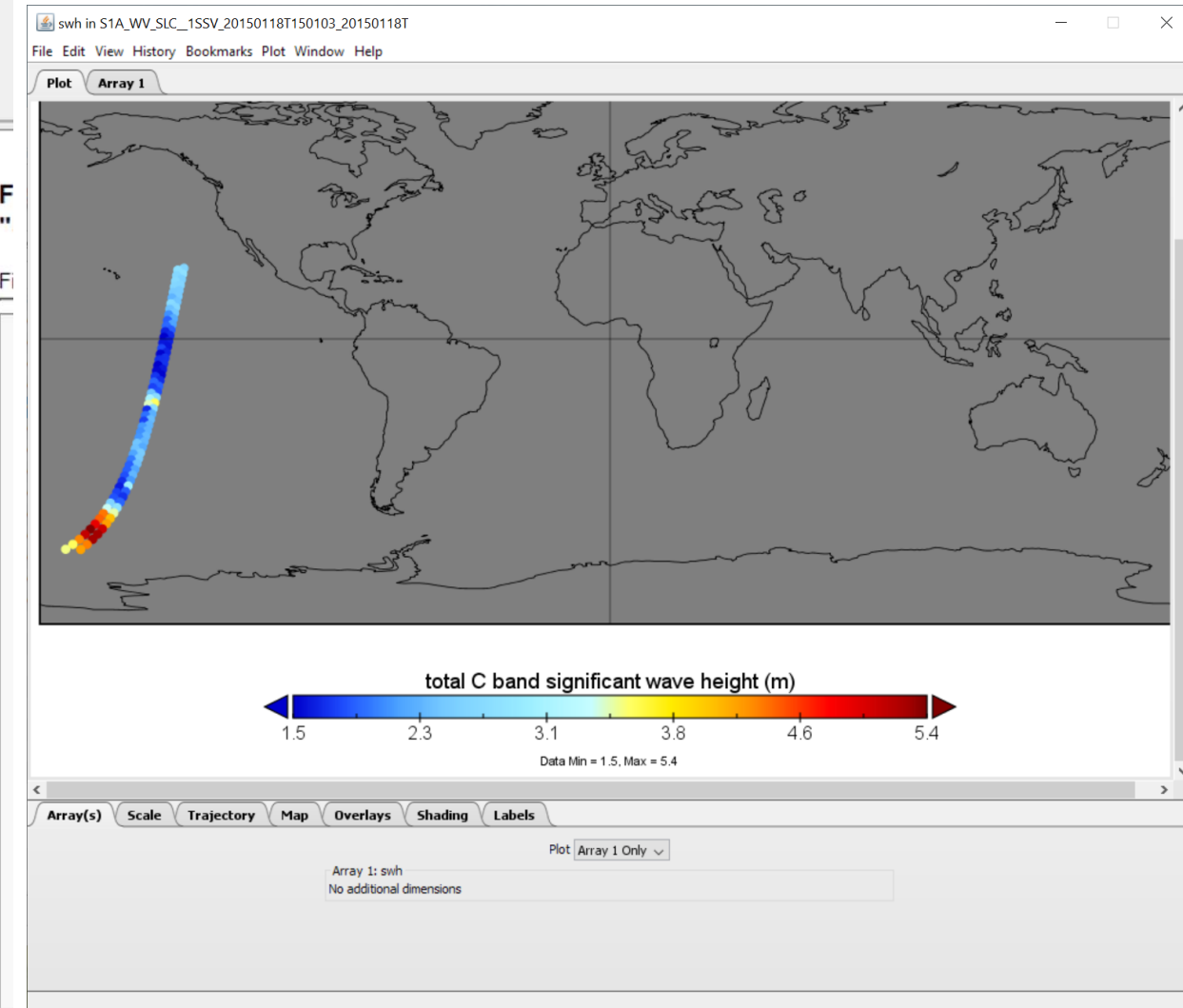
Panoply: Panoply — Sources

File Edit View History Bookmarks Plot Window Help

Datasets Catalogs Bookmarks

Name	Long Name	Type
▼ S1A_WV_SLC_1SSH_20150104T1339...	ESA CCI Sea State L2P derived from Sentinel-1...	Local File
lat	latitude	1D
lon	longitude	1D
swell_swh_primary	C band Dominant swell wave height	GeoTraj
swell_swh_secondary	C band Secondary swell wave height	GeoTraj
swh	total C band significant wave height	GeoTraj
swh_quality	quality of C band SAR significant wave height ...	GeoTraj
swh_rejection_flags	consolidated Significant Wave height quality flags	GeoTraj
swh_uncertainty	best estimate of significant wave height stand...	GeoTraj
time	time	1D
Tm0	C band Mean wave period	GeoTraj
Tm1	C band First moment period	GeoTraj
Tm2	C band Second moment period	GeoTraj
windwave_period	C band Windsea wave period	GeoTraj
windwave_swh	C band Windsea wave height	GeoTraj

Show: Plottable variables

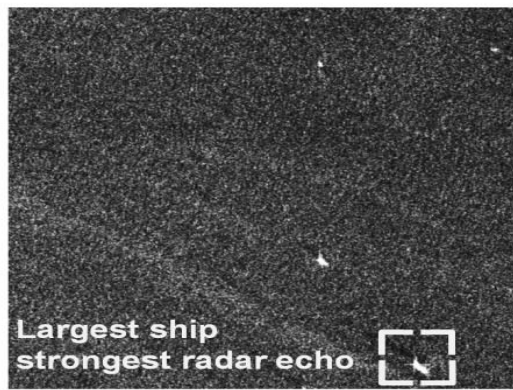


1. Overview
2. Actual progress – parameters / rmse
3. Storing results – *.txt / *.nc
- 4. Sea State processor and Methodology**
5. Ground Truth, Training/Validation/Cross-Validation
6. Summary

4.1. Sea State Processor for SENTINEL-1 and TerraSAR-X

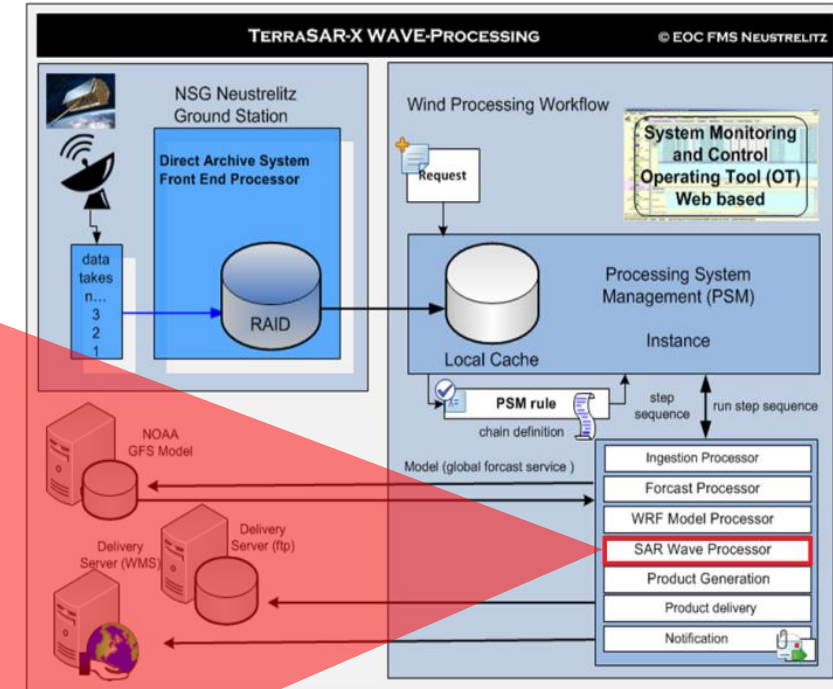
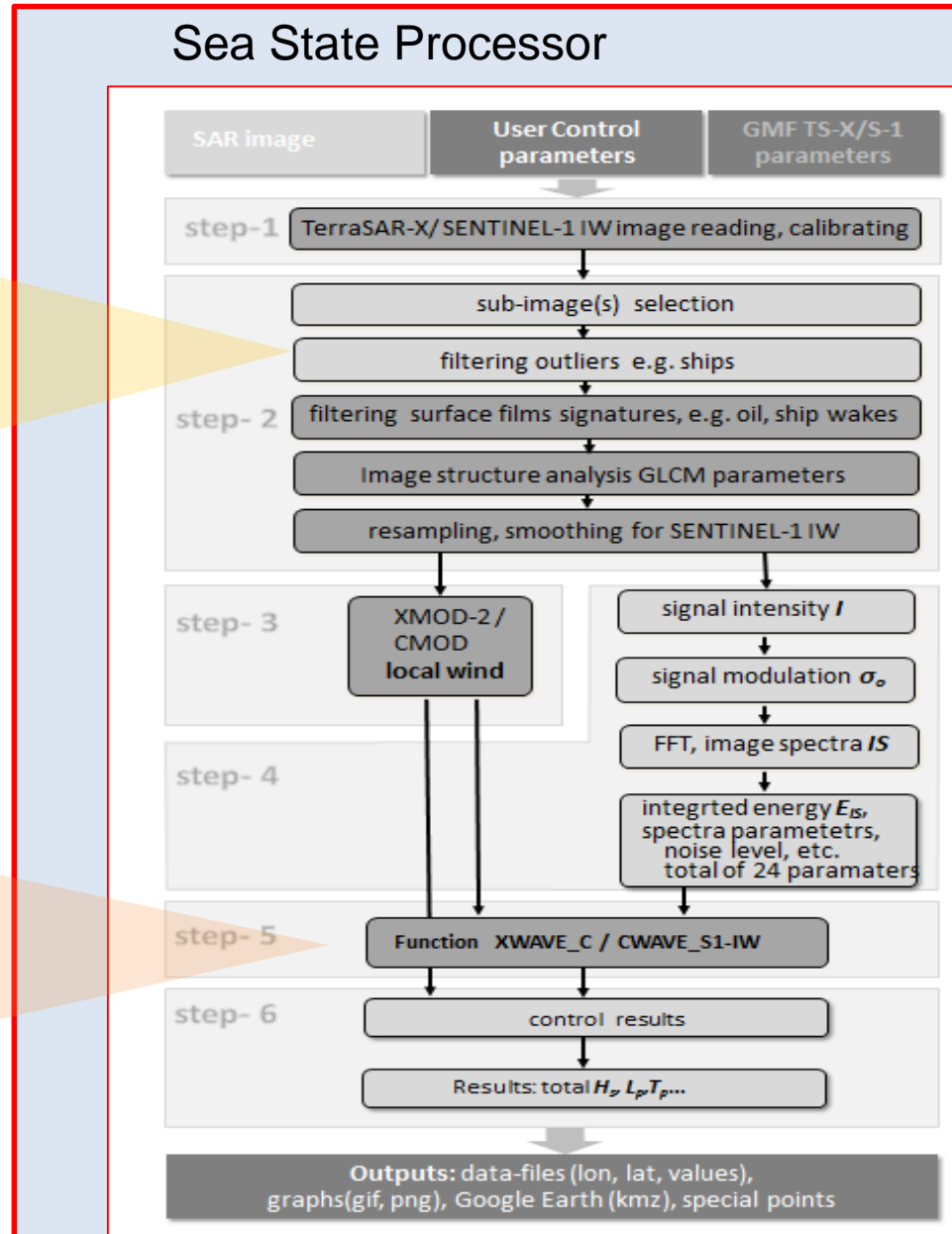
Infrastructure developed

artefact pre-filtering



Sea State Functions
TerraSAR-X
Sentinel-1

- Spectral parameters
- Local wind
- GLCM parameters



NRT chain in Neustrelitz

Daily NRT service for German NRT waters: eastern-North Sea and western Baltic S1 IW

<https://mariss.eoc.dlr.de>

4.2. General methodology work flow

2 stages: based on linear regression and machine learning

SAR Archive + Ground Truth Data (different hindcast model + in-situ measurements/buoys)

SAR Scene

SAR Sub-scene (9 subscenes for wv, filtered valid values > mean)

SAR features (5 groups, 60 first order, 60 second order – 120 features)

Empirical Mathematical Function (EMF) based on linear regression (First Guess Solution (FGS))

Improved sea state parameters using machine learning (support vector machine (SVM) technique)

4.3. SAR features used

1 km

Sentinel-1 WV
SAR imagette (vignette) 20 km × 20 km

4.3. SAR features used

SAR features type

SAR features first order

1. Subscene properties and statistics

NRCS, Norm.-variance, skewness, kurtosis, incidence-angle

2. Geophysical

Wind (CMOD, XMOD)

3. GLCM (grey level co-occurrence matrix)

GLCM-mean, variance, entropy, correlation, homogeneity, contrast, dissimilarity, energy

4. Spectral-A

using spectral bins for different wavelengths

Goda-parameter, Longuet-Higgins-parameter,
+ 5 additional parameters

5. Spectral-B

20 parameter by using orthonormal functions,
cutoff by ACF (autocorrelation function)

60 features first order, 60 features second order (combinations) – 120 features

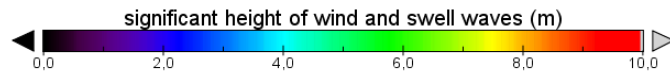
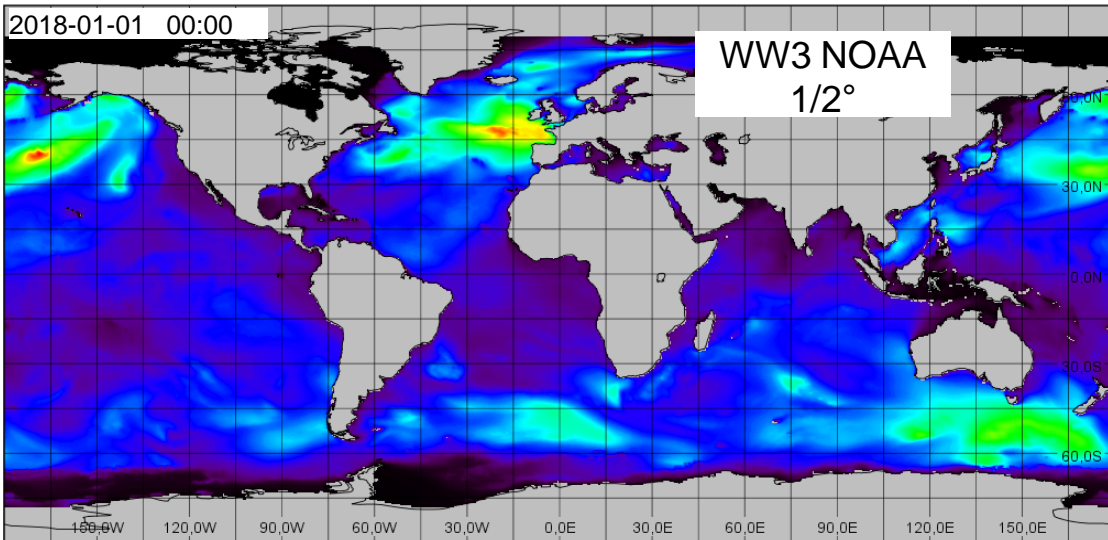
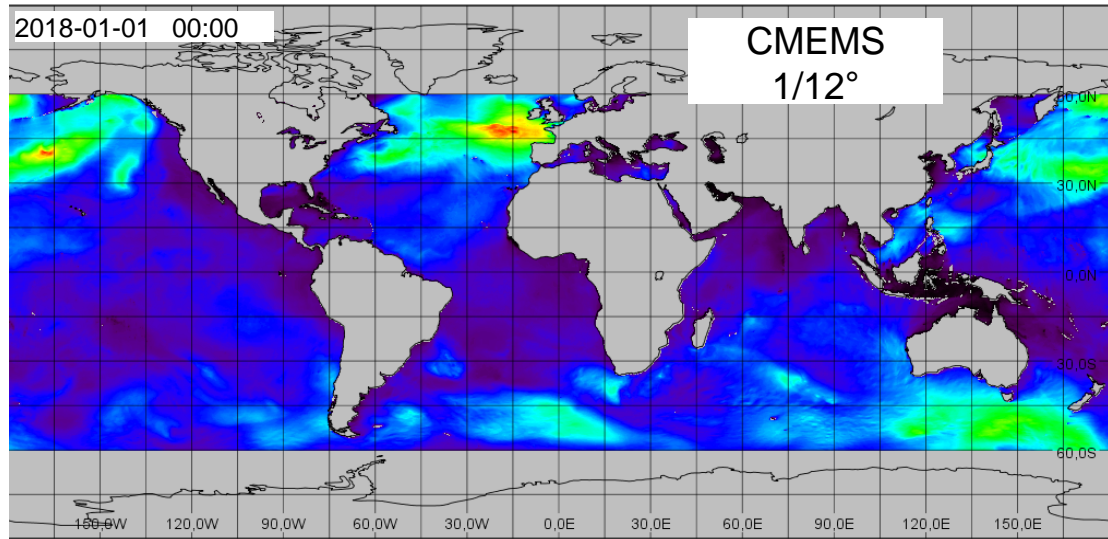
Black: features of standard CWAVE (Stellen-Schulzfleth 2006) and used by Stopa 2017, Li 2020

Blue: additional features introduced and used by DLR for S1 IW,EW, WV and TerraSAR-X SM/SL

1. Overview
2. Actual progress – parameters / rmse
3. Storing results – *.txt / *.nc
4. Sea State processor and Methodology
- 5. Ground Truth, Training/Validation/Cross-Validation**
6. Summary

5.1. Hindcast data: two independent models CMEMS and WW3-NOAA

Spectral significant wave height (Hm0)



model collocations for buoy-located S1 WV orbits:

~90 orbits

~ 6000/6000 imageries ww1/ww2 per month

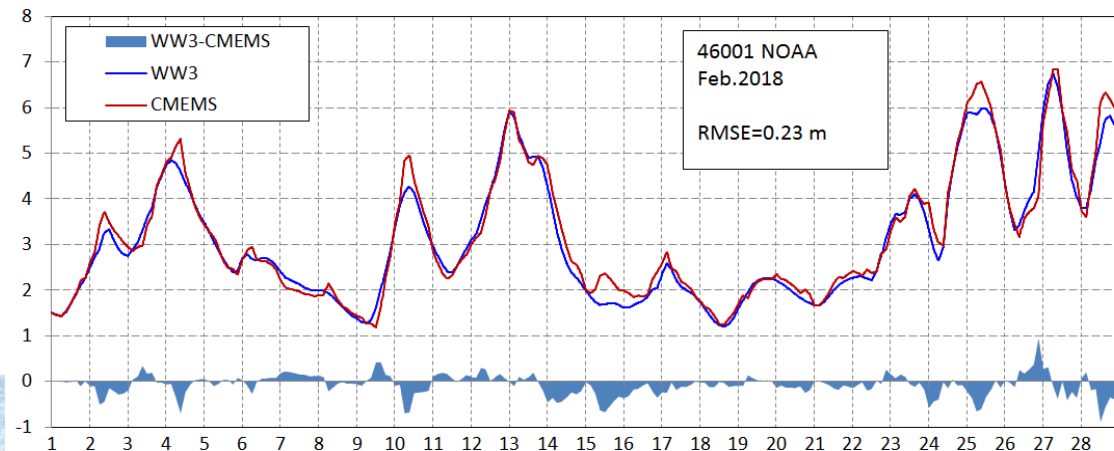
Conditions for algorithms training:

Latitude: $-60^\circ < \text{LAT} < 60^\circ$

Comparison WW3 and CMEMS (at position NDBC 46001)

Temporary: 3h output → 10min interpolated

Spatially: WW3 on 0.5deg → 0.25deg

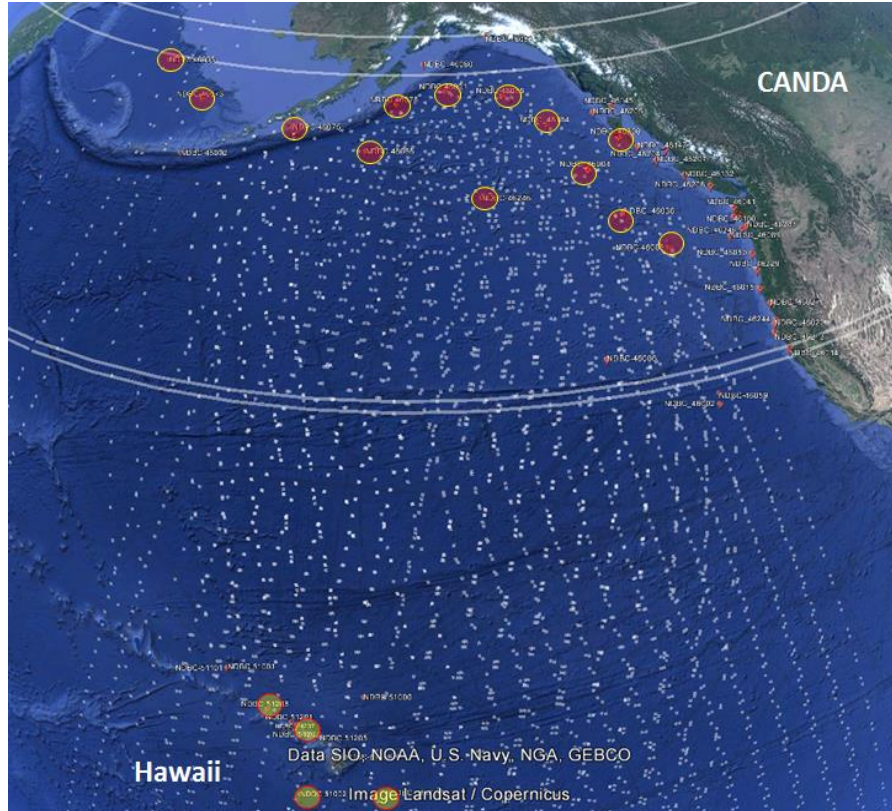


5.2. In-situ data - collocated NOAA buoys/orbits

61 active buoy deliver SWH and collocated under 50km with S1 wv

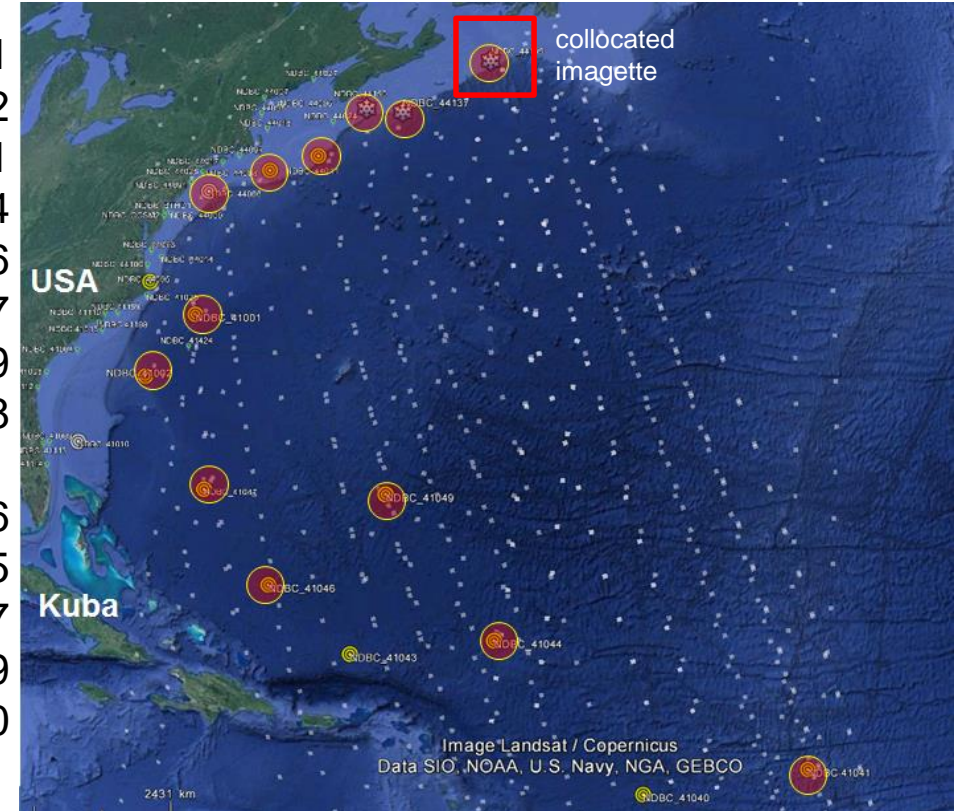
Alaska, Canada (groop-1)

- 46001
- 46004
- 46005
- 46035
- 46036
- 46066
- 46073
- 46075
- 46078
- 46085
- 46184
- 46208
- 46246



Atlantic (groop-3)

- 41001
- 41002
- 41041
- 41044
- 41046
- 41047
- 41049
- 44008
- 44011
- 44066
- 44095
- 44137
- 44139
- 44150

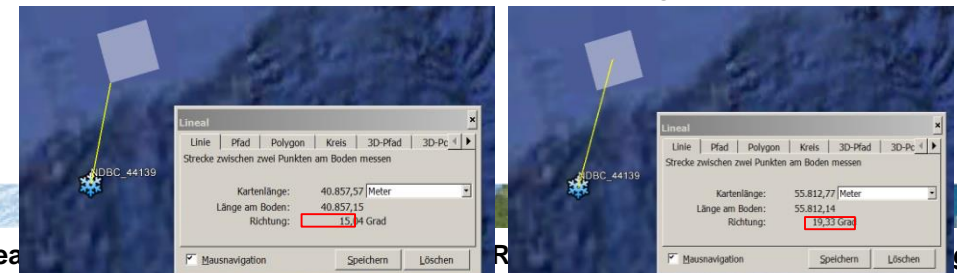


Hawaii (groop-2)

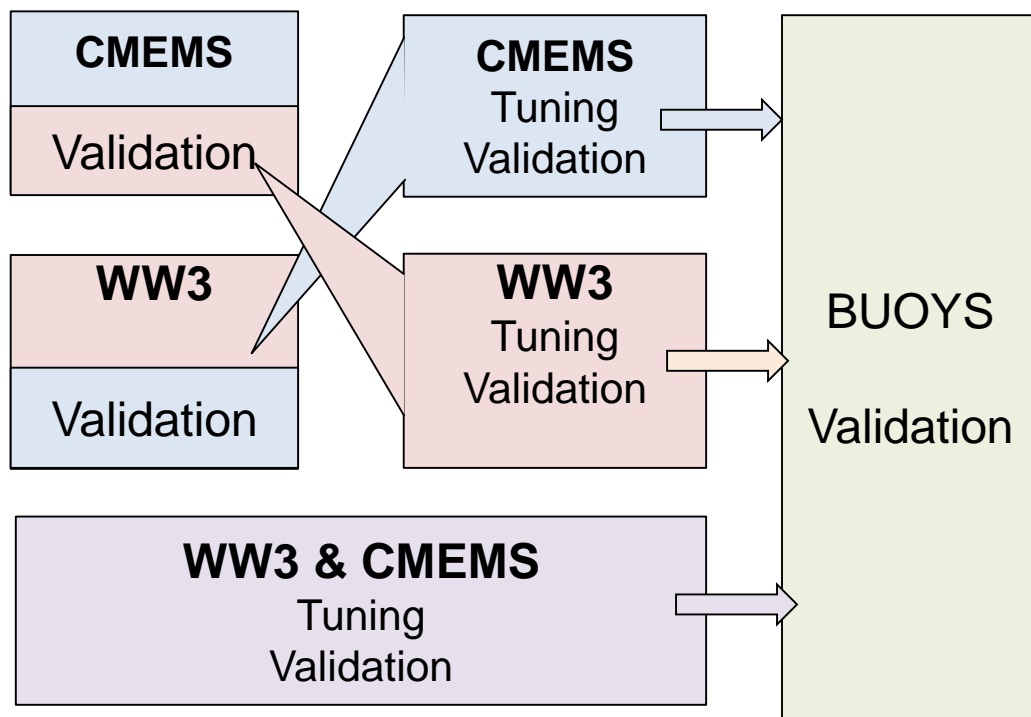
- 51002
- 51004
- 51202
- 51208



Collocation < 50km – < 65 km from imagette center



5.3. Cross validation SWH: two models and NDBC buoys



wv1 / wv2 RMSE (m)

TUNING DATA	VALIDATION DATA		
	CMEMS	WW3	BUOYS
CMEMS	0.33 / 0.38	0.35 / 0.40	0.42 / 0.44
WW3	0.34 / 0.39	0.34 / 0.39	0.44 / 0.46
WW3 & CMEMS	0.34 / 0.39		0.43 / 0.45

5.4. Machine Learning Training and Validation Procedure

Support vector machine (SVM) method > ThunderSVM
function type: epsilon-SVR kerneltype: radial basis f

1. Training hyper parameters

Training data: 2016-06 – 2017-05 ~500.000 s

Testing data: 2017-06 – 2017-12 ~300.000 s

2. Training model

Training data: 2016-06 – 2017-05
+ high sea > 4m 2017-06 – 2017-12 ~600.000

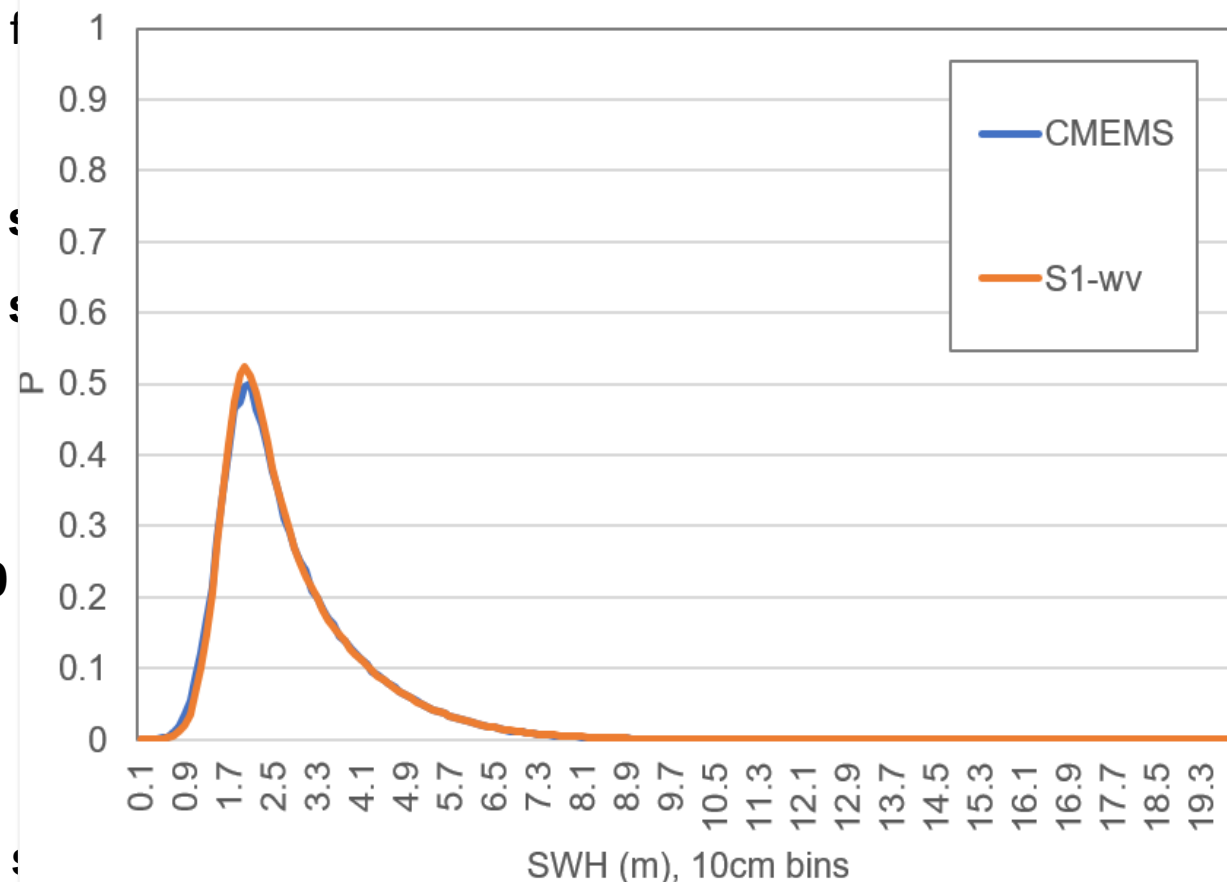
3. Validation (CMEMS)

2018-01 – 2020-12 ~1.800.000 s

4. Validation (NDBC)

2017-01 – 2019-12 3.000 collocations, RMSE 41 cm

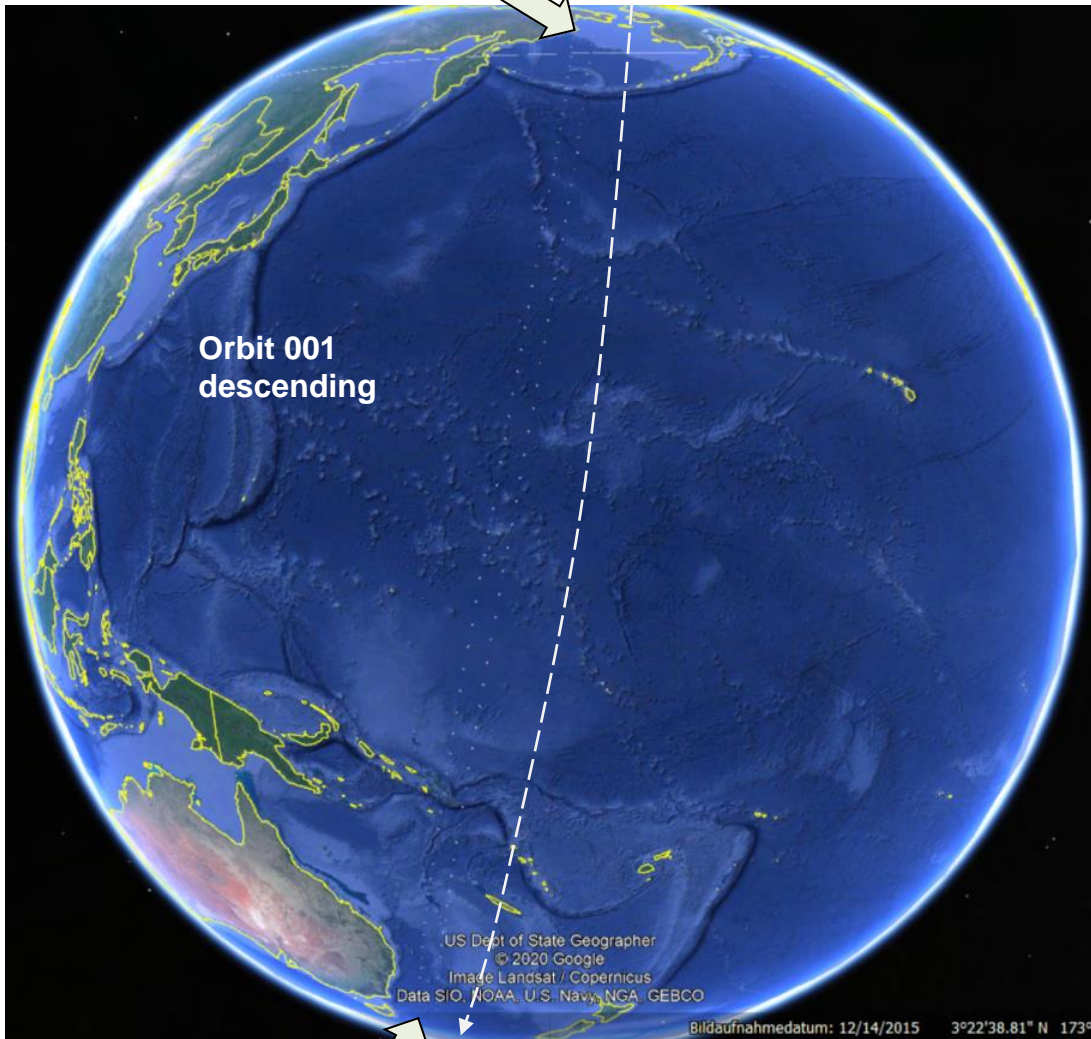
Histogramm build using 10cm bins: CMEMS and S1-wv



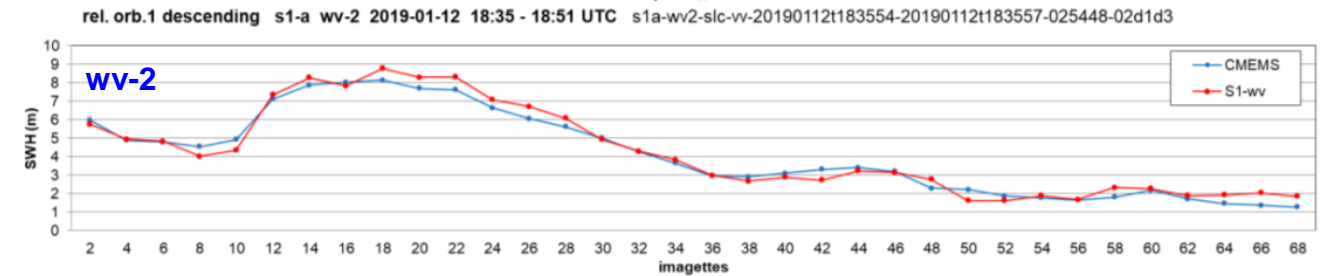
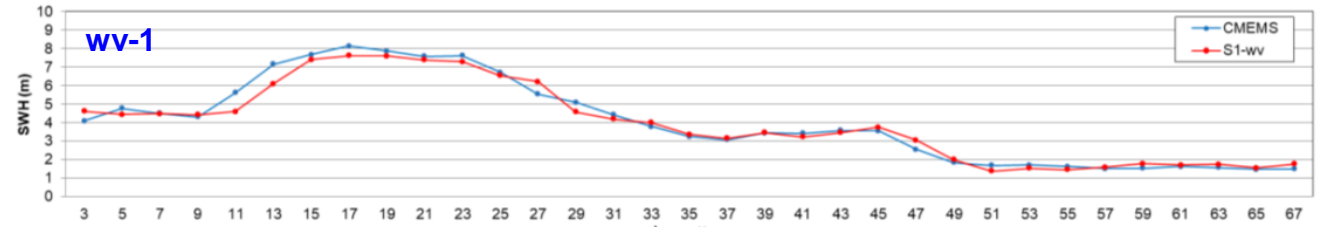
5.5. Along track sample

2 examples orbit N1 (descending, Pacific) 15 products/3months

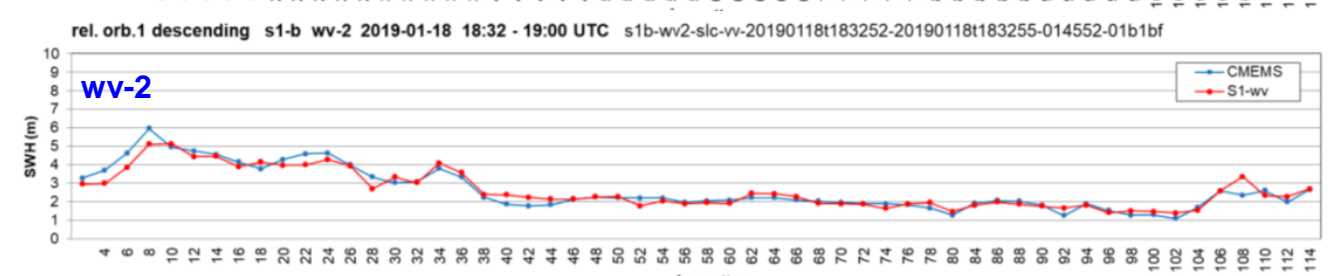
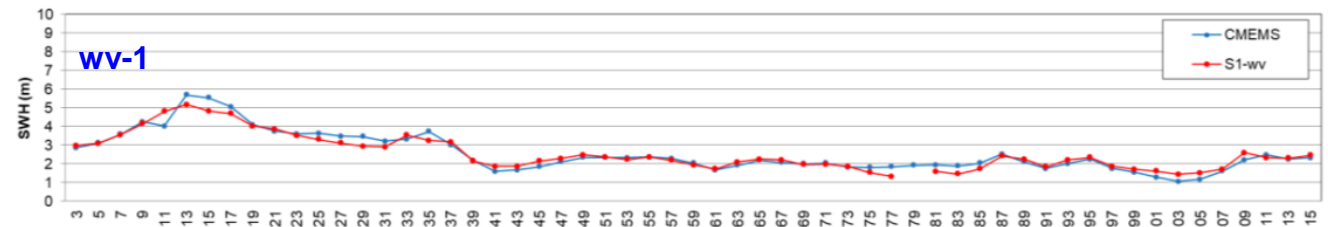
start



2019-01-12 S1A_WV_SLC_1SSV_20190112T183525_20190112T185149_025448_02D1D3_7A86
rel. orb.1 descending s1-a wv-1 2019-01-12 18:35 - 18:51 UTC s1a-wv1-slc-w-20190112t183554-20190112t183557-025448-02d1d3



2019-01-18 S1B_WV_SLC_1SSV_20190118T183208_20190118T190015_014552_01B1BF_F3EF
rel. orb.1 descending s1-b wv-1 2019-01-18 18:32 - 19:00 UTC s1b-wv1-slc-w-20190118t183252-20190118t183255-014552-01b1bf

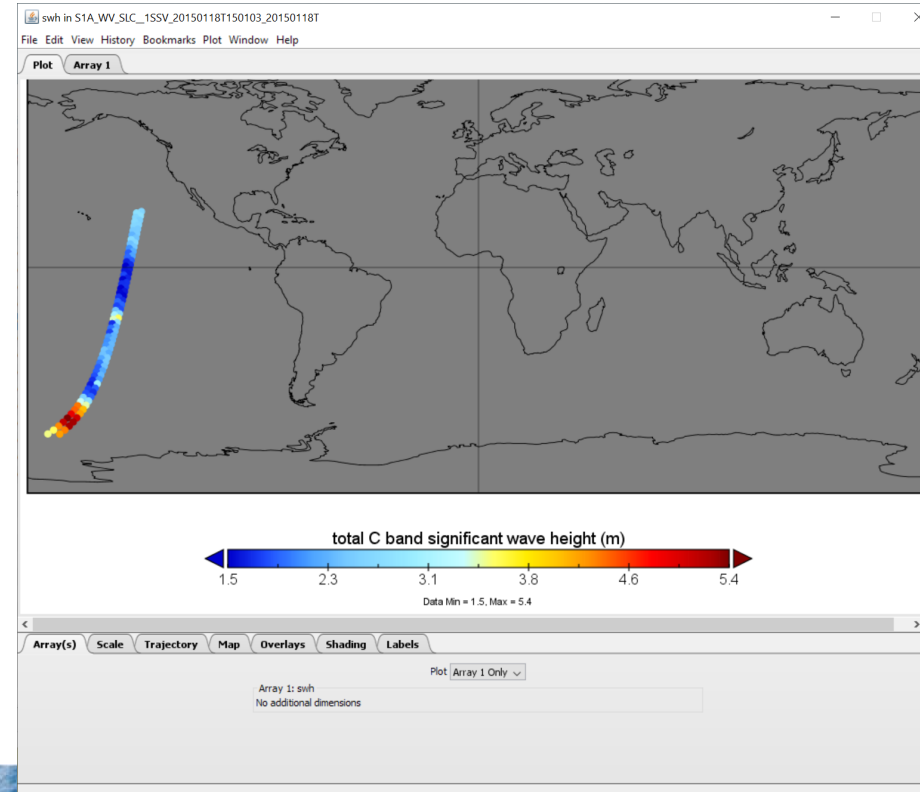
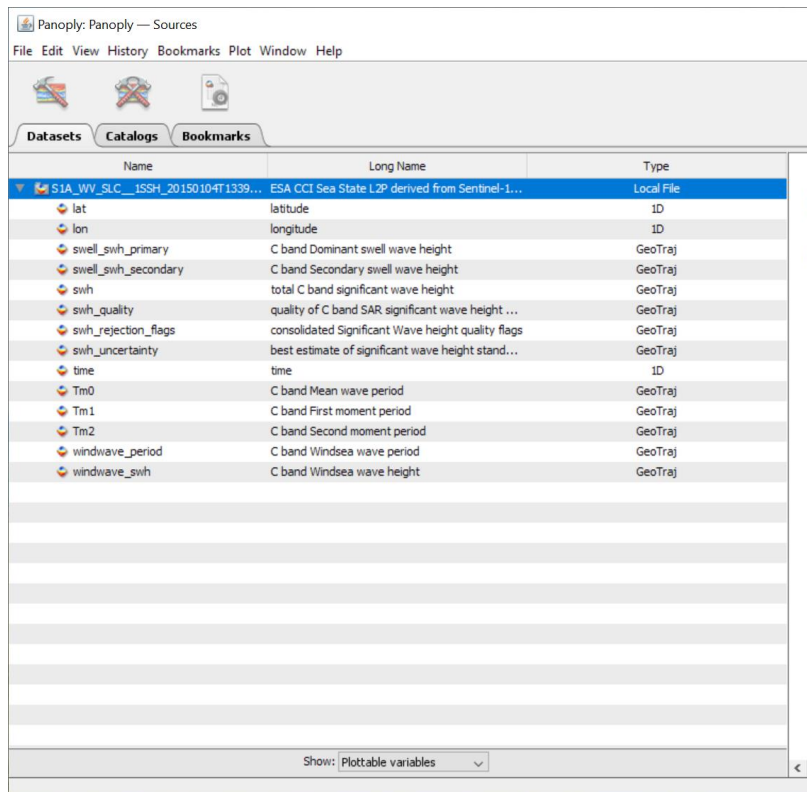


end

1. Overview
2. Actual progress – parameters / rmse
3. Storing results – *.txt / *.nc
4. Sea State processor and Methodology
5. Ground Truth, Training/Validation/Cross-Validation
- 6. Summary**

Summary

- Sentinel-1 wv **archive 2014-2020** (~120.000 Scenes, ~450 TB) processed, the results are stored as „ID.nc”
- Archive 2021 processing is running
- **SWH RMSE** is actually ~ 26 cm using machine learning technique (24.5 cm wv1, 27.3 cm wv2), **BIAS=-1cm**
- **High sea >6m SWH** is improved **RMSE=53cm**
- **Actual training** includes ~600.000 samples 2016-2017 and **validation** 2018-2020 includes ~3 Mio samples



Summary

SAR products, output and total **RMSE** (all sea state conditions) for **8 sea state parameters: NRT version**

Sea State Parameter	Description	S1 WV	S1 IW	S1 EW	TS-X SM / SL
	products used >	SLC	GRDH	GRDM	MGD RE/SE
	output type>	Along track (imagettes 20km×20km each 100 km)	Sea state fields (raster)	Sea state fields (raster)	Sea state fields (raster)
SWH (m)	Total significant wave height	0.35 → 0.26 m reprocessing	0.62	0.64	0.36
T _{m0} (s)	Mean wave period	0.62	0.96	0.86	0.72
T _{m1} (s)	First moment period	0.52	0.97	0.85	0.59
T _{m2} (s)	Second moment period	0.45	0.82	0.86	0.51
SW1 (m)	Dominant swell wave height	0.46	0.68	0.63	0.33
SW2 (m)	Secondary swell wave height	0.35	0.38	0.44	0.27
SWW (m)	Windsea wave height	0.41	0.77	0.66	0.37
T _{mw} (s)	Windsea wave period	0.62	0.97	0.95	0.71

Daily NRT service for German waters: eastern-North Sea and western Baltic S1 IW: sea state and wind products at <https://mariss.eoc.dlr.de>

Sentinel-1 WV SAR

Thank you for your attention