German Aerospace Center (DLR)
Remote Sensing Technology Institute
Maritime Security Lab

HIGH RESOLUTION WIND AND WAVE MEASUREMENTS FROM TerraSAR-X IN COMPARISON TO MARINE FORECAST

Susanne Lehner,
Andrey Pleskachevsky

German Aerospace Center (DLR)

Jens Kieser
Thomas Bruns

German Weather Service (DWD)

Approach ● Sea State Processor ● Examples

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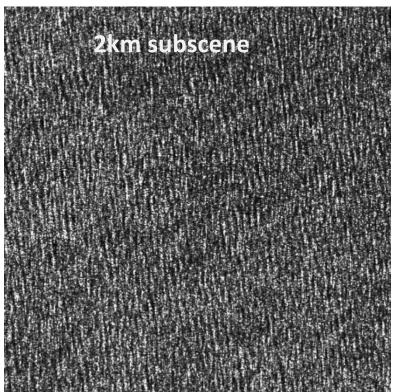
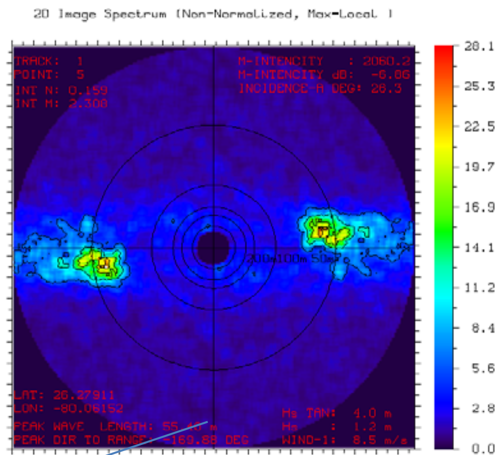
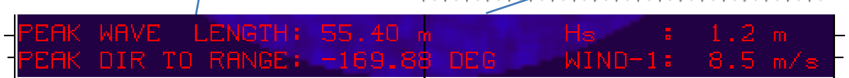
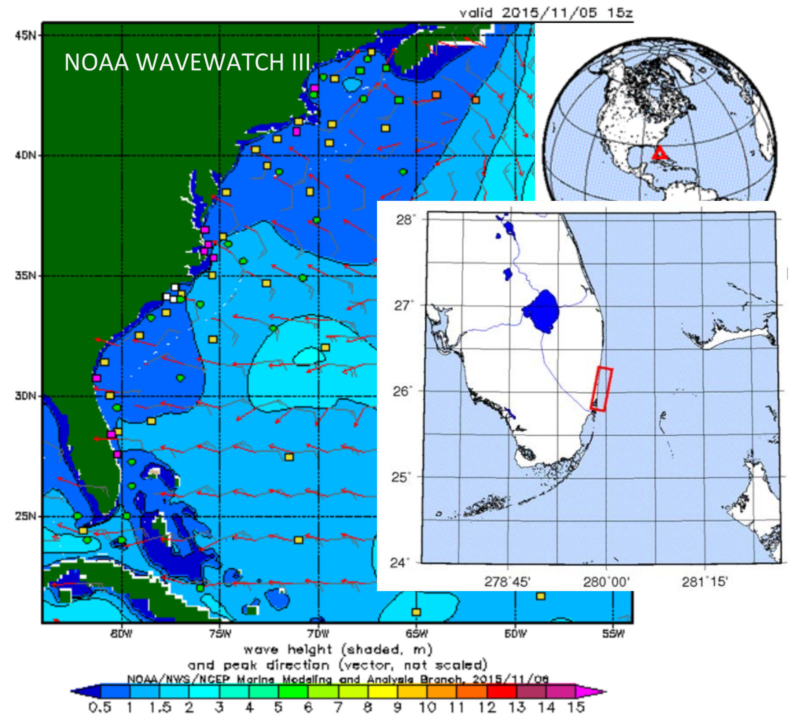
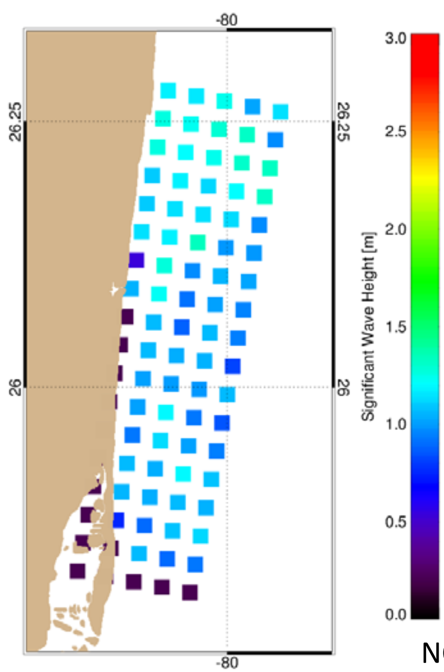
Recently:
Wave Experiment NOVA SE University – 2015-11-05 11:26 UTC

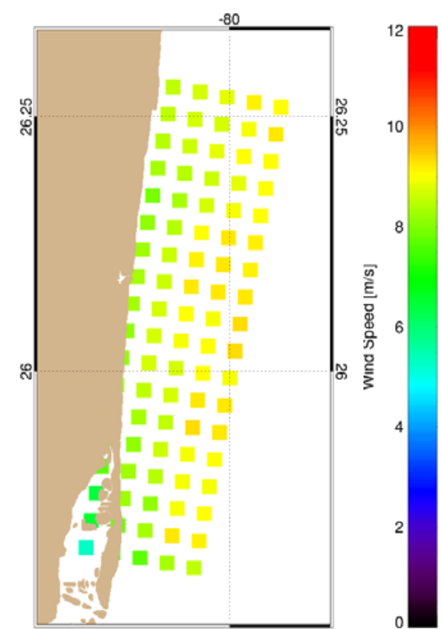












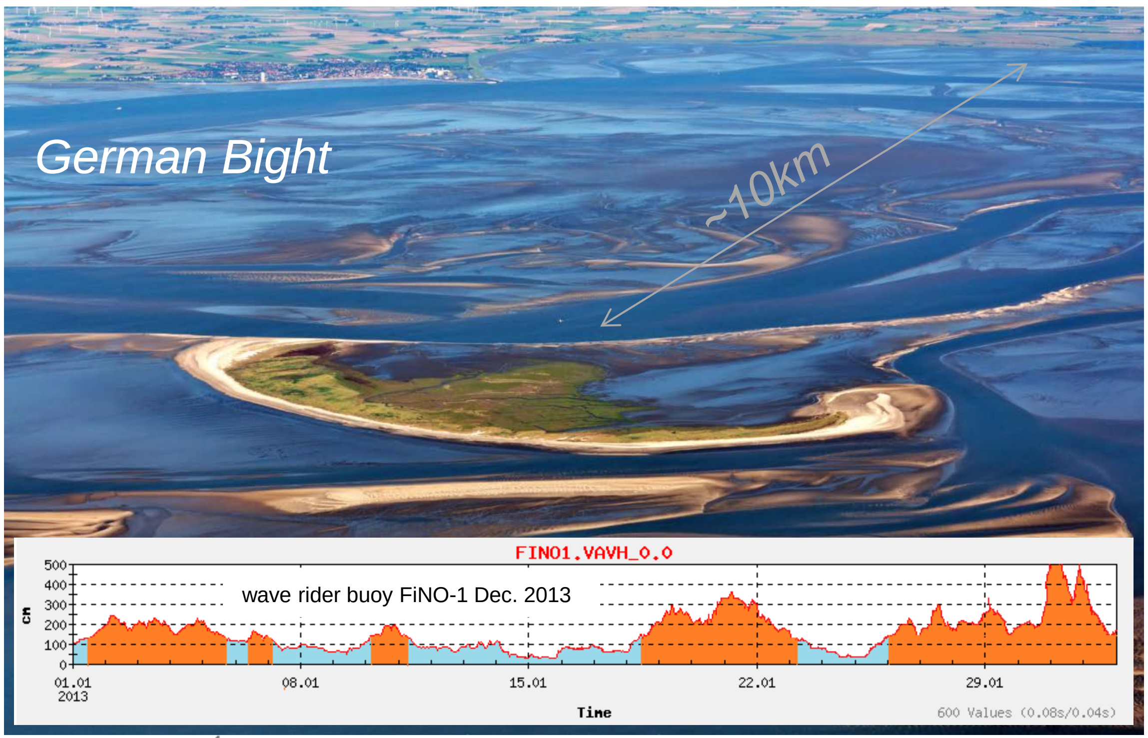
NOAA MIA01 11:00 UTC H_S=0.92m (26.25N 79.50W)

NOAA buoys

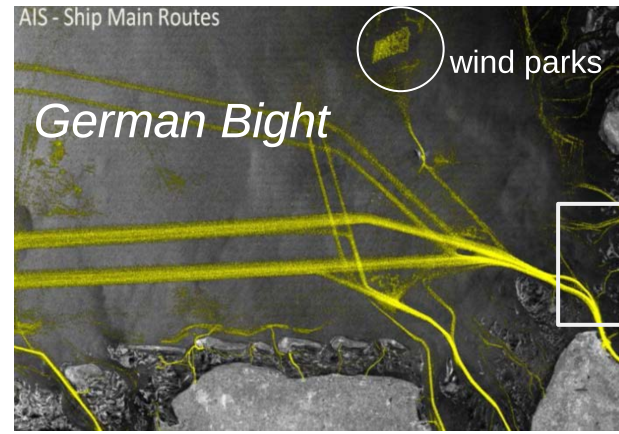
Introduction:
Sea state in coastal areas

German Bight:

- high temporal and spatial variability of sea state, interaction waves/bathymetry/currents
- high activity: shipping and building offshore constructions



AIS messages mapped on TerraSAR-X image



condition: wave height<1.3m –
accurate forecast necessary

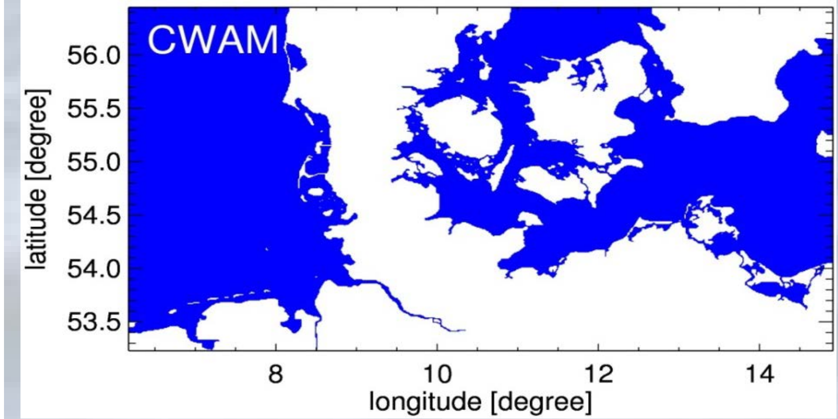
Coastal Wave Model (CWAM) — European Wave Model (EWAM)

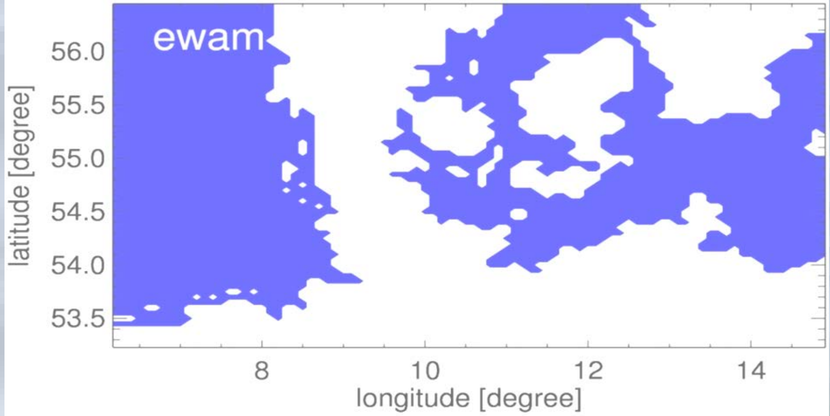
NEW! CONVENTIONAL

→ Wind input from COSMO-EU,

→ spectral resolution: 36 directions, 30 frequencies

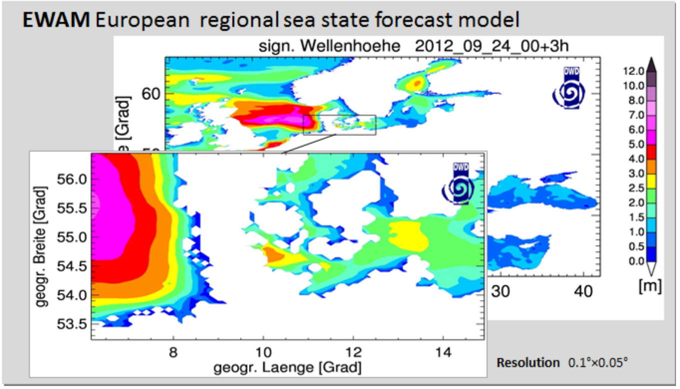
Coastal Wave Model (CWAM)	European Wave Model (EWAM)
→ increment longitude: 0.01389°	→ increment longitude: 0.1°
→ increment latitude: 0.00833°	→ increment latitude: 0.05°
→ coupled with the ocean circulation model (HBM) that provides current and water depth	



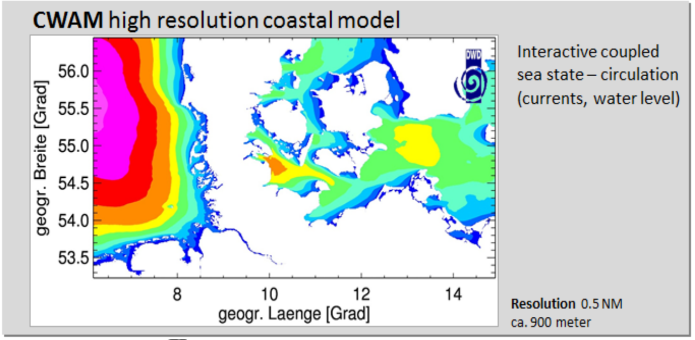


Introduction: SEEGANGSMONITOR-Project
Remote sensing for validation of forecast model

DWD-German Meteorological Service:
Sea sate Forecast -
improvement for coastal regions



Development of a new coastal wave model 900m resolution, interactively coupled with BSH circulation model



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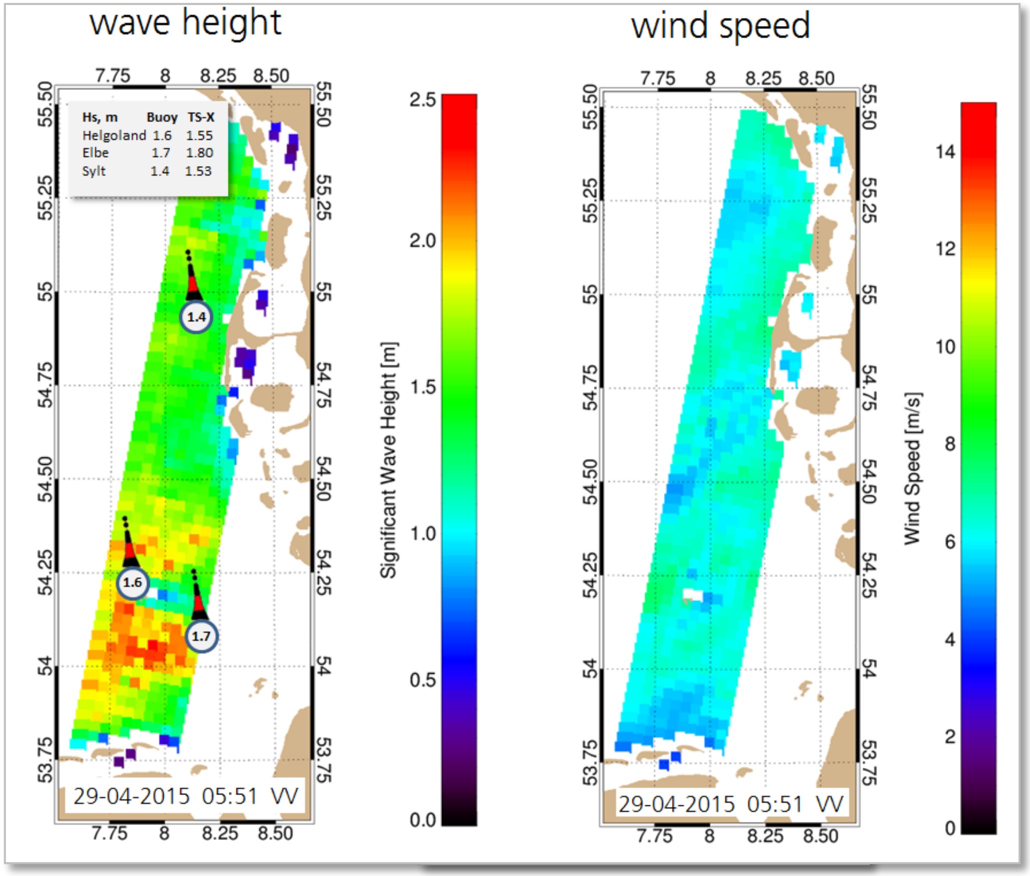
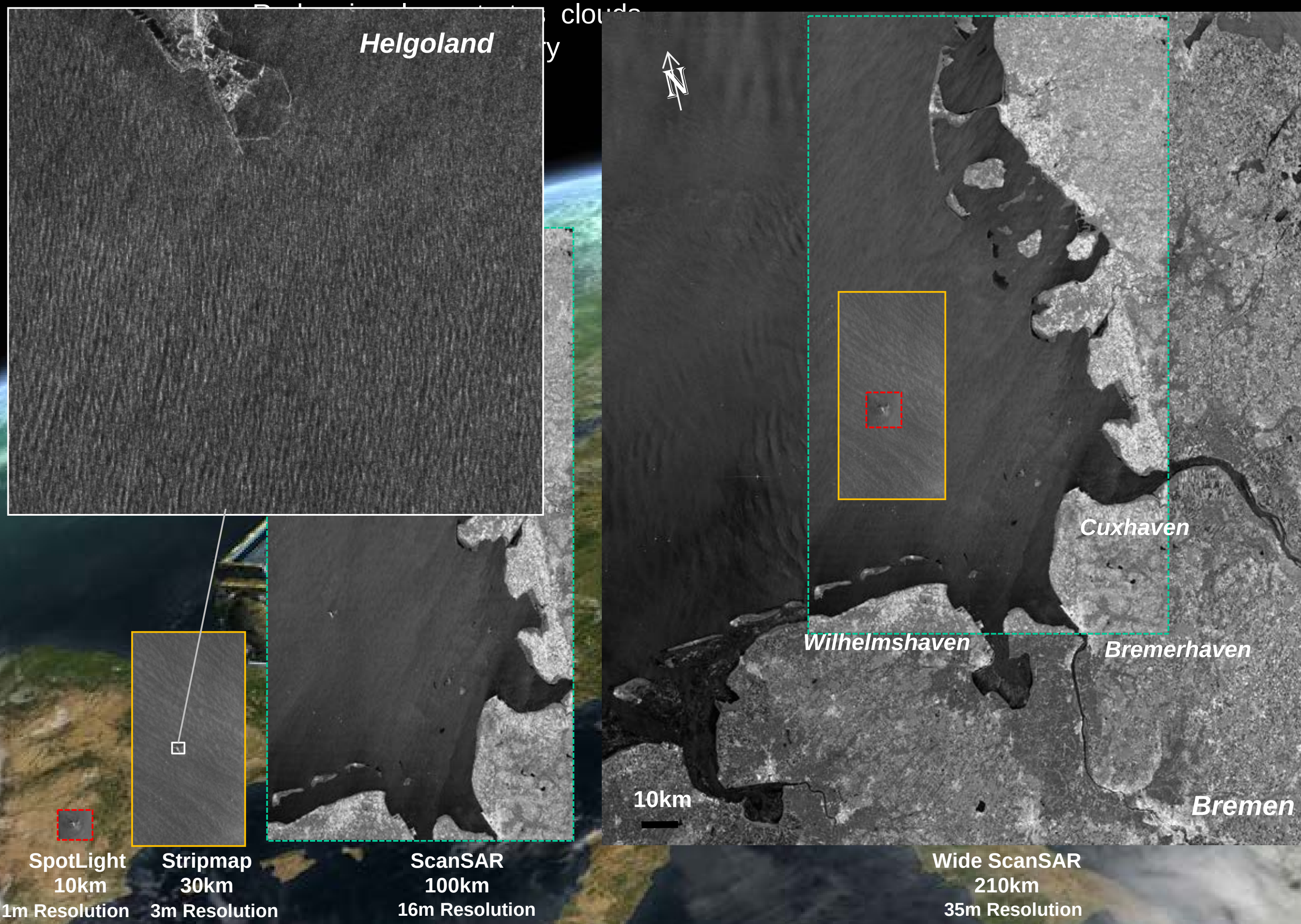
Remote Sensing -
Sea State Data for Validations



1. Approach

- Satellites & Data
- Methods & Objectives

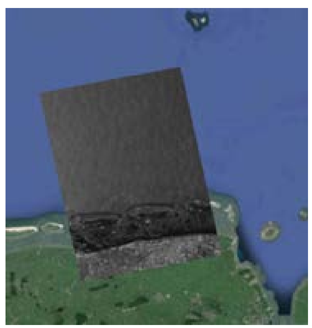
Satellites:
X-band SAR TerraSAR-X and TanDEM-X

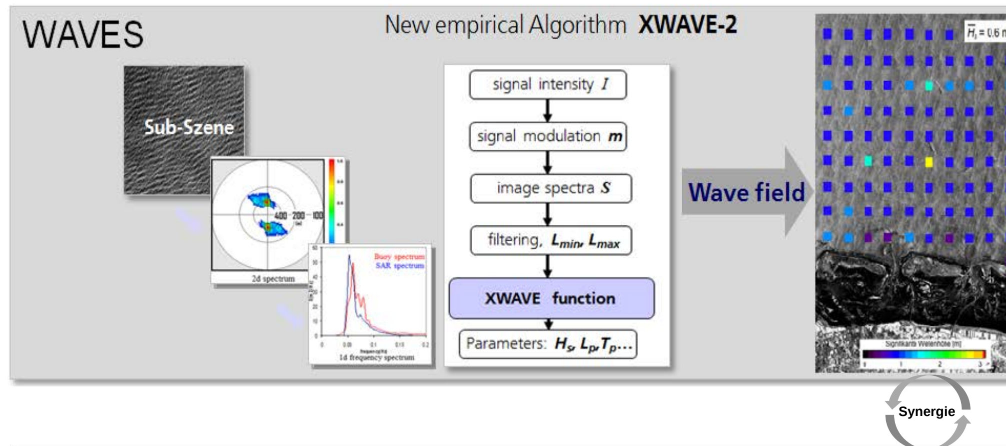


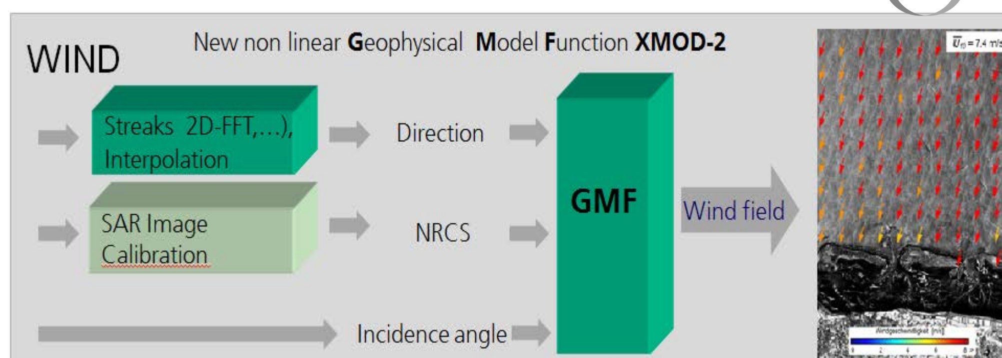
Developments:
Wind and Waves from TerraSAR-X Products for NRT

Algorithm and processing requirements - raster analysis, fast, robust, automatic

wind and waves from TerraSAR-X



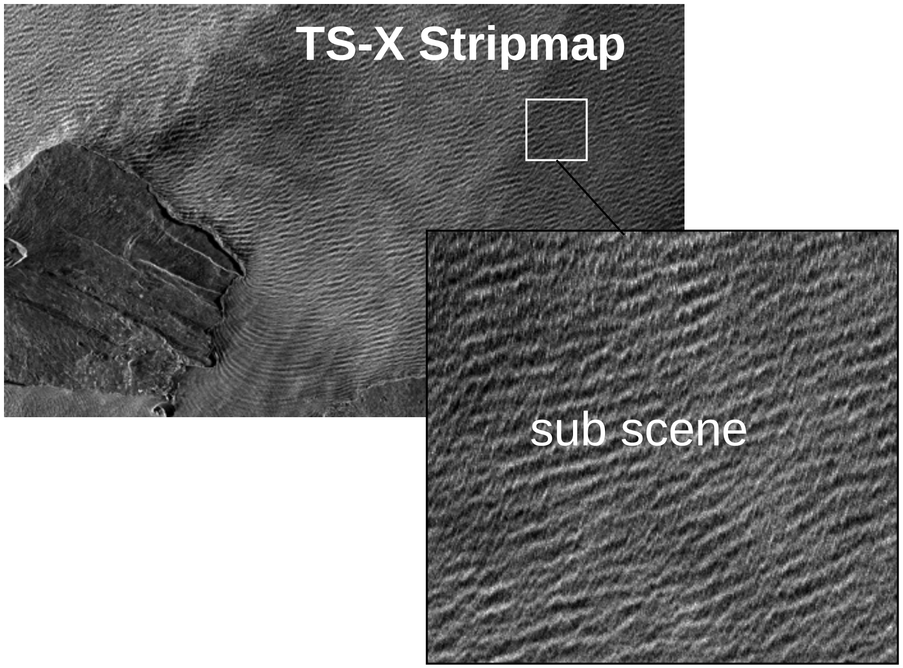




2. Sea Sate Processor

- Principe
- Deep water application

XWAVE empirical algorithm: GMF principle and structure



$$m = \frac{I(i,j) - mean}{mean}$$

$$S = FFT(m)$$

$$E = \int_{k=\max}^{k=\min} S(k,\theta)\,dk\,d\theta$$

signal intensity ***I***

↓

signal modulation ***m***

↓

image spectra ***S***

↓

filtering, L_{min}, L_{max}

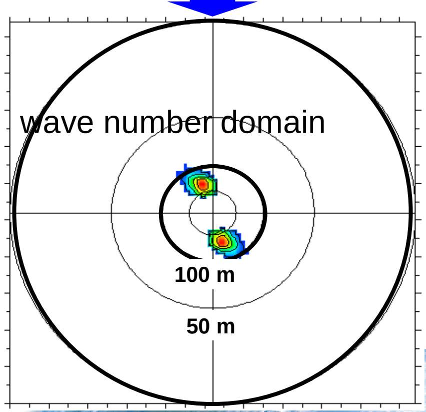
↓

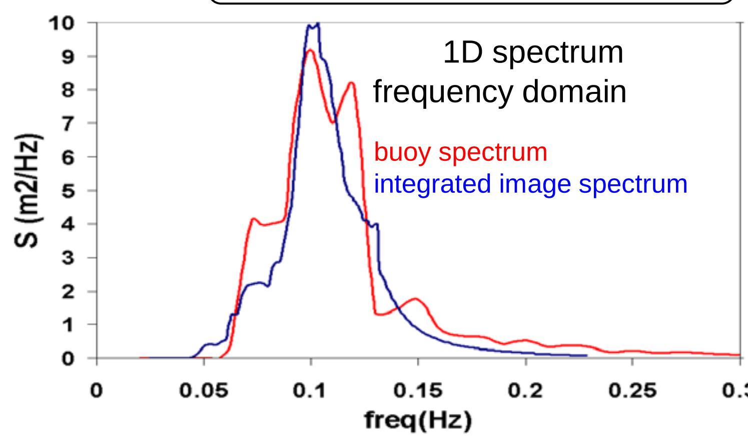
Local Wind (XMOD) → **XWAVE GMF function**

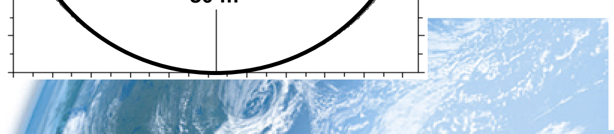
↓

Parameters: H_s, L_p, T_p...

2D image spectrum







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XWAVE empirical algorithm:
Deep water version for open ocean regions

Empirical Geophysical Model Function

$$H_s = x_1 \cdot \sqrt{E(1.0+\cos(\alpha))} + x_2$$

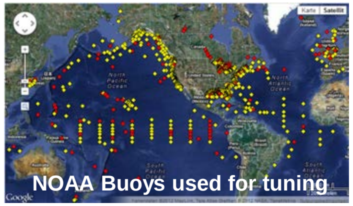
XWAVE
(first guess)

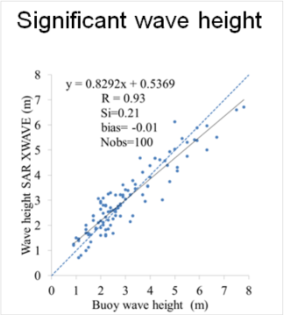
$$Hs^{1m-4m} = a_1\sqrt{E\cdot\tan(\theta)} + a_2 U^{10}_{XMOD} + a_3$$

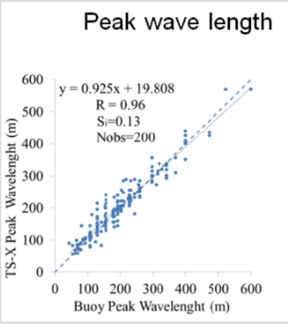
$$Hs^{5m-8m} = a_4\sqrt{E\cdot\tan(\theta)} + a_5 U^{10}_{XMOD} + a_6\cos(\alpha) + a_7$$

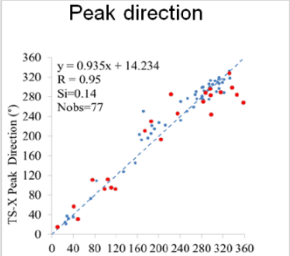
XWAVE-1
deep water,
sea state does not visible change spatially

Tuning



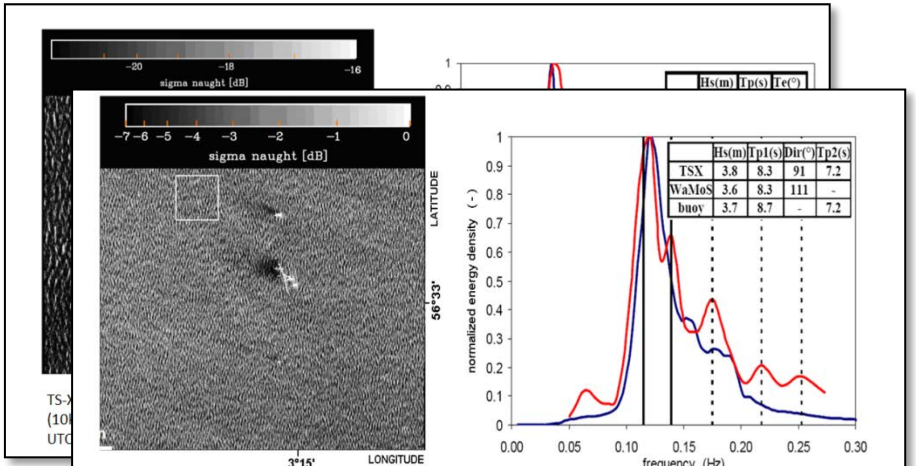






peak wave directions for wavelength below 120 m
wave peak directions for wavelength above 120 m

Examples



TS-X Spotlight mode VV polarization image acquired on May 15, 2009 at 17:19 UTC over **Ekofisk oil platform in North Sea**

Normalized spectrums: 1D integrated TS-X (red) and WaMoS (blue) on May 15, 2009 at 17:19 UTC over **Ekofisk oil platform**. The vertical black lines correspond to the buoy peak frequency

VARIABLES

E -energy density of image spectrum in wave number domain; k_{max}=0.2; k_{min}=0.01 in deep water (L_{min}=30m; L_{max}=600m).

α -wave peak direction related to the azimuth direction

θ - SAR incidence angle

a_1, a_2 $a_{3...}$ parameters tuned to various data sets:
- collocated buoy measurements,
- WaMoS-II monitoring system,
- Radar altimeter data,
- DWD wave hindcast model results **(Bruck and Lehner 2013).**

U_{10} – wind speed estimated using XMOD algorithm from the same SAR sub-scene

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3. Sea State Processor: GMF Adaption for Coastal Application

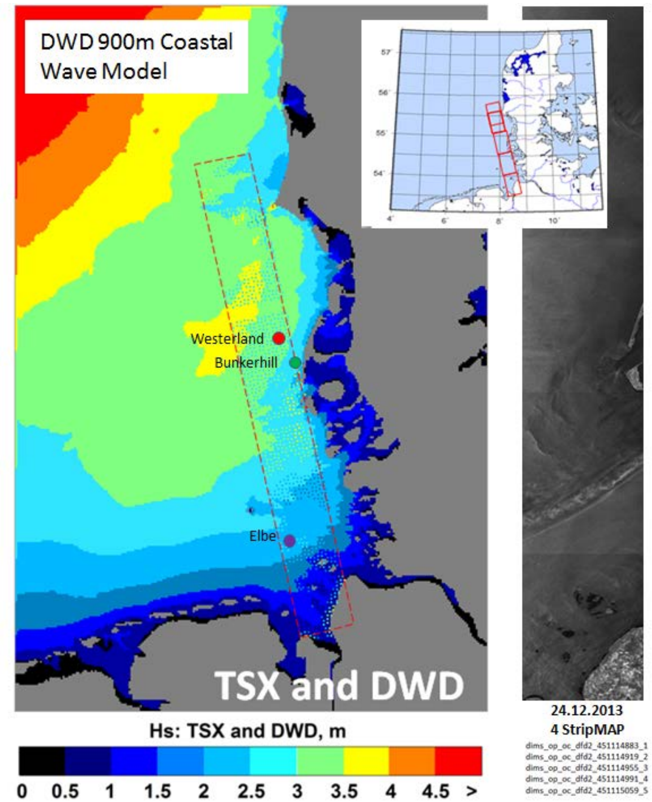
sea state safe estimation in raster mode

- Data: Acquisition concept for German Bight
- Filtering artefacts before analysis
- GMF Improvements
- Examples of tuning / explanation

Date acquisition concept: TerraSAR-X Strips covering DWD model domain

6 Buoys in DWD Model domain „German Bight“

Example: TS-X Scene with 5 images



- One TerraSAR-X StripMap scene “strip” cowers 30km x 50-300km
- To date: **51** TerraSAR-X Scenes (overflights/events/days 2013-2015) with **188** Images and **81** buoy collocations

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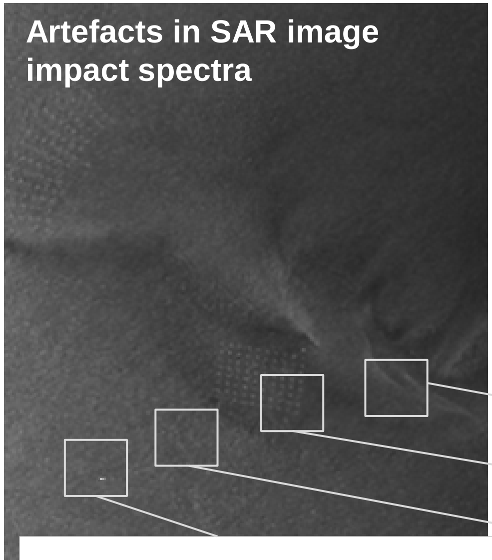
Coastal applications: artifacts impacts spectral analysis

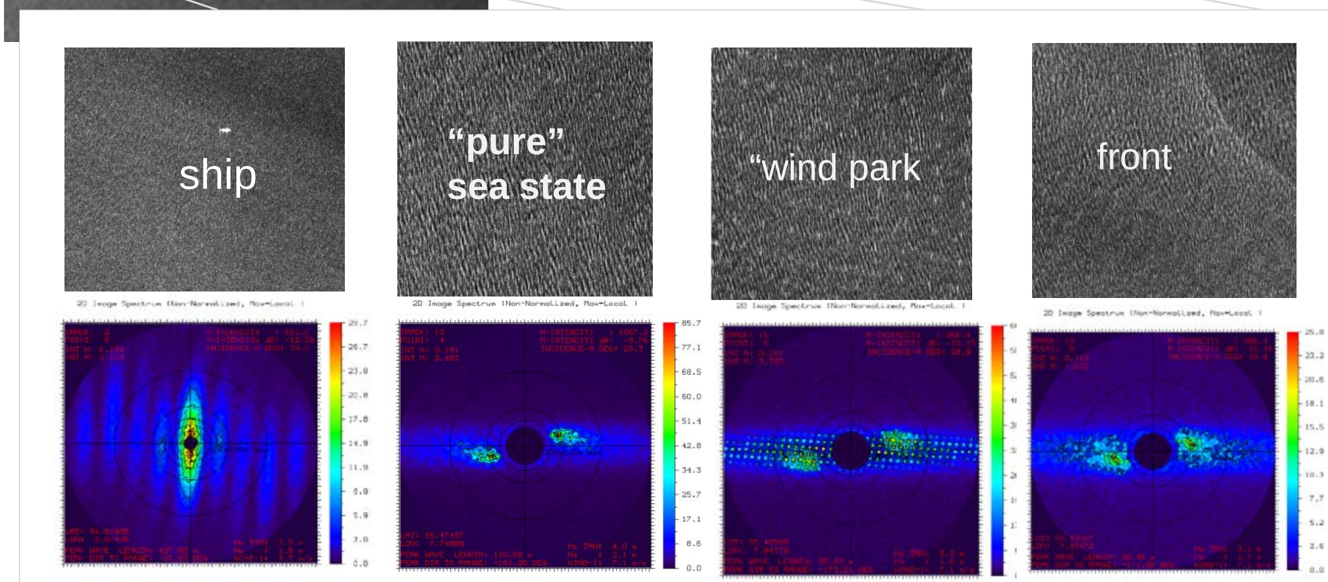


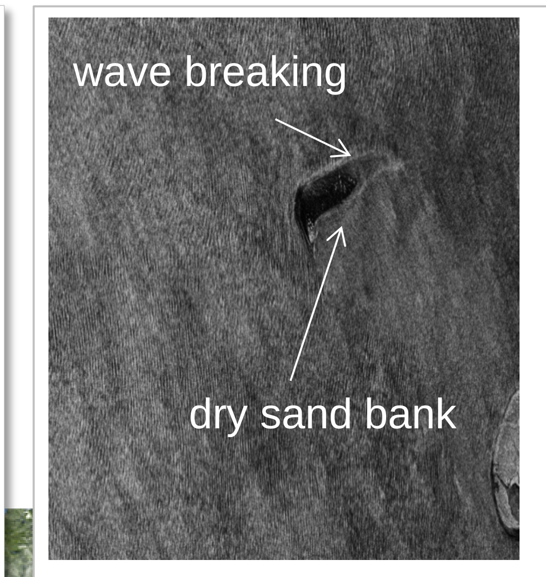
Task №1 - removing artefacts before analysis

- Sand banks
- Wave breaking
- Ships, Buoys, Wind parks
- Current fronts, ship wakes

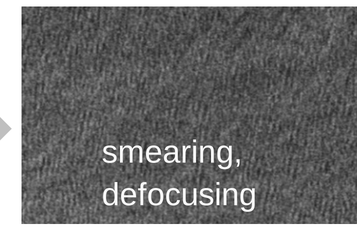
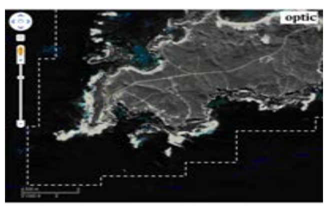
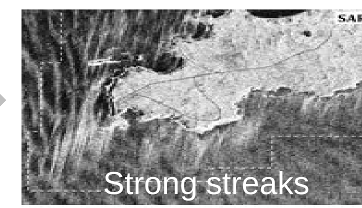
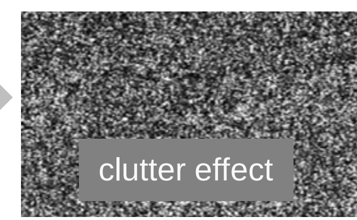
GMF is applicable for “pure” sea state case only:
Pre-filtering of images is necessary for raster analysis

Without pre-filtering Integrated energy and *Hs* can > 10 times overestimate real value





SAR imaging of ocean surface waves: a composition of different schemas for complete Hs

	Sea State	**Imaging**	**SAR Image**
1. Swell, weak wind **wave height 0m-3m**		„Bragg“ waves, III modulations	
2. Developed wind sea moderate wind **wave height 1m-5m**		„Bragg“ waves, III modulations + individual scatterers (step crests of wind waves, “white capping” scatterers)	
3. Wave breaking Underwater hindrance or by wind > 15m/s **wave height 0m-5m**		flying scatterers, high turbulent surface in breaking zone	
4. Low wind sea, waves interact with currents and bathymetry **wave height 0m-1m**		Noise due to amount of small “non- systemized” wave-targets, waves imaged hardly visible	

costal algorithm: more focus on last 3 types

GMF improvement for coastal applications

GMF Deep water

$$Hs^{XWAVE-2} = c_1\sqrt{E_{IS}\cdot\tan(\theta)} + c_2U_{10} + c_3 + c_4\cos(\alpha)$$

Tuning

Step 1: spatial, using model data to get “Ansatz function”

Step 2: collocated, buoy data to correct coefficients

new GMF_Coastal

$$Hs^{XWAVE\_C} = a_1\sqrt{B_1E_{IS}\tan(\theta)} + a_2B_2 + a_3B_3 + a_4B_4 + a_5B_5$$

“physical” positive term

“fishing” outliers different origin

***a_1 … a_5* - coefficients (constants) tuned**

***B_1 … B_5* - functions of spectral parameters**

B_1 - noise scaling of total energy E_{IS}

a_2B_2 - wind impact according to the original XWAVE

a_3B_3 and a_4B_4 - corrections for eliminating the impact of short (e.g. wave breaking induced) and long (e.g. wind streaks) structures in the SAR image.

a_5B_5 - correction for outliers produced by extra-large structures like sand banks or ship wakes

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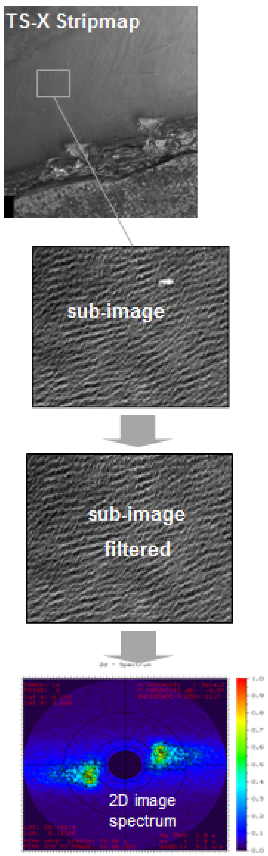
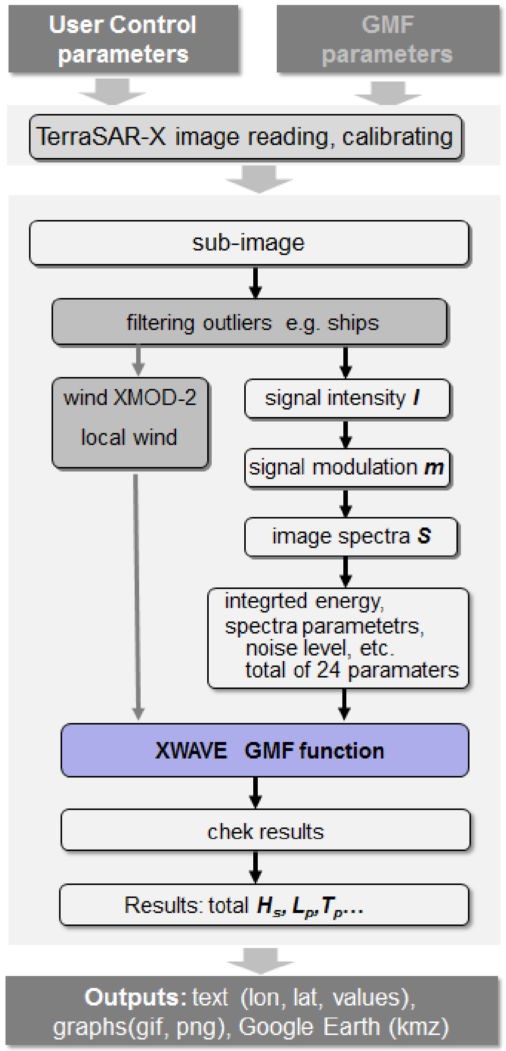
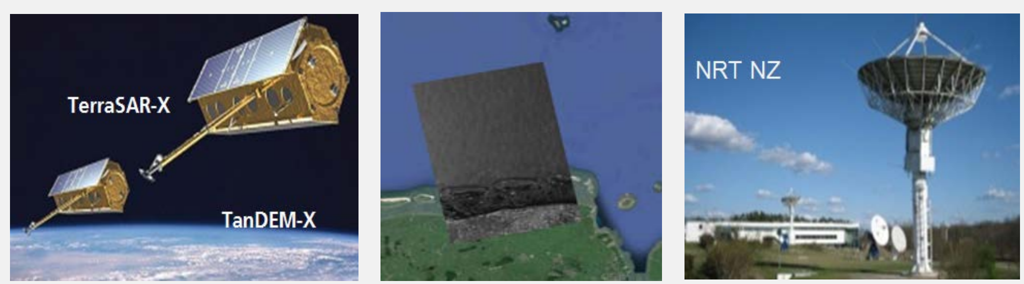
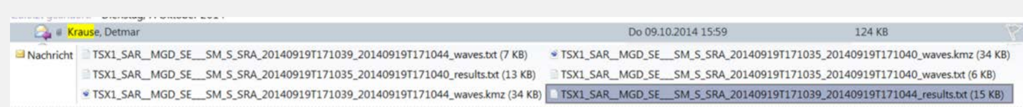
Integrating GMF into Sea State Processor: Whole automatic sea state processing for NRT





Step-1: sub-scene pre-filtering (remove image intensity outliers like ships, buoys etc. based on local intensity statistics)
Step-2: calculation of XMOD-2 wind
Step-3: spectral analysis of subscene (FFT, integration and spectral parameters e.g. noise level)
Step-4: new XWAVE-2 GMF (SSP core)
Step-5: checking of results using wind speed and integrated spectral parameters





Example of a NRT delivery per e-mail txt file: *lon, lat, Hs*

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Statistics:
Comparison spatial (model) and at locations (buoys)

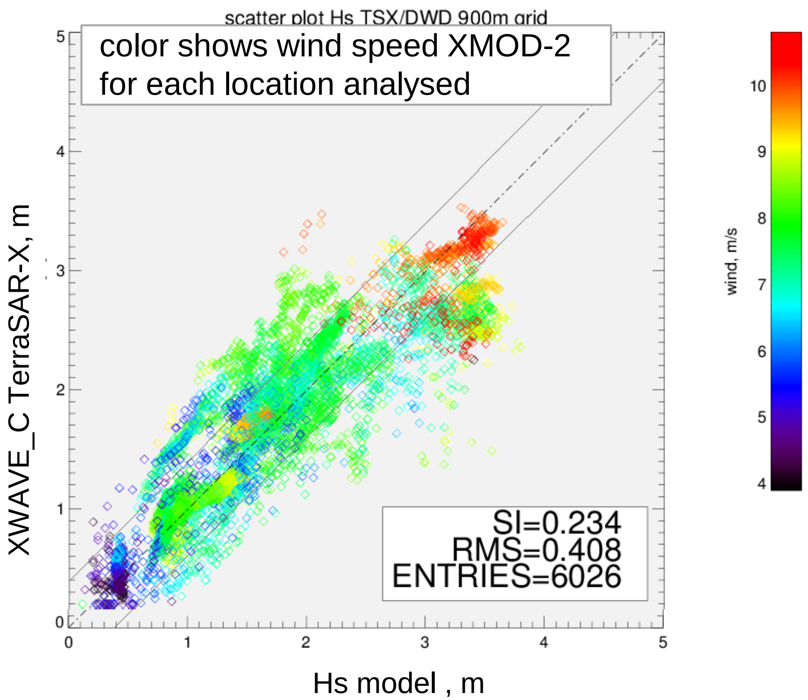
TS-X analysis with raster step of 3km → **1 StripMap** 30kmx50km 10x15 =**150 subscenes**

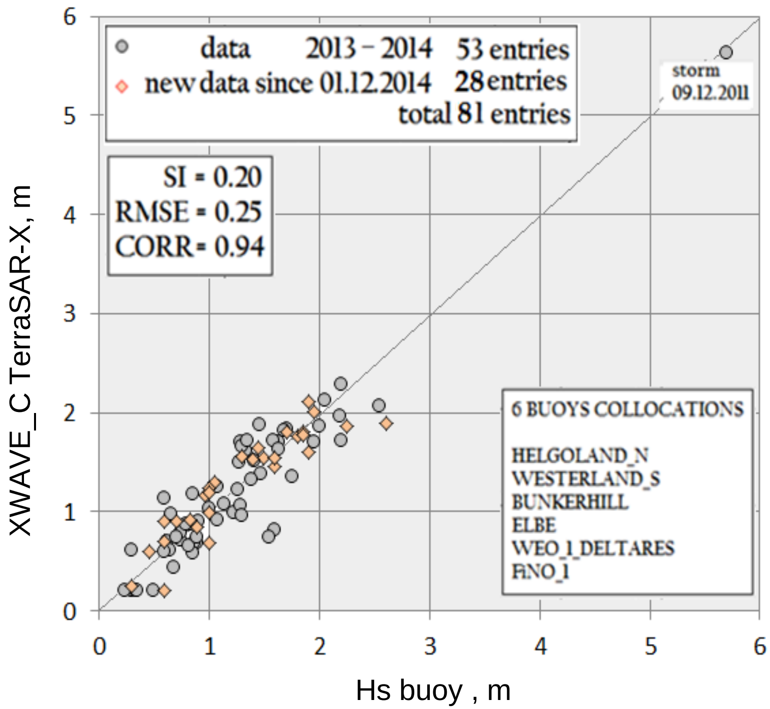
comparison TS-X/wave model (spatial)

- **21** overflights with **64** TS-X images
- Depth>5m

comparison TS-X/Buoy (at location)

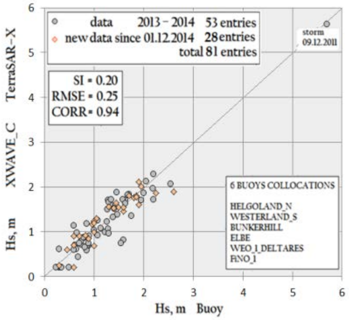
- **51** overflights with **188** TS-X images
- collocation +/-20min,
  subscene center +/- 5km from buoy location

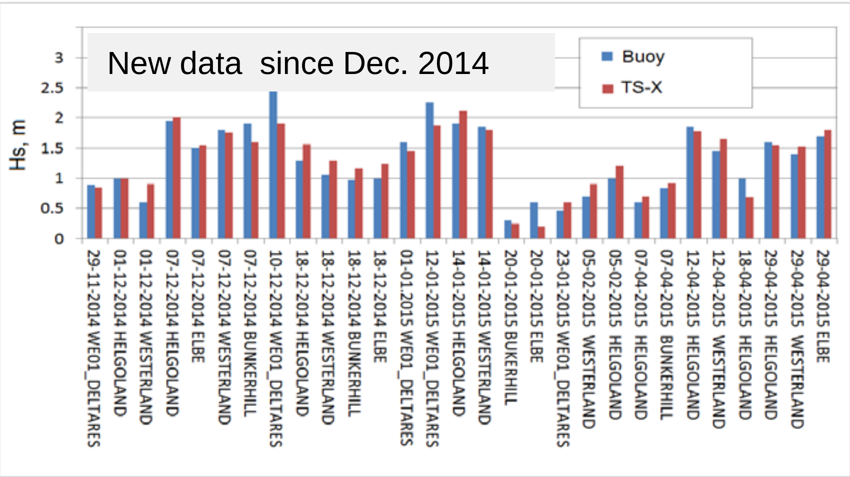


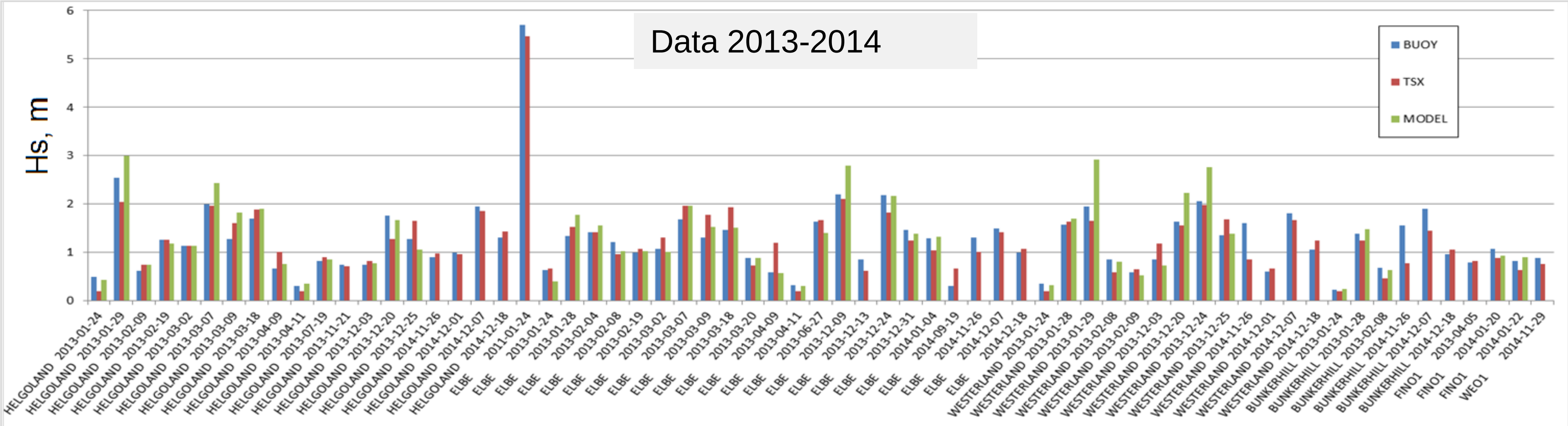


Statistics:
Comparison with buoys: all collocated data

6 Buoys in German Bight comparison
SI=20% RMSE=0.25





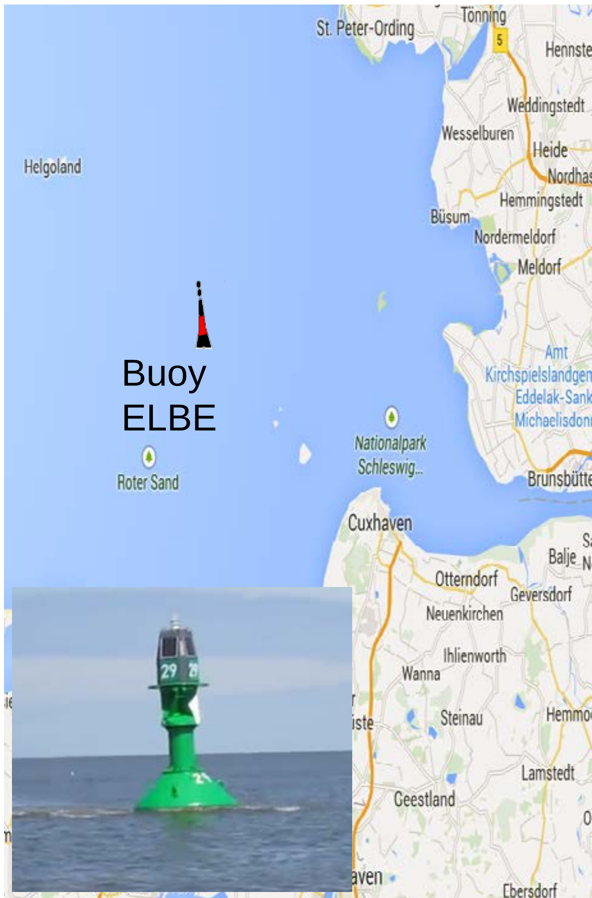


4. Examples

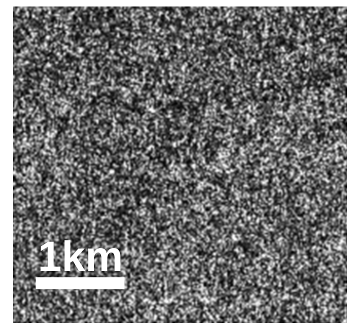
- Different sea state at the same location
- Different wind condition in German Bight

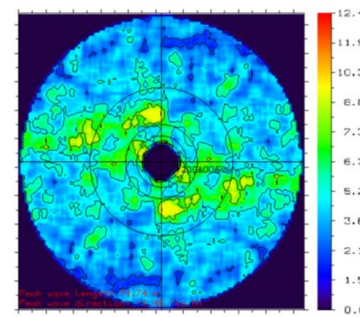
Different condition at the same location in North Sea: Low wind and swell with improved GMF

- Low wind condition: wave-like strictures are hardly visible
- H_S can be estimated based on noise properties of spectra and wind information.

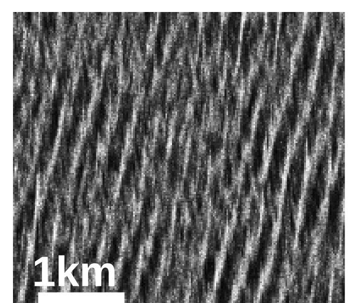


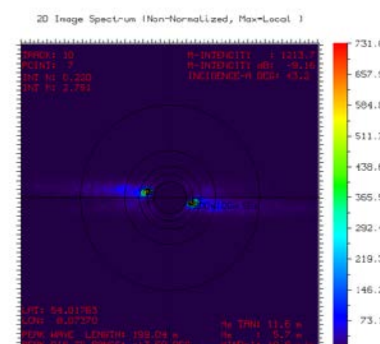
	Buoy	XWAVE	
Hs	0.50m	0.46m	**Wind** 7m/s





	Buoy	XWAVE	
Hs	5.80m	5.72m	**Wind** 19m/s

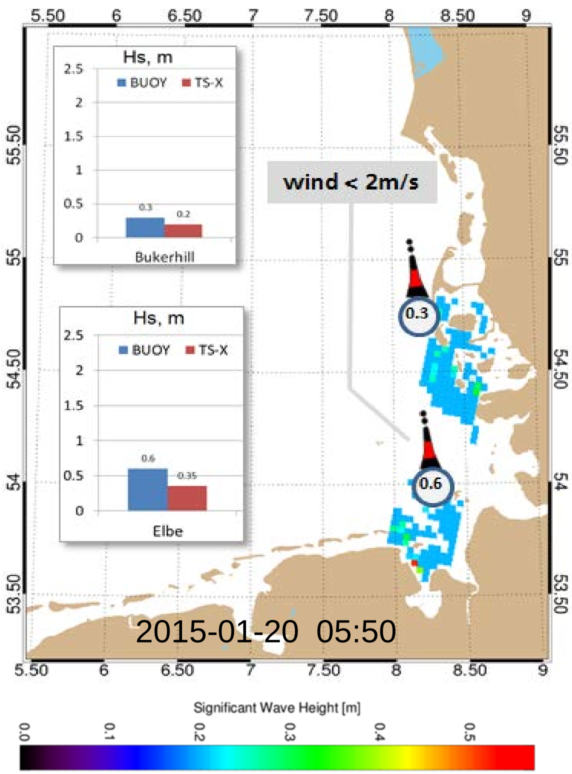




Different wind conditions in German Bight with TerraSAR-X data using new XWAVE_C (coastal)

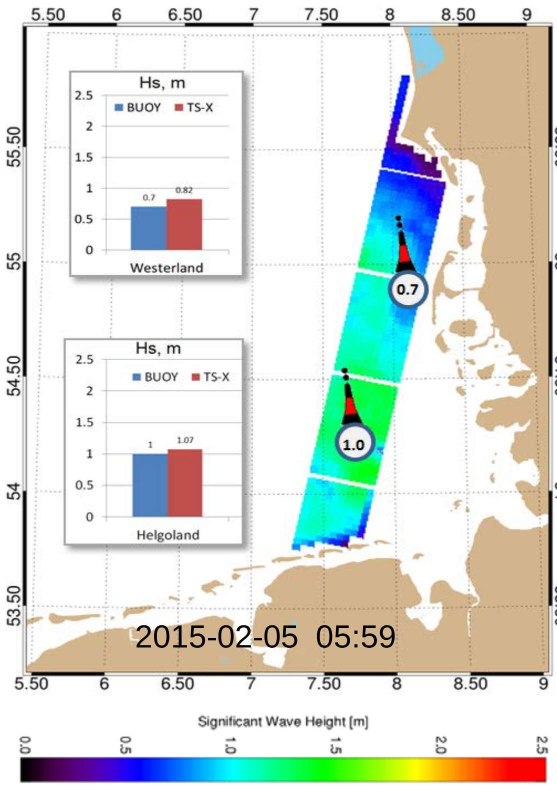
Light breeze 1- 3 m/s

Beaufort 2



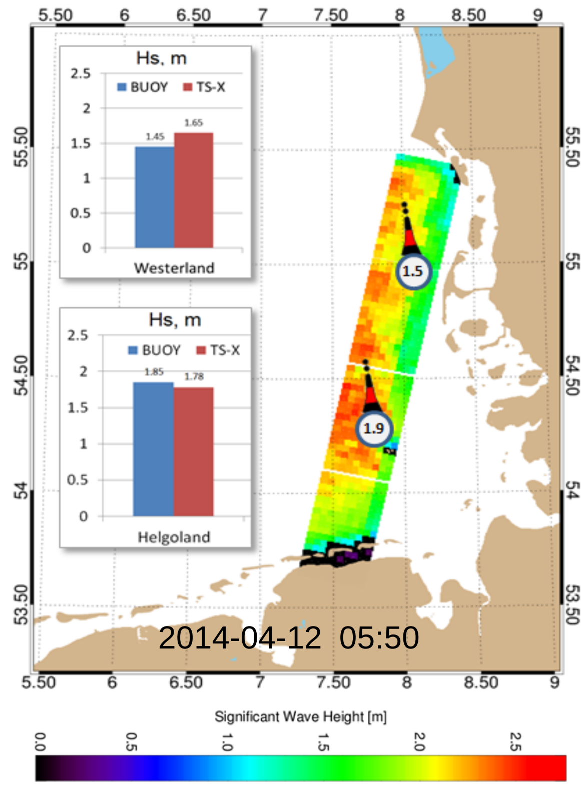
Moderate breeze 5 – 8 m/s

Beaufort 4



Fresh/strong breeze 8 – 12 m/s

Beaufort 5/6



Summary

- High Resolution Spatial Distribution of Hs and Peak Parameters
- Tested over North Sea for Offshore Windfarming
- Scatter Hs < 20 %
- Available in NRT (<15 min after acquisition at station)
- Offer: To be tested over other areas

Thank you for your attention!