Multiparametric Sea State from spaceborne Synthetic Aperture Radar and Sentinel-1 Wave Mode Archive Processing in Scope of ESA Climate Change Initiative CCI

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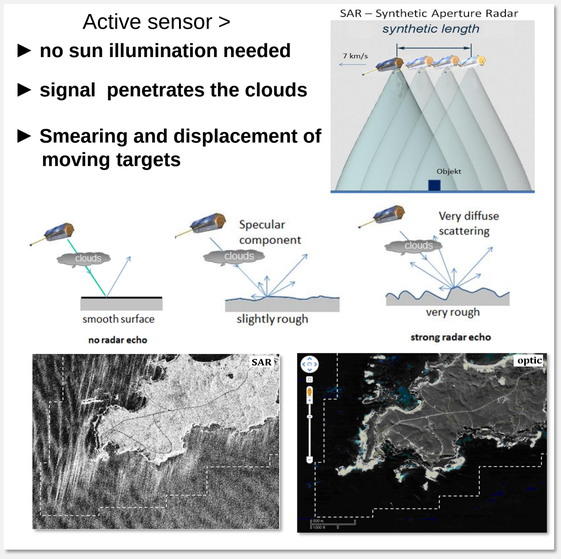
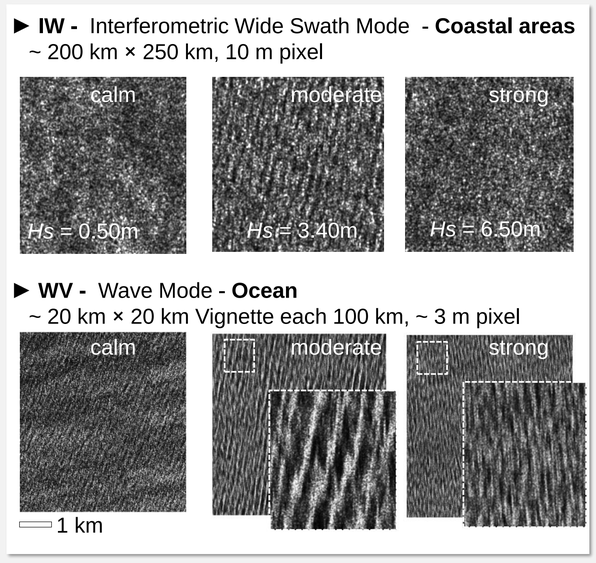
1. Sensor and data

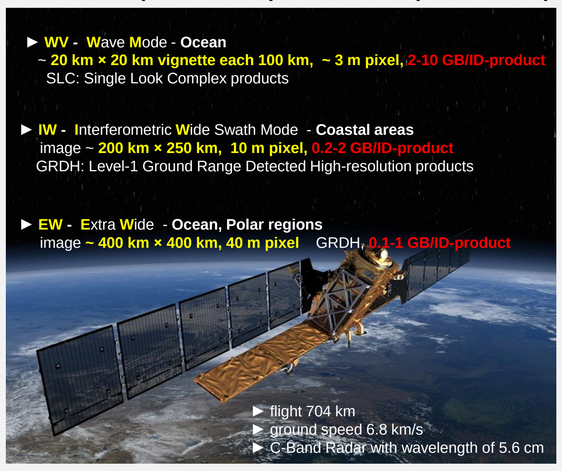
SAR – Synthetic Aperture Radar



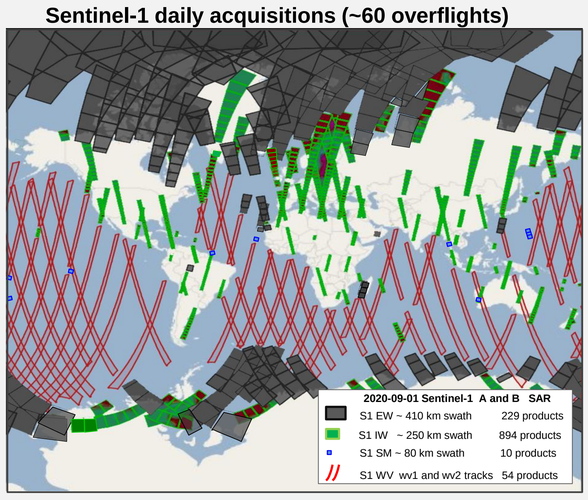
Sea State SAR imaging



Sentinel-1A (launch 2014), Sentinel-1B (launch 2016)



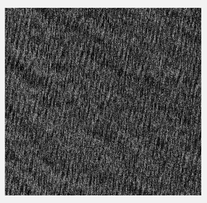
Sentinel-1 daily acquisitions (~60 overflights)



2. Processing and validation techniques

Subscene

-calibrated
-pre-filtered
-denoised



Total:
60 first-order features

SAR features

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)

Black: features of published CWAVE approach
Blue: additional introduced features

Empirical Functions

I-stage: simple empirical

II-stage: linear regression

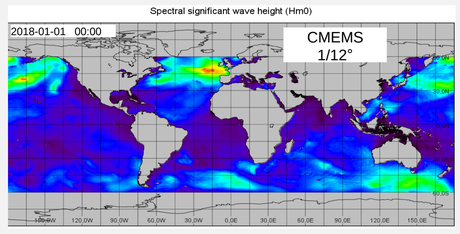
II-stage machine learning

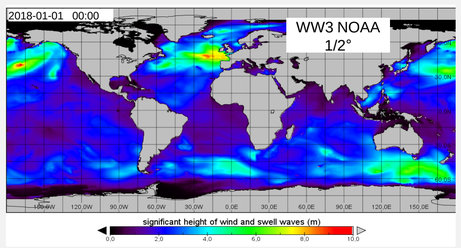
Results

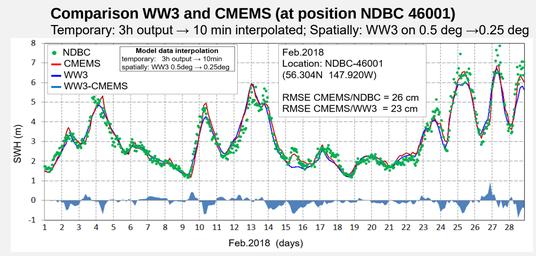
Sea state parameters

+
Control of results, filtering

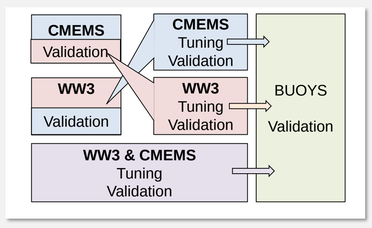
Ground truth: different hindcast models and buoys







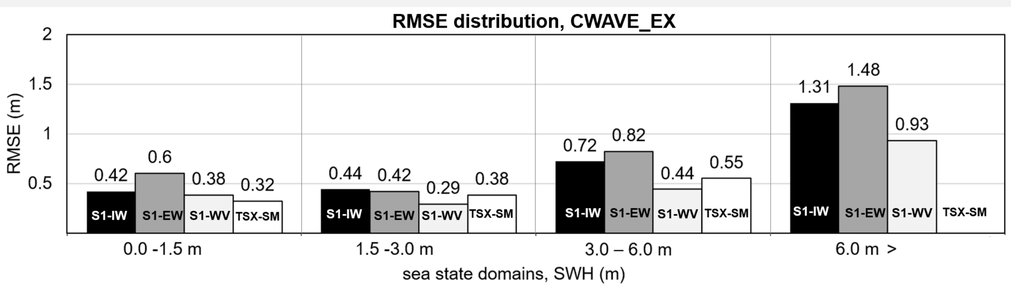
Cross-validation



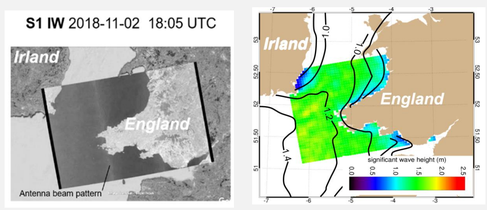
3. Accuracy for 8 integrated sea state parameters

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

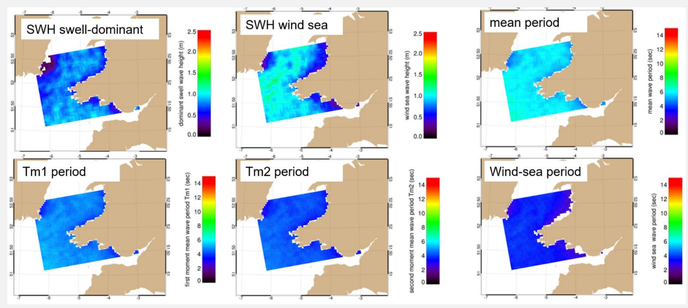
Sea State Parameter	Description	S1 IW	S1 EW	S1 WV	TS-X SM / SL
	products used >	GRDH	GRDM	SLC	MGD RE
	output type >	Sea state fields (raster)	Sea state fields (raster)	Along track imagettes 20km×20km each 100 km	Sea state fields (raster)
SWH (m)	**Total significant wave height**	**0.62**	**0.64**	**0.25**	**0.36**
T_{m0} (s)	Mean wave period	0.96	0.86	0.62	0.72
T_{m1} (s)	First moment period	0.97	0.85	0.52	0.59
T_{m2} (s)	Second moment period	0.82	0.86	0.45	0.51
SW1 (m)	Dominant swell wave height	0.68	0.63	0.46	0.33
SW2 (m)	Secondary swell wave height	0.38	0.44	0.35	0.27
SWW (m)	Windsea wave height	0.77	0.66	0.41	0.37
T_{mw} (s)	Windsea wave period	0.97	0.95	0.62	0.71

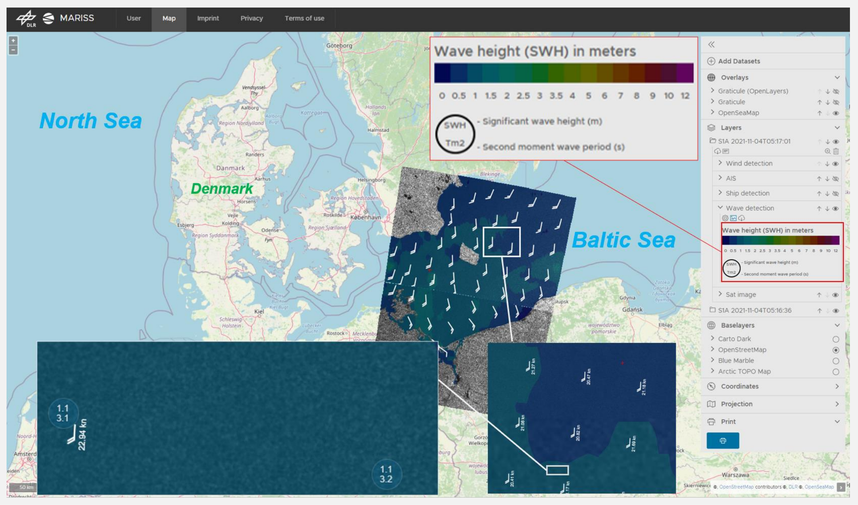


4. Sea state fields and Near Real Time processing



Example sea state fields estimated from S1 IW image acquired on 2018-11-02. Isolines show the Hs from CMEMS on 2018-11-02 at 18:00 UTC.





Screenshot of the demonstrator for NRT services at Ground Station Neustrelitz.

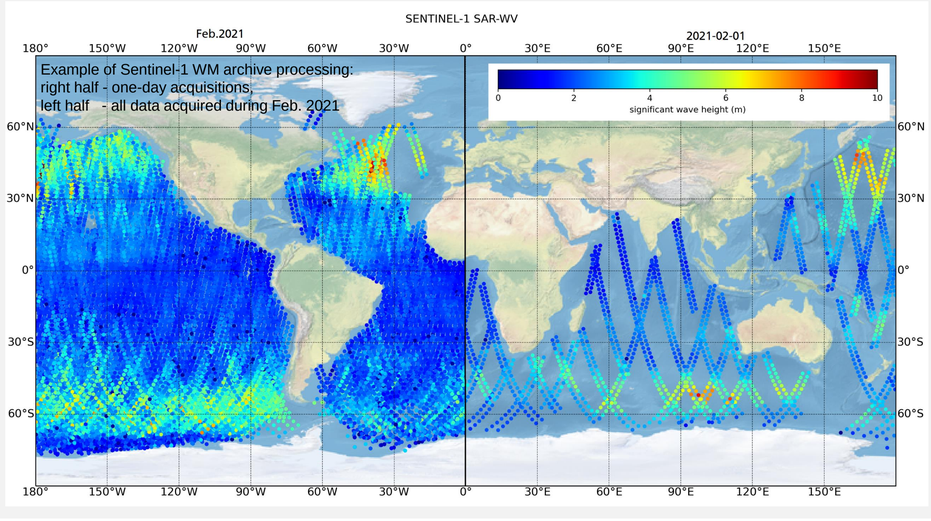
The demonstrator runs daily for Sentinel-1 IW in North and Baltic Seas. The actual processing raster is 3 km, the wave-detection layer shows wave height (colored) and period (in circles: Hs above, Tm2 below). Data for all eight sea state parameters can be downloaded as google-earth file (scene ID.kmz). The wind-detection layer shows the wind speed estimated from the SAR image and wind direction.

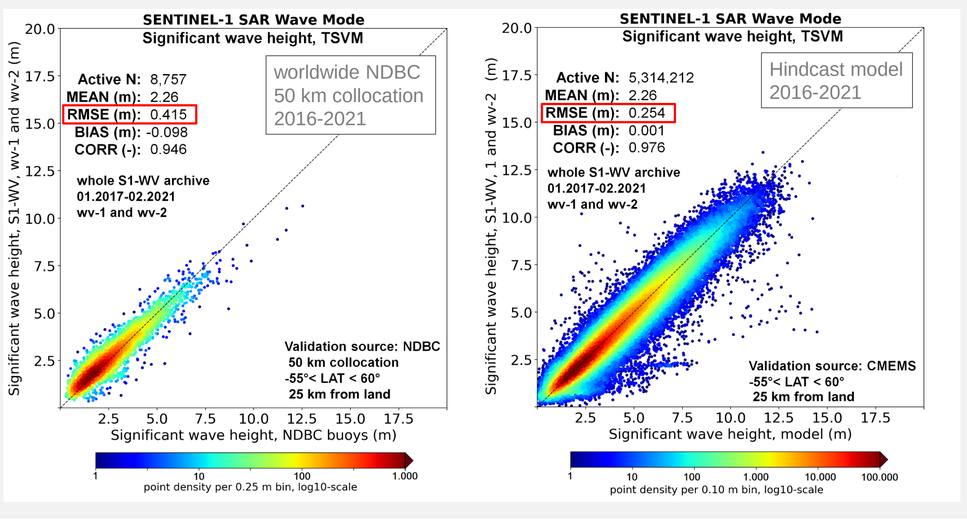
5. Sentinel-1 Wave Mode Archive Processing in Scope of ESA Climate Change Initiative

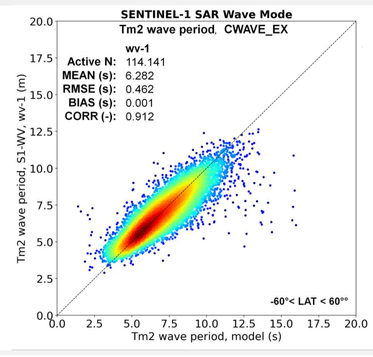
— Sentinel-1 Wave-Mode whole archive 2014-2021 processed (~15 Mio imagettes), validated, delivered to ESA:
8 sea state parameters: wave height (swell's, wind-sea), periods (mean, cross-zero, wind-sea). Format: ID.nc for each ID-product

— Accuracy of 24 cm reached (significant wave height) – comparable to accuracy of altimeter and ground truth noise
combination of classical approaches with machine learning

— Method adopted for Sentinel-1 modes IW, EW, WV and also for TS-X SM







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