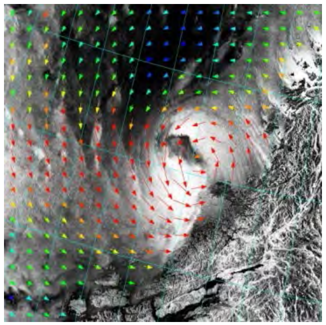
Monitoring MetOcean parameters from space - Implications for offshore safety and security

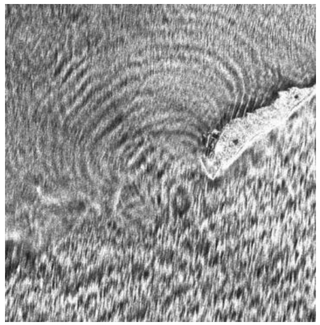
Dr. Sven Jacobsen
Maritime Safety and Security Lab Bremen
German Aerospace Center (DLR)

DLR

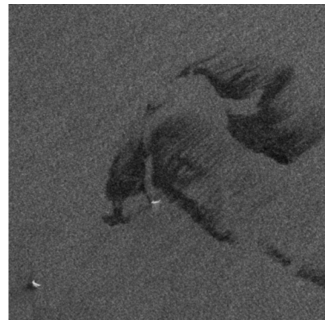
Sea Surface Parameters from SAR



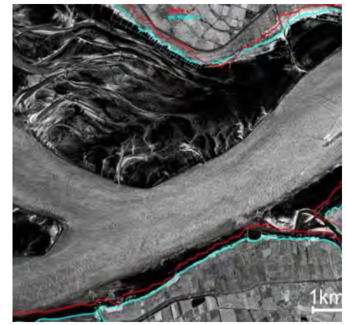
Wind



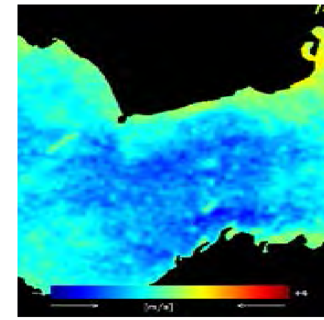
Sea State



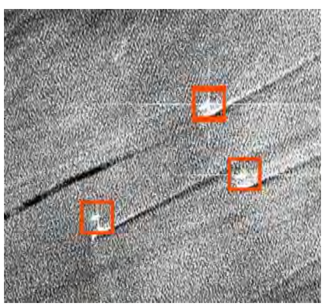
Oil



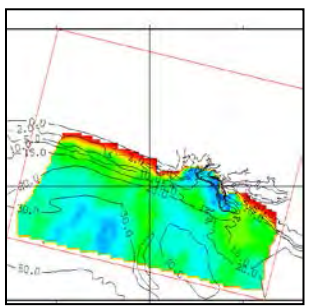
Land-Water Line



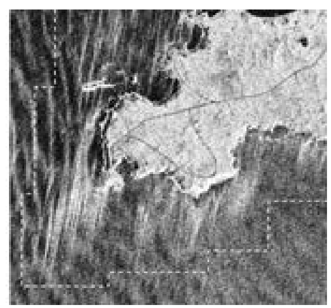
currents



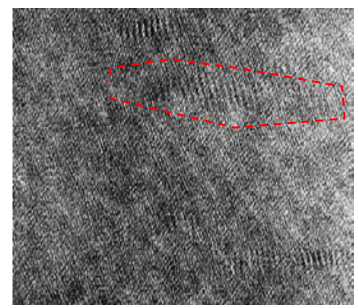
Ships



Bathymetry

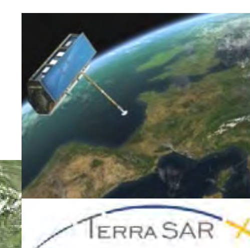


Wave breaking



Wave groups

ice, Icebergs



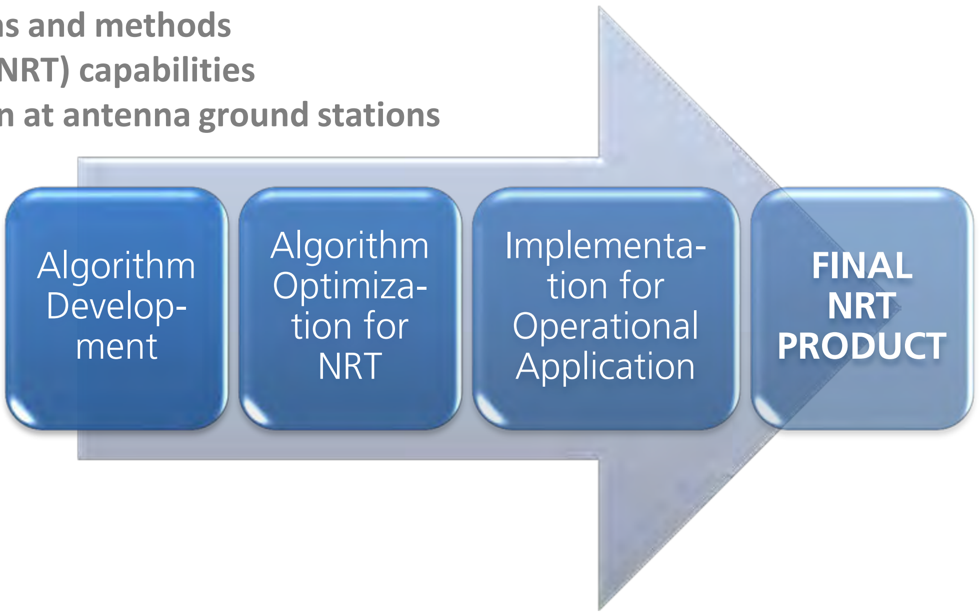
Sea Surface Parameters from SAR

1. Basic Research - Functions & Algorithms

- Fundamental research in SAR Imaging Mechanisms
- Finding interdependencies between SAR imaging and geophysical or oceanographic properties
- Develop (empirical) model functions to deduce sea surface properties from SAR

2. Software Development - Prototype & NRT Processor

- Robust implementation of developed algorithms and methods
- Performance optimisation for Near-Real-Time (NRT) capabilities
- Integration in operational data processing chain at antenna ground stations



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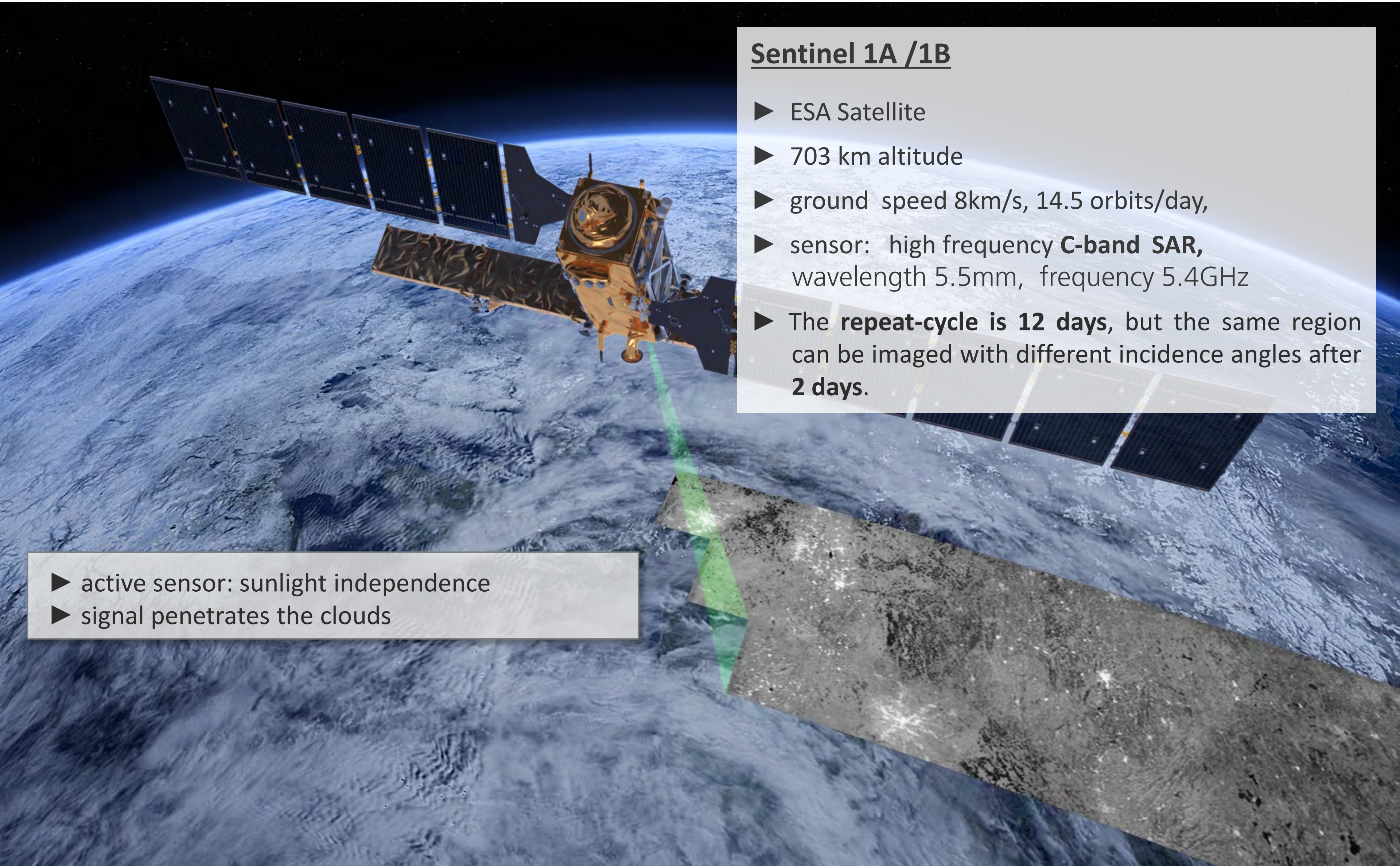
3. Processing, Databases and Scientific Exploitation

- Contribution to improve forecasts, oceanographic and geophysical understanding
- Analysis of extreme events
- Possible applications for institutions and industry

Satellites: X-band SAR (synthetic aperture radar)

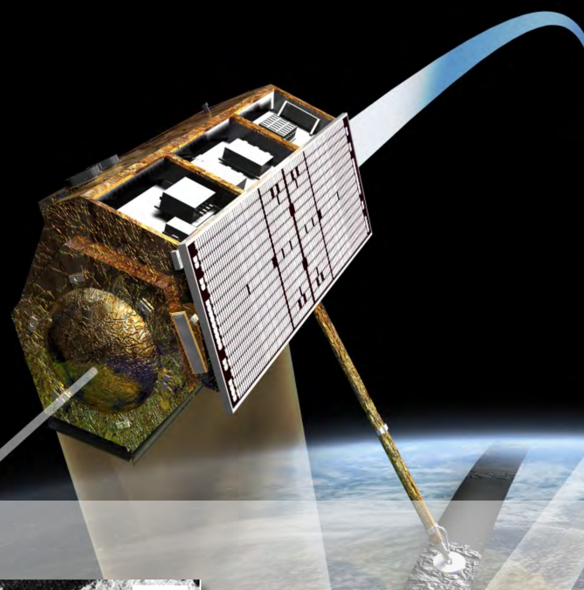


Sentinel 1A /1B

- ESA Satellite
- 703 km altitude
- ground speed 8km/s, 14.5 orbits/day,
- sensor: high frequency **C-band SAR,** wavelength 5.5mm, frequency 5.4GHz
- The **repeat-cycle is 12 days**, but the same region can be imaged with different incidence angles after **2 days**.

- active sensor: sunlight independence
- signal penetrates the clouds

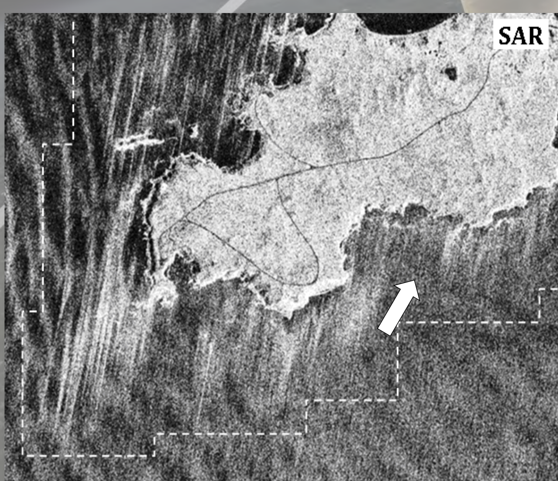
Satellites: X-band SAR (synthetic aperture radar)



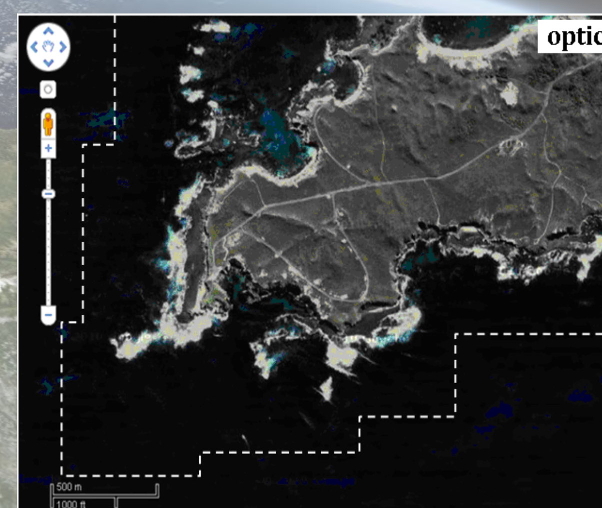
TerraSAR-X / TanDEM-X

- DLR/AIRBUS Cooperation
- 514 km altitude
- ground speed 7km/s, 15 orbits/day,
- sensor: high frequency **X-band SAR,** wavelength 31mm, frequency 9,6GHz
- The **repeat-cycle is 11 days**, but the same region can be imaged with different incidence angles after **2 days**.

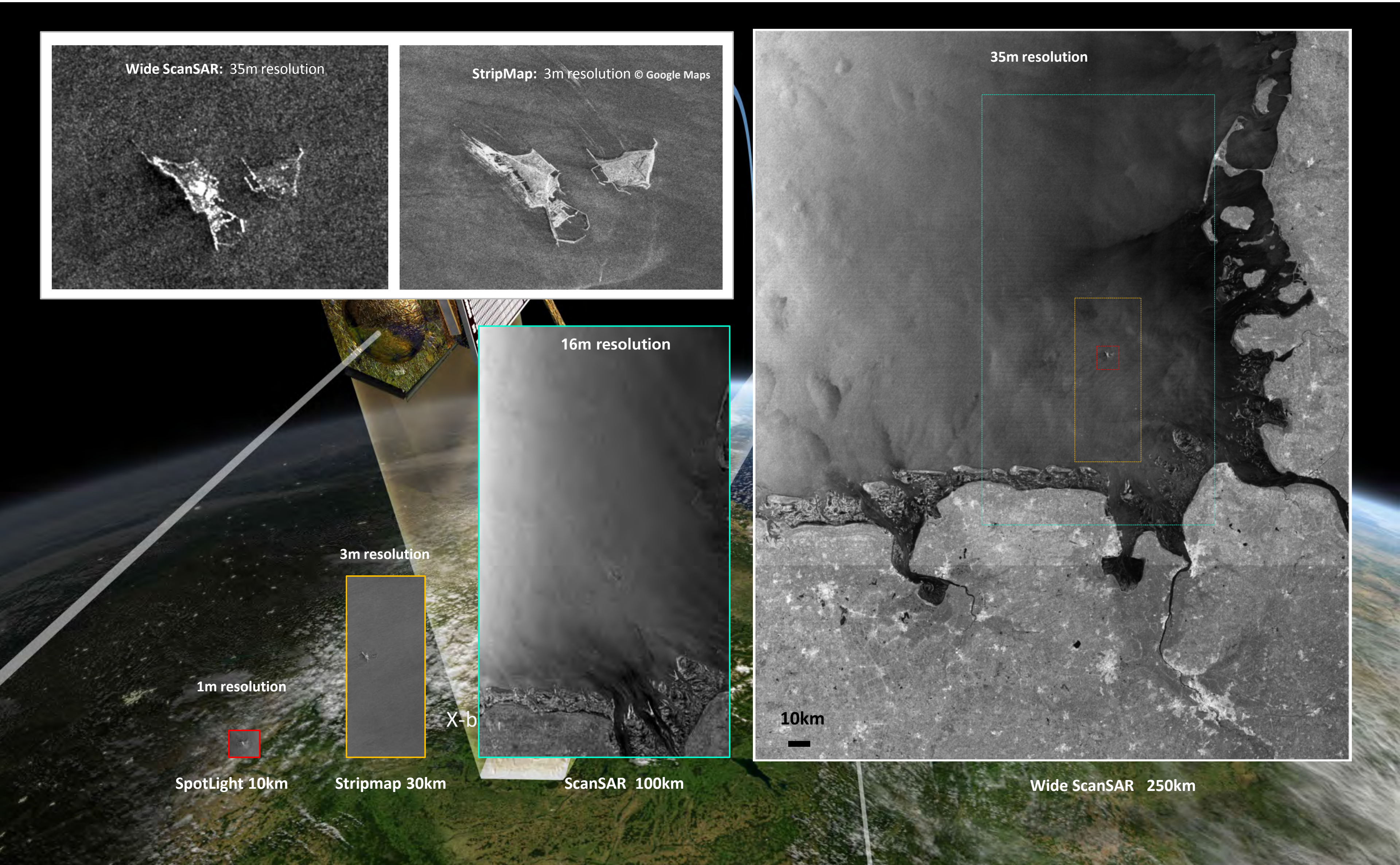
SAR



OPTICAL

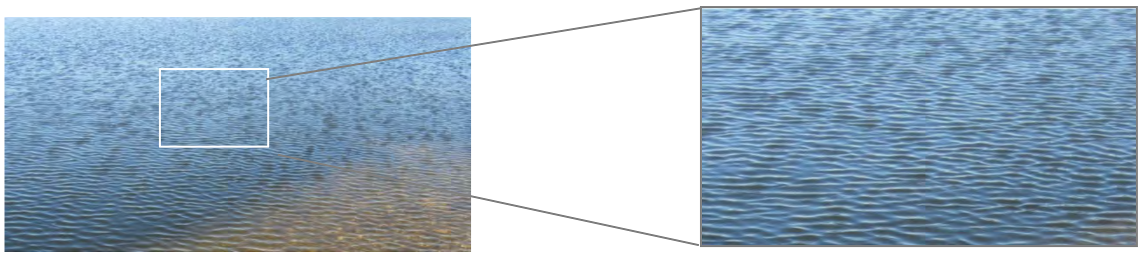


Satellites: X-band SAR (synthetic aperture radar) TerraSAR-X

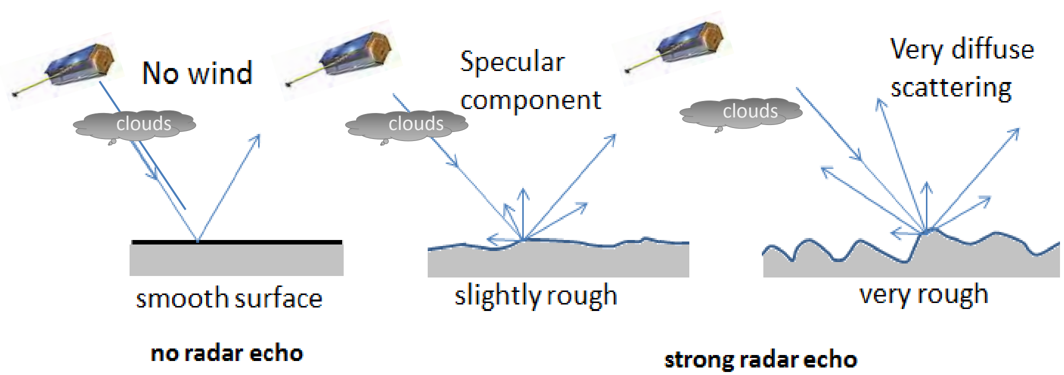


SAR-Derived Wind Fields

Synthetic aperture radar is capable of providing wind information over the ocean by measuring the **roughness of the sea surface**.

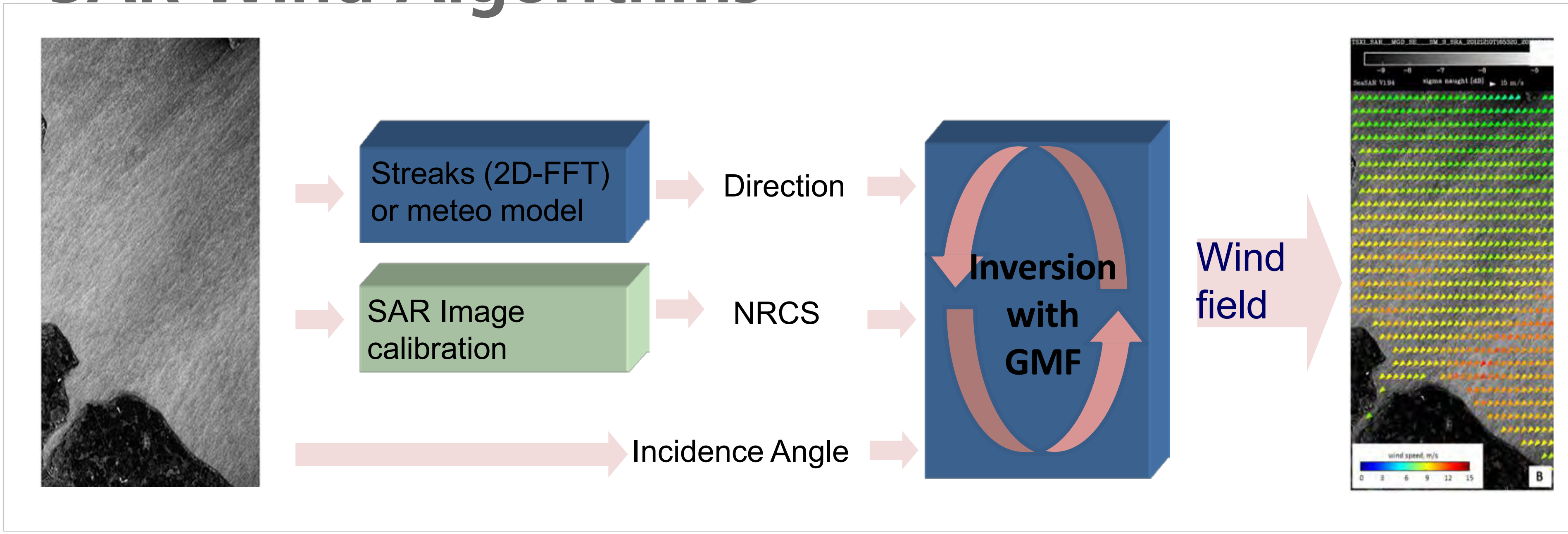


Capillary waves traveling along the boundary layer of a fluid are dominated by the effects of surface tension. The source is the turbulent fluctuations of wind vector.



stronger wind → high surface roughness → stronger radar backscatter

SAR Wind Algorithms



Geophysical Model Function (GMF):

$$\sigma_0 = B_0(v,\theta)\left(1 + B_1(v,\theta)\cos\phi + B_2(v,\theta)\cos 2\phi\right)$$

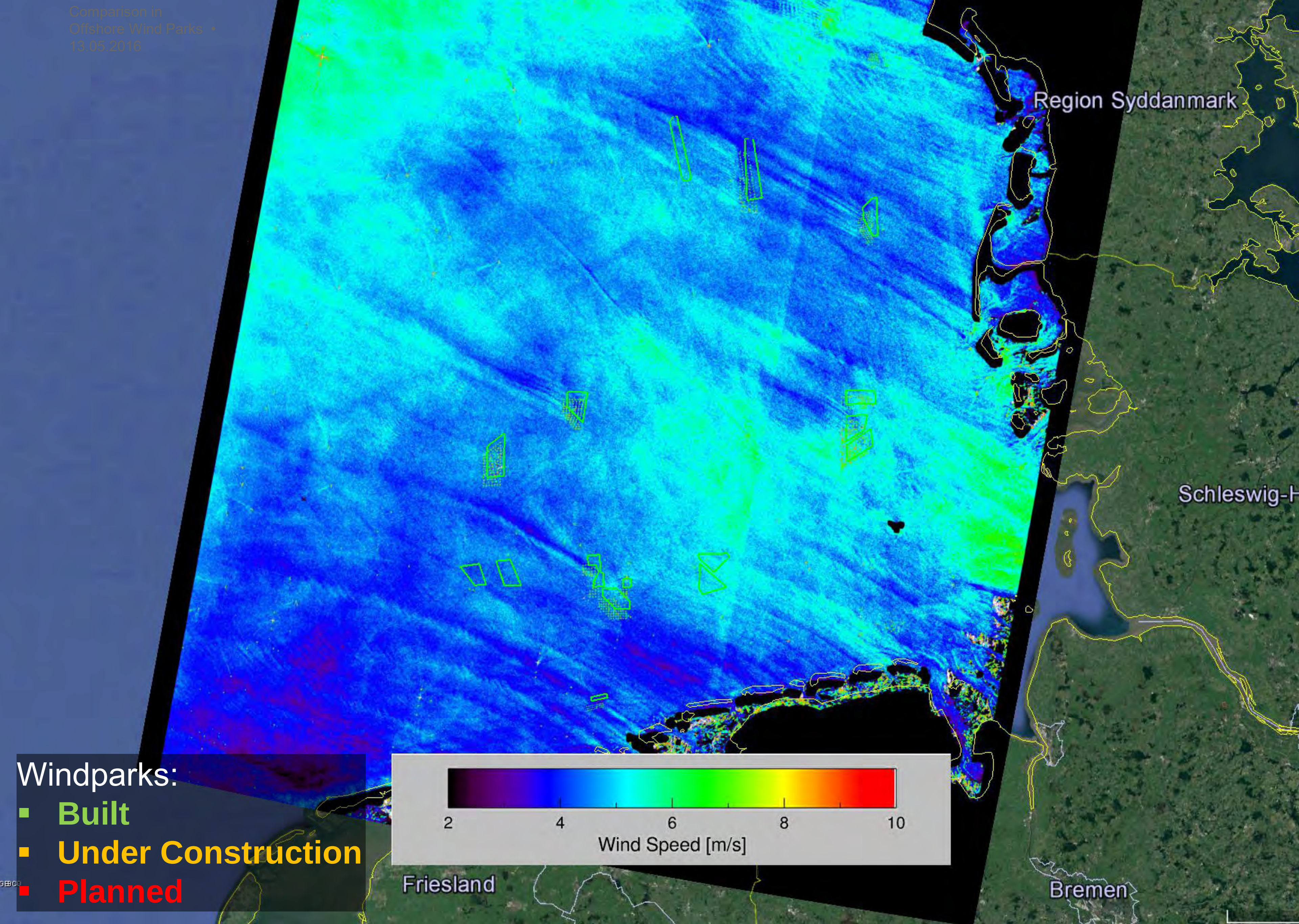
v: Wind Speed

θ: Incidence Angle

φ: Wind Direction

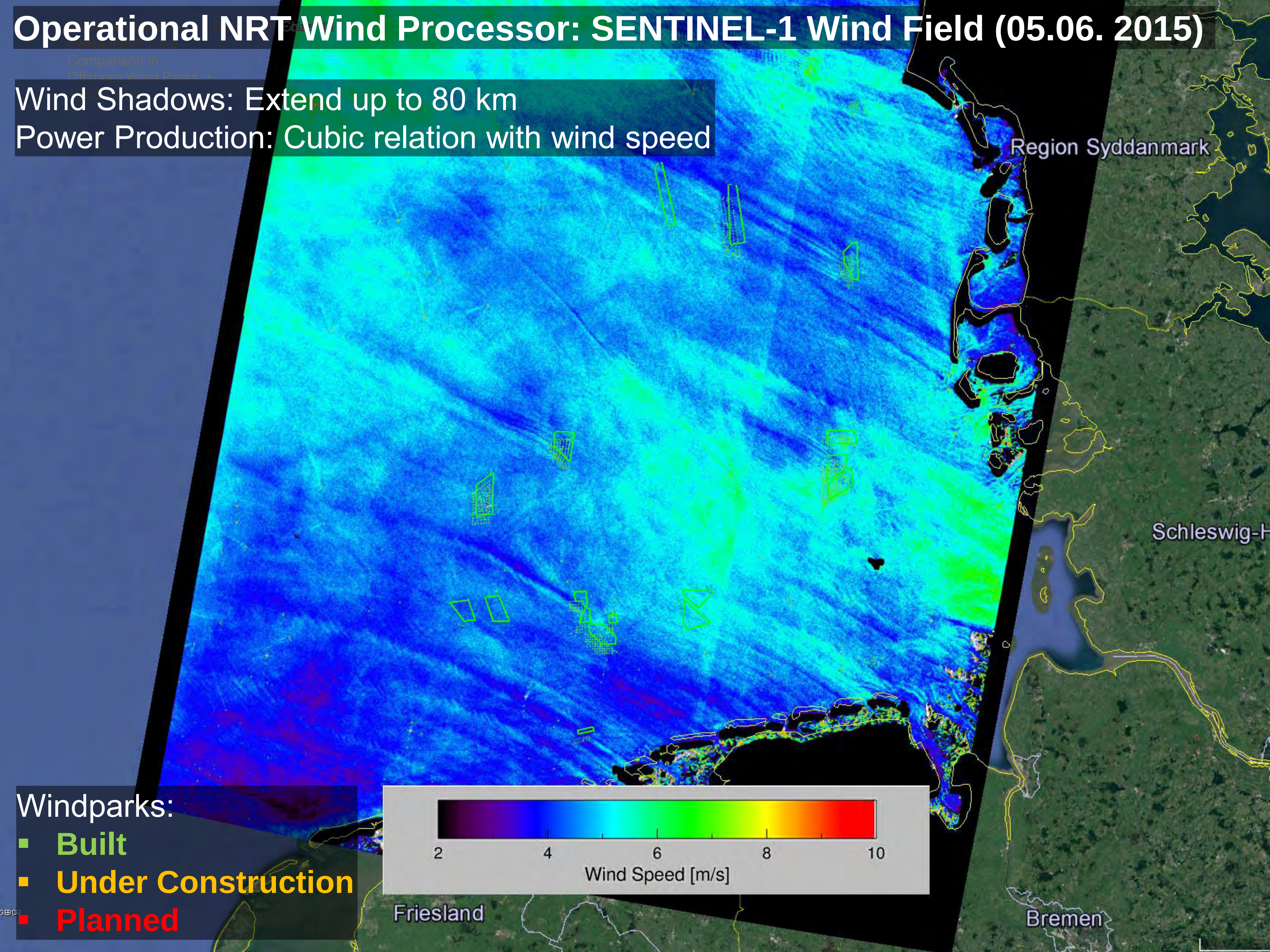
Radar band	GMF	Spaceborne SAR Sensors
C-band (5.6GHz)	CMOD4,CMOD5/5N	ERS/SAR,ENVISAT/ASAR, RADARSAT-1/2
L-band (1.3GHz)	LMOD1/2	JERS-1, ALOS PALSAR-1/2
X-band (9.6GHz)	**XMOD/XMOD2**	TerraSAR-X/TanDEM-X, Cosmo-SkyMed

Operational NRT Wind Processor: SENTINEL-1 Wind Field (05.06. 2015)



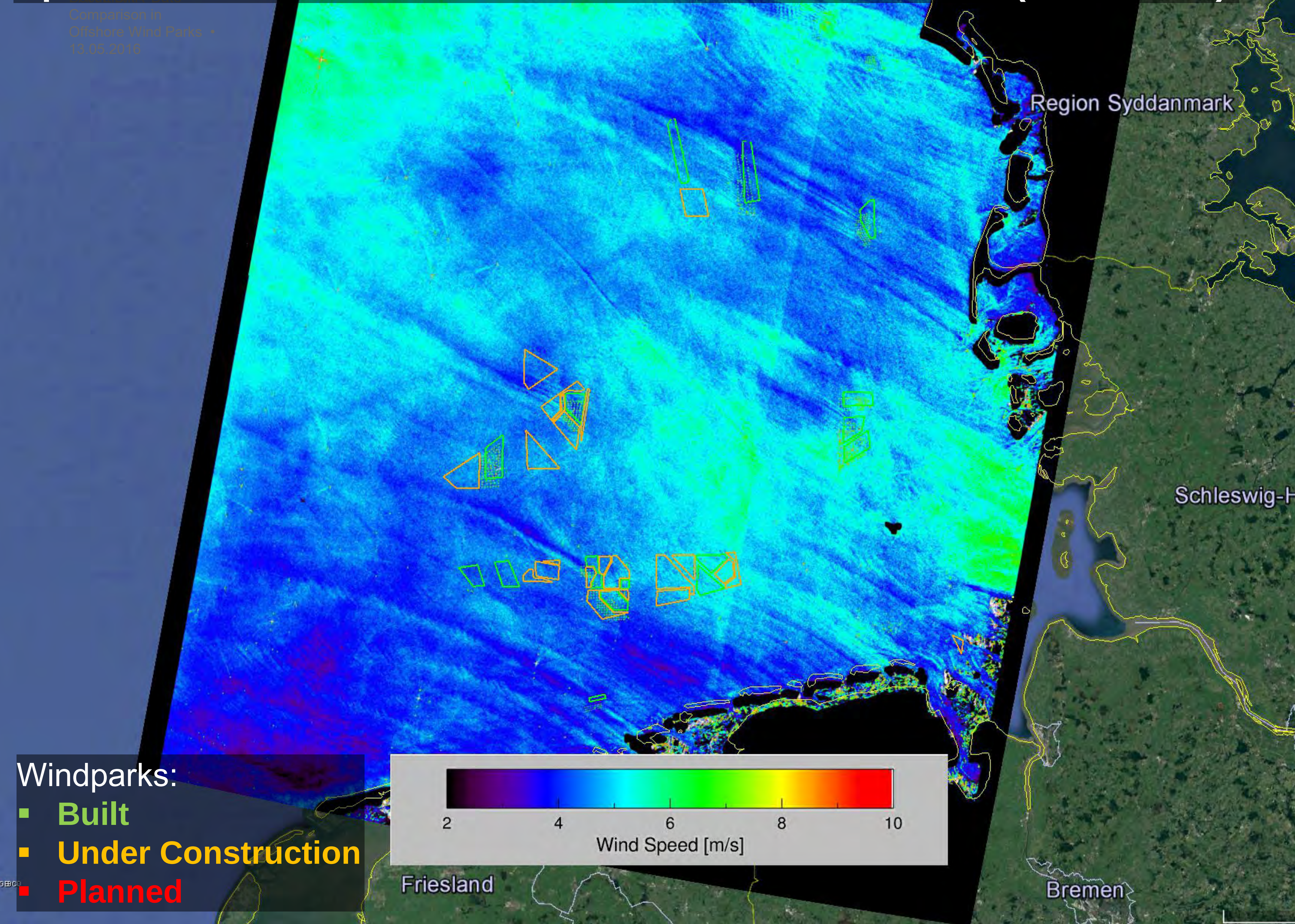
Operational NRT Wind Processor: SENTINEL-1 Wind Field (05.06. 2015)

Wind Shadows: Extend up to 80 km
Power Production: Cubic relation with wind speed

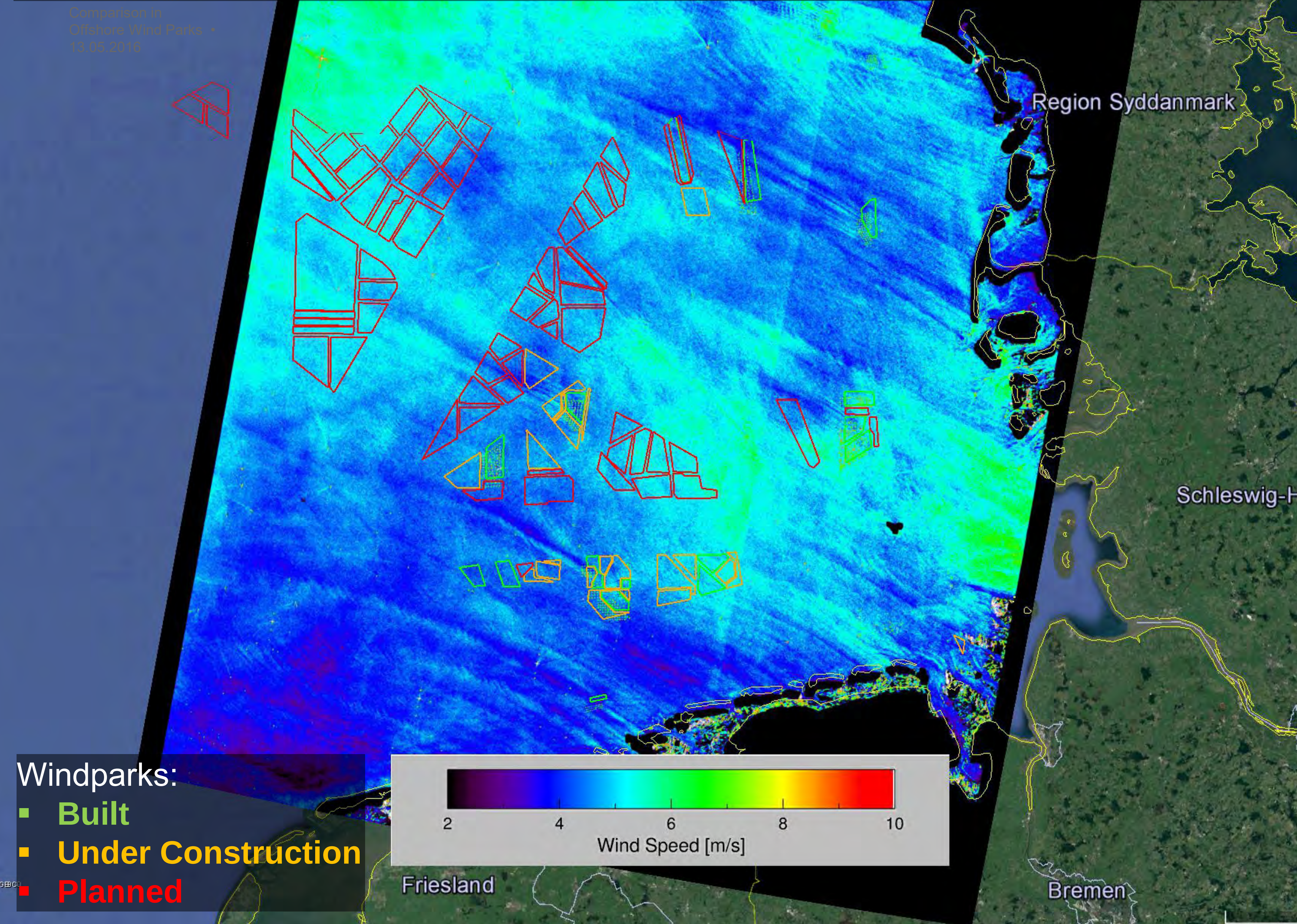


Windparks:
- Built
- Under Construction
- Planned

Operational NRT Wind Processor: SENTINEL-1 Wind Field (05.06. 2015)



Operational NRT Wind Processor: SENTINEL-1 Wind Field (05.06. 2015)



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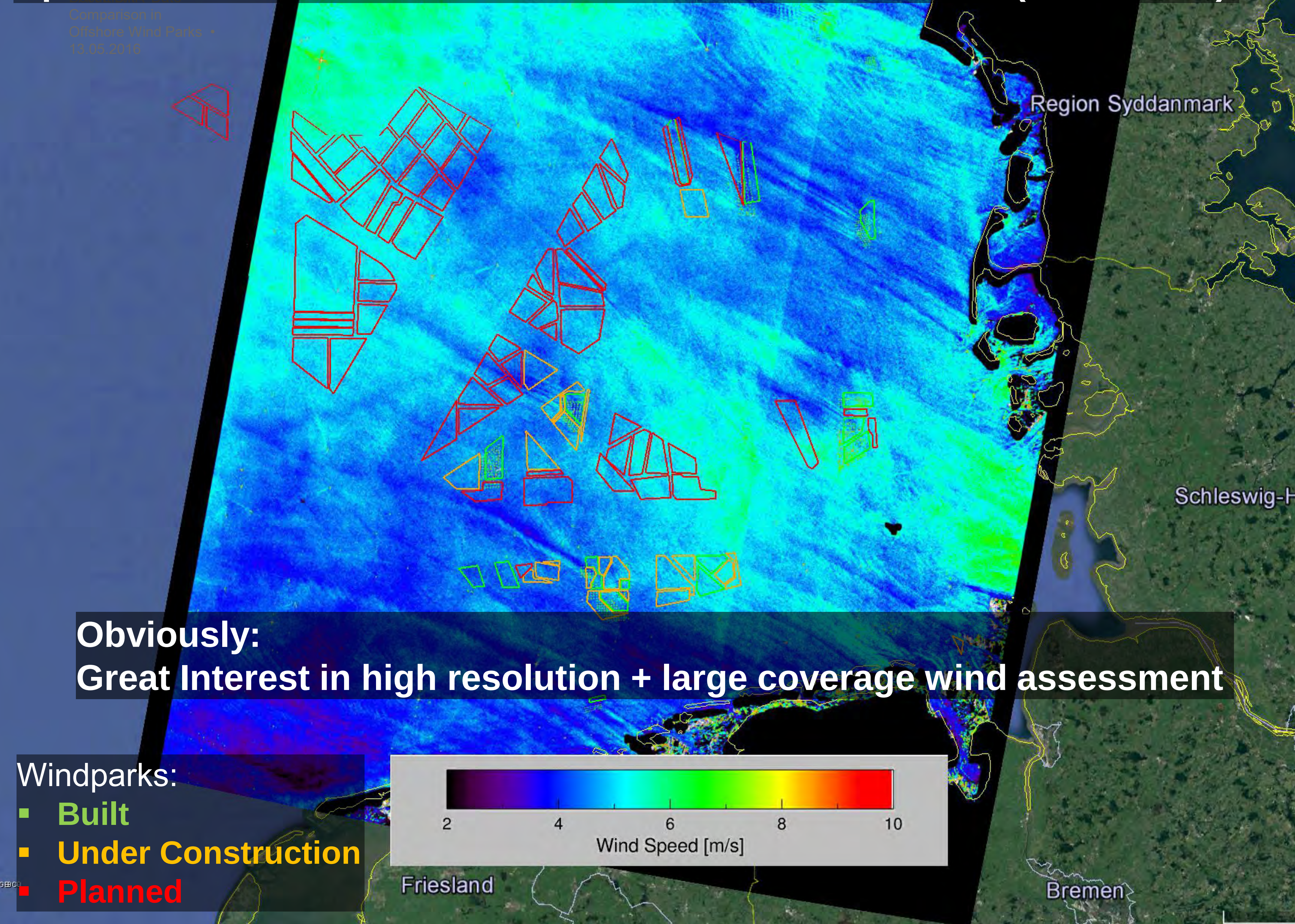
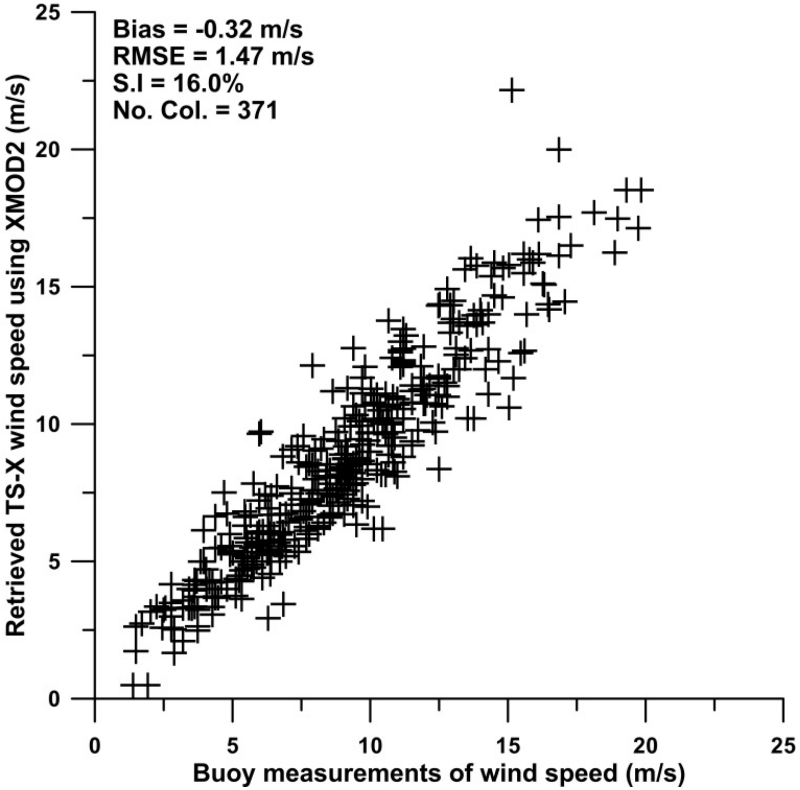


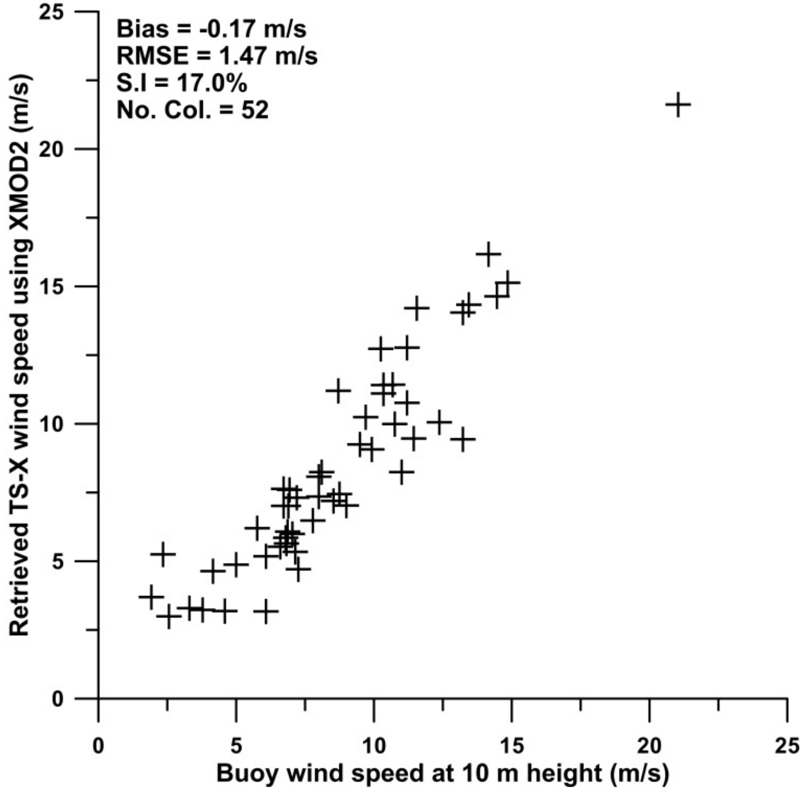
Obviously:
Great Interest in high resolution + large coverage wind assessment

Open Questions:

- How accurate are GMFs designed for and validated with larger footprints to wind variations on 100m-500m scale ?
- How accurately can small-scale SAR wind variations be extrapolated to greater heights ?

XMOD2 Validation



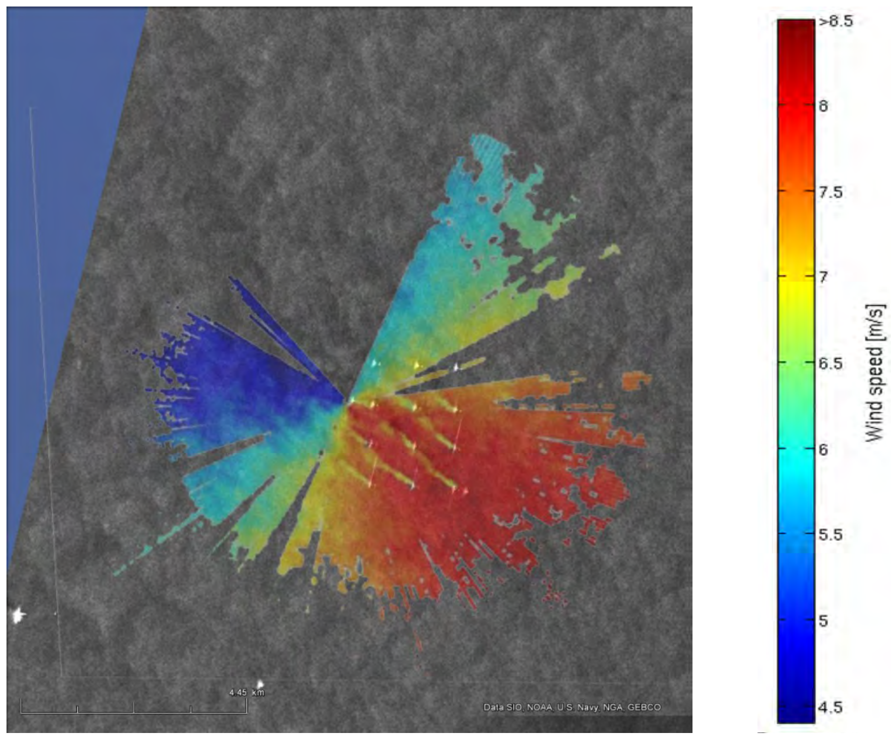


Colocations	Bias	RMSE	SI
371 (training)	-0.32 m/s	1.47 m/s	16.0%
52 (validation)	*-0.17 m/s*	*1.47 m/s*	*17.0%*

X.-M. Li and S. Lehner, "Algorithm for Sea Surface Wind Retrieval From TerraSAR-X and TanDEM-X Data," *IEEE Transactions on Geoscience and Remote Sensing*, vol. Early Access Online, 2013.

DLR ForWind Center for Wind Energy Research

Approach: Wind Fields From two Independent Methods



Alpha Ventus Offshore Wind Park

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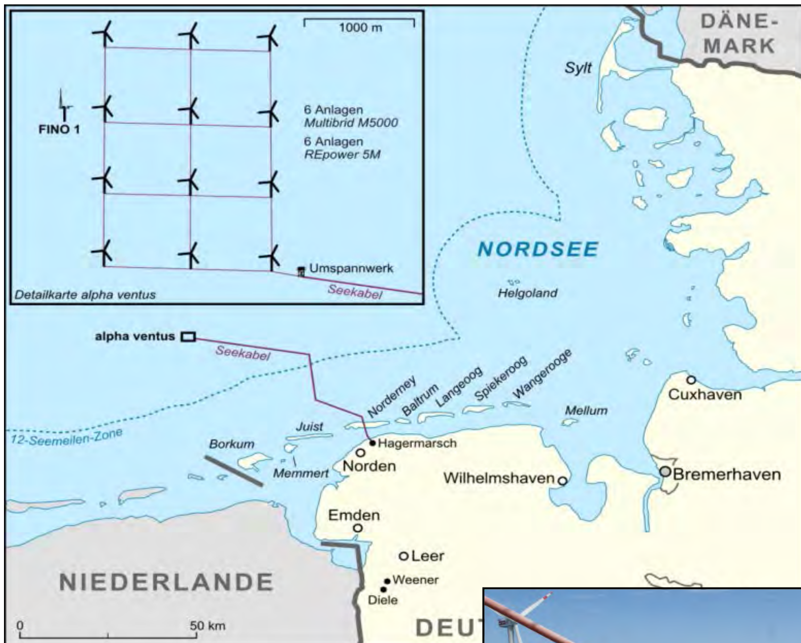
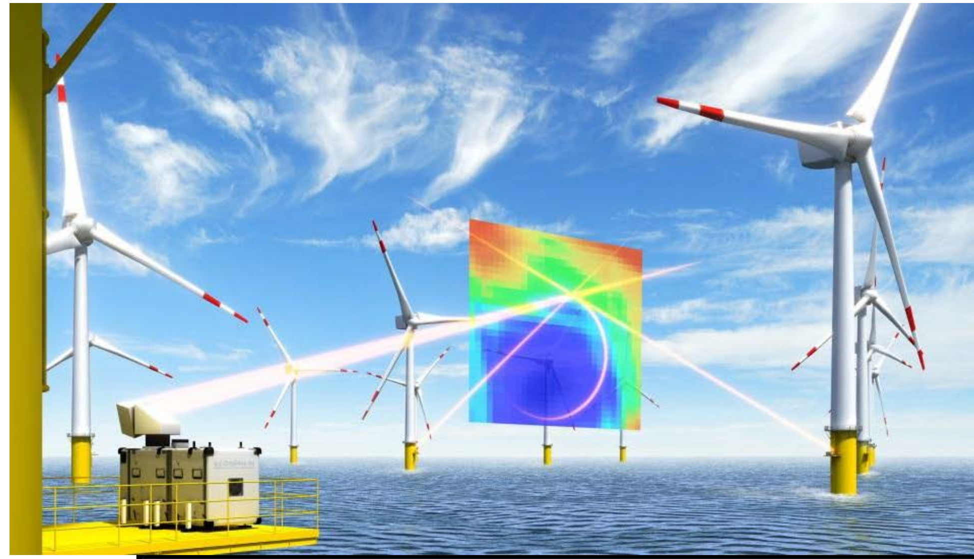
ForWind Center for Wind Energy Research

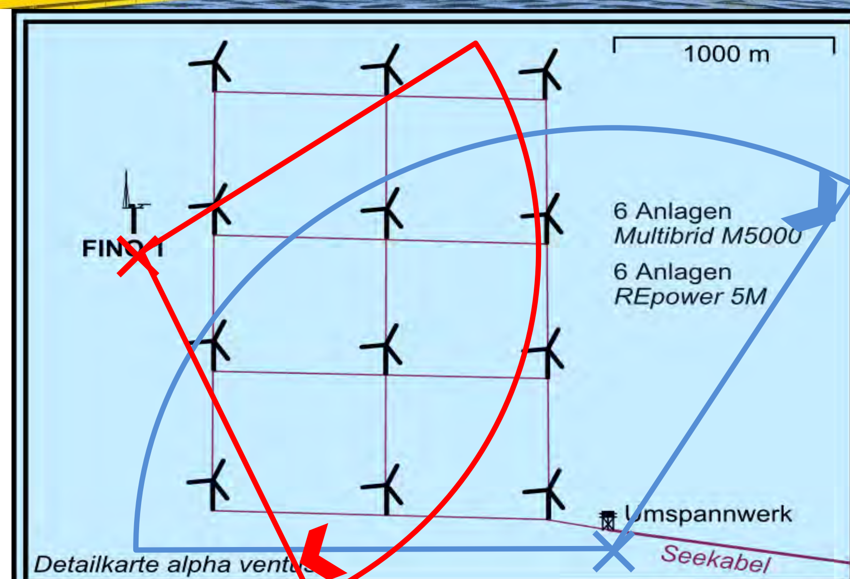
Joint Campaign with ForWind (Oldenburg)

Center for Wind Energy Research
Bremen
Hannover
Oldenburg

On-Site LIDAR

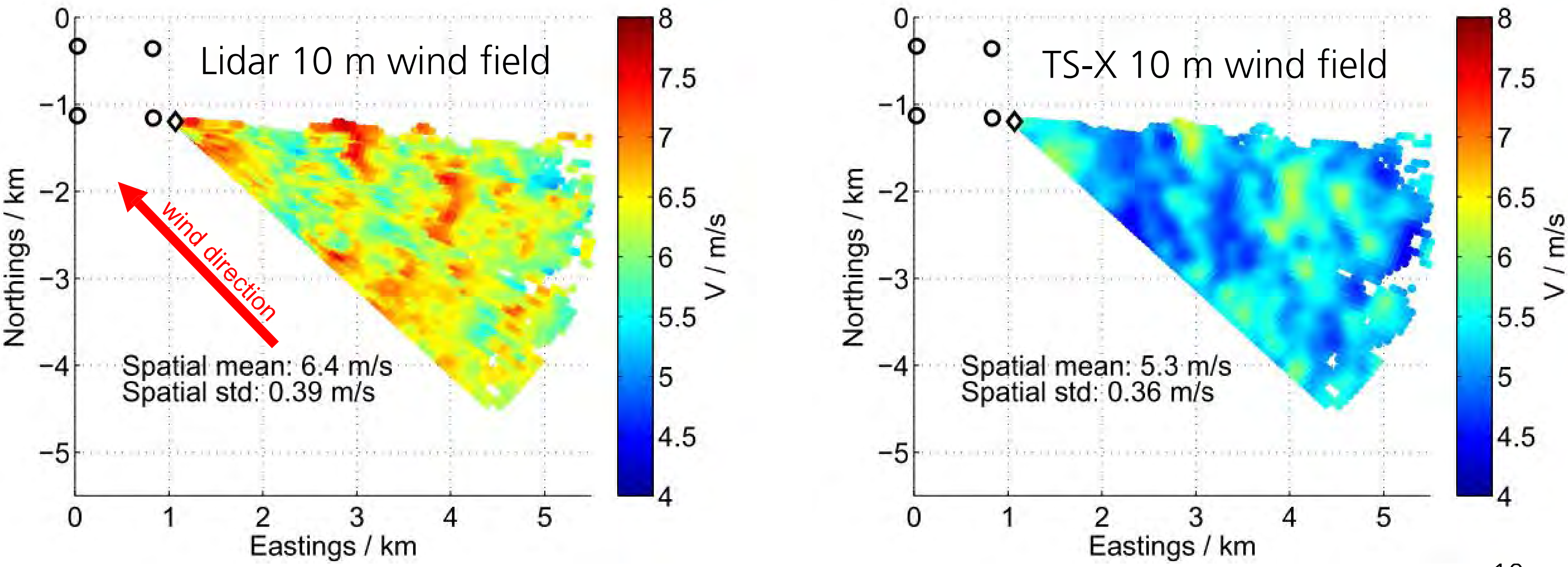






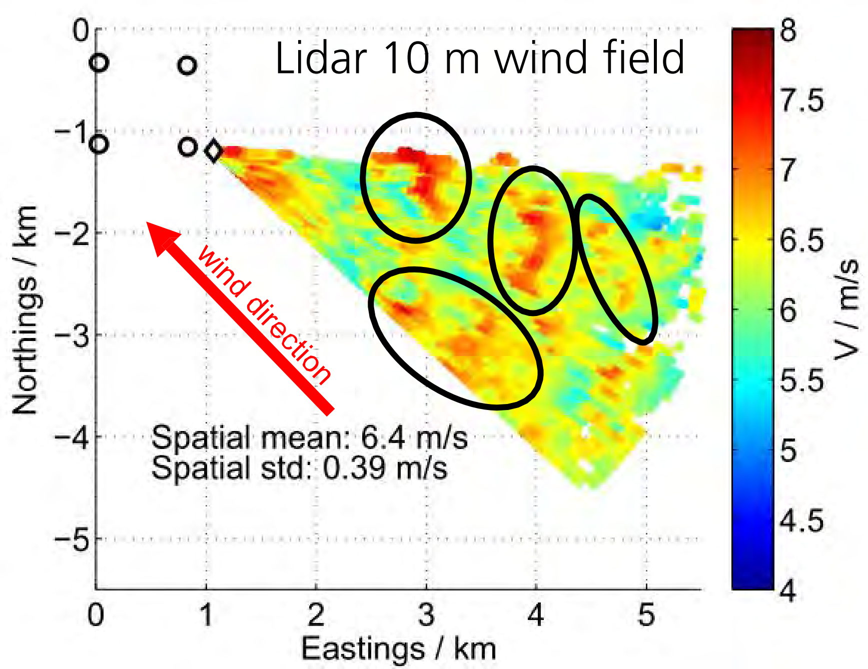
Results in free flow
Comparison of spatial structures

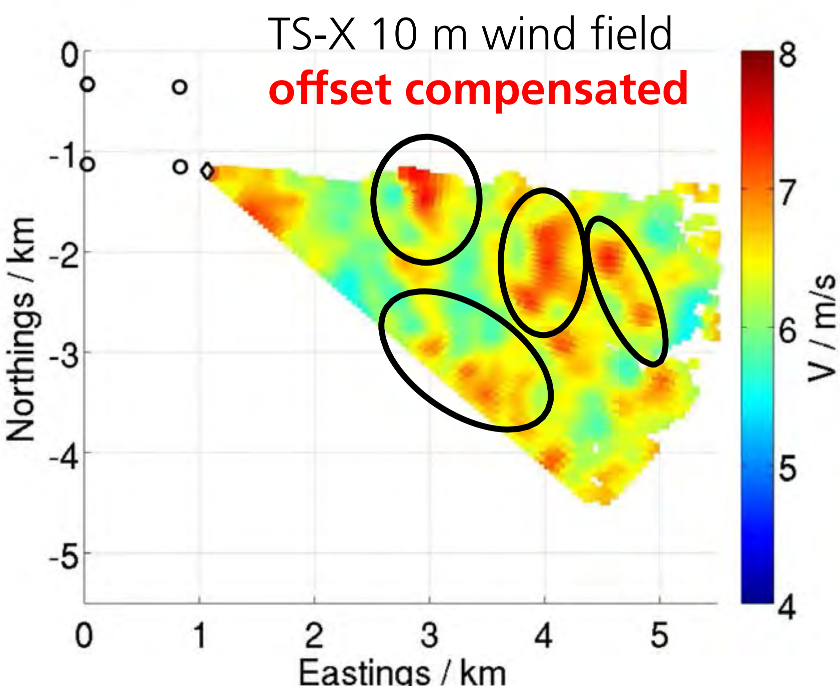
- Offset in average wind measurement 1.1 m/s
- Spatial standard deviation comparable



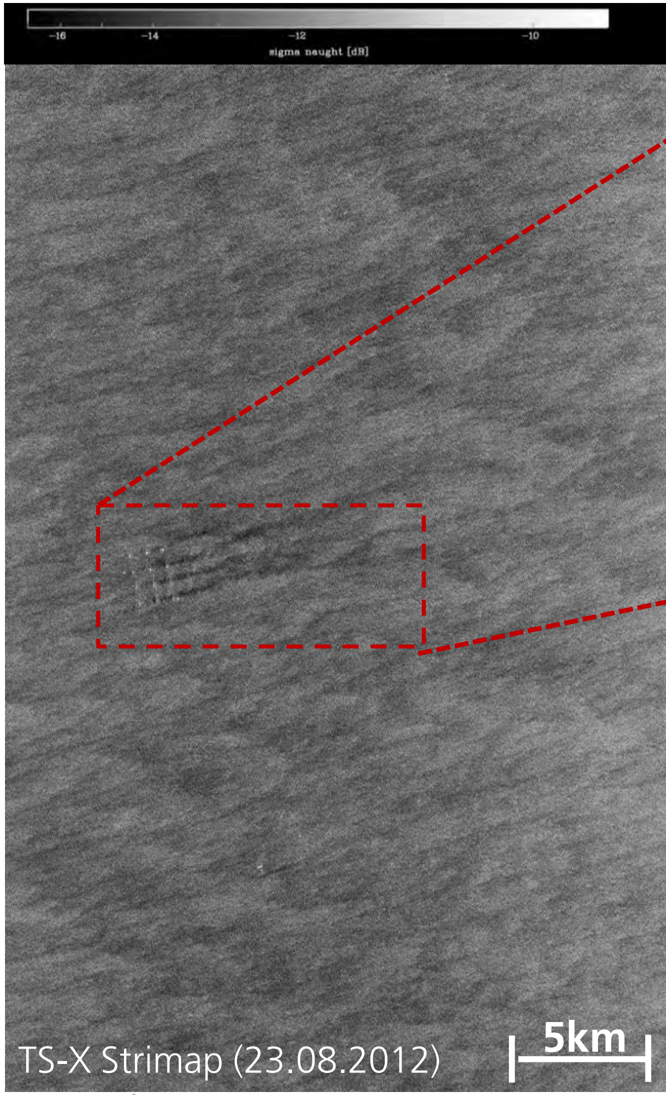
Results in free flow
Comparison of spatial structures

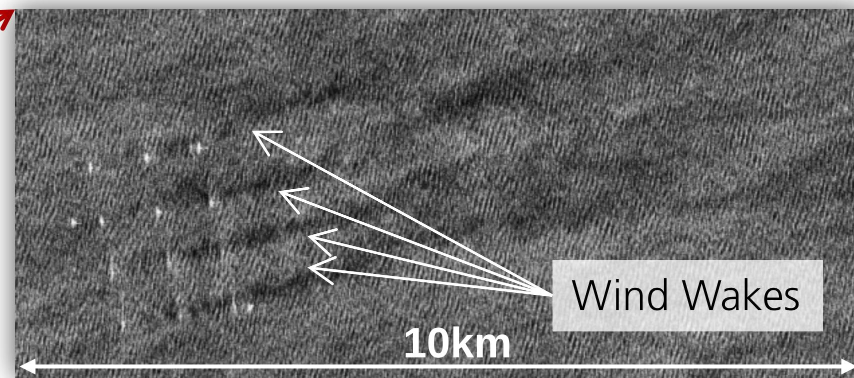
- Spatial structures of lidar measurement well observable in TS-X measurement

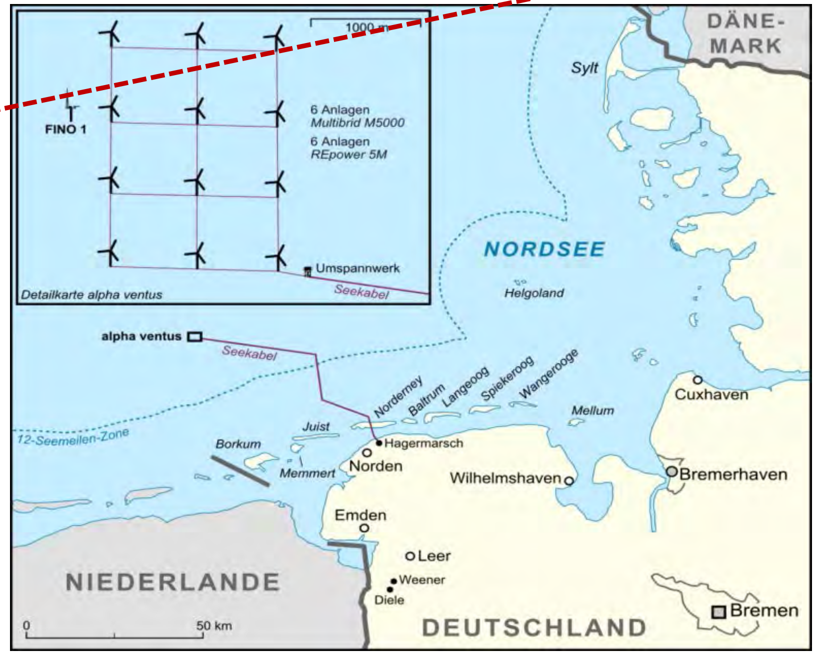


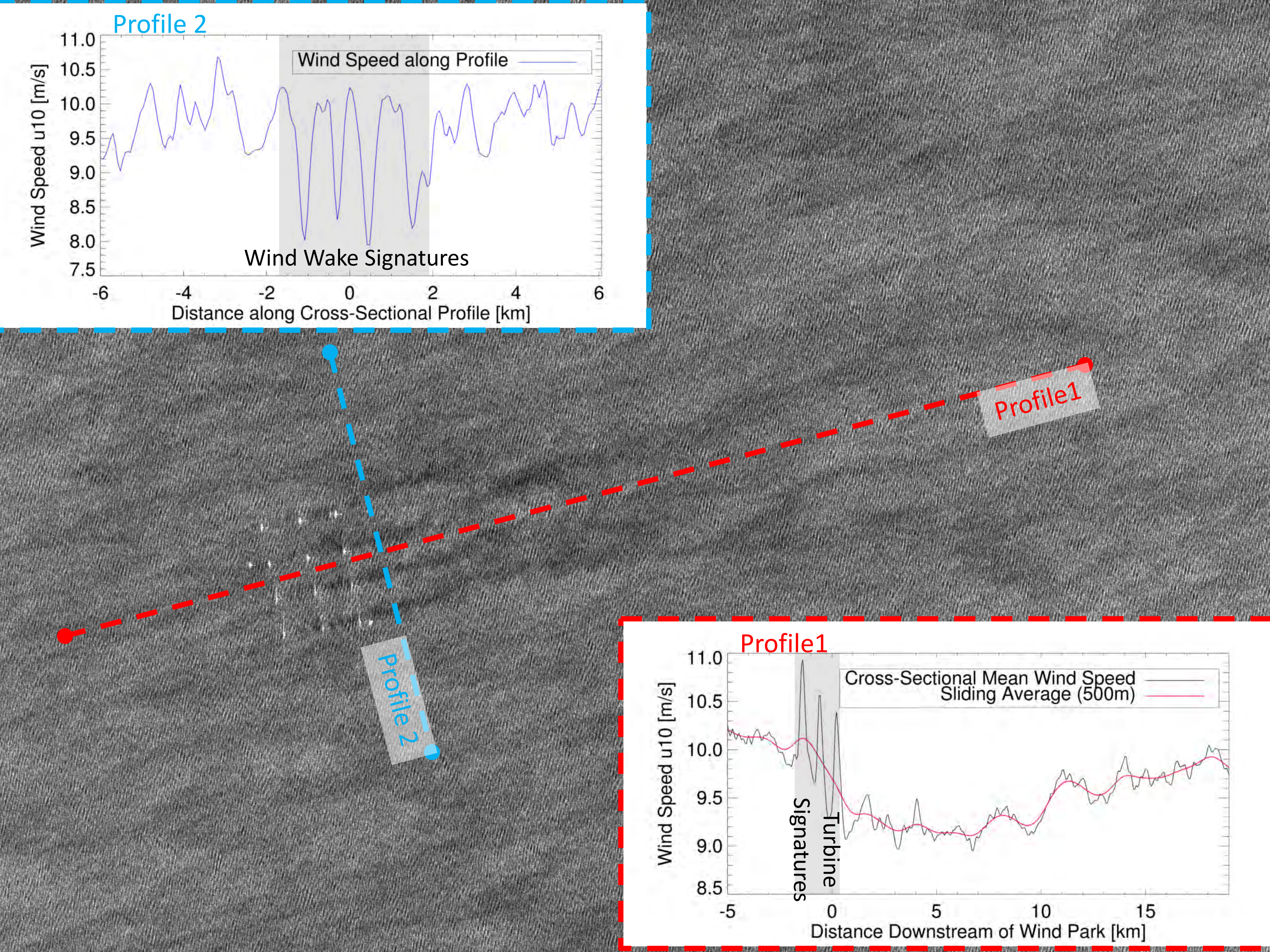


Alpha Ventus Offshore Wind Park



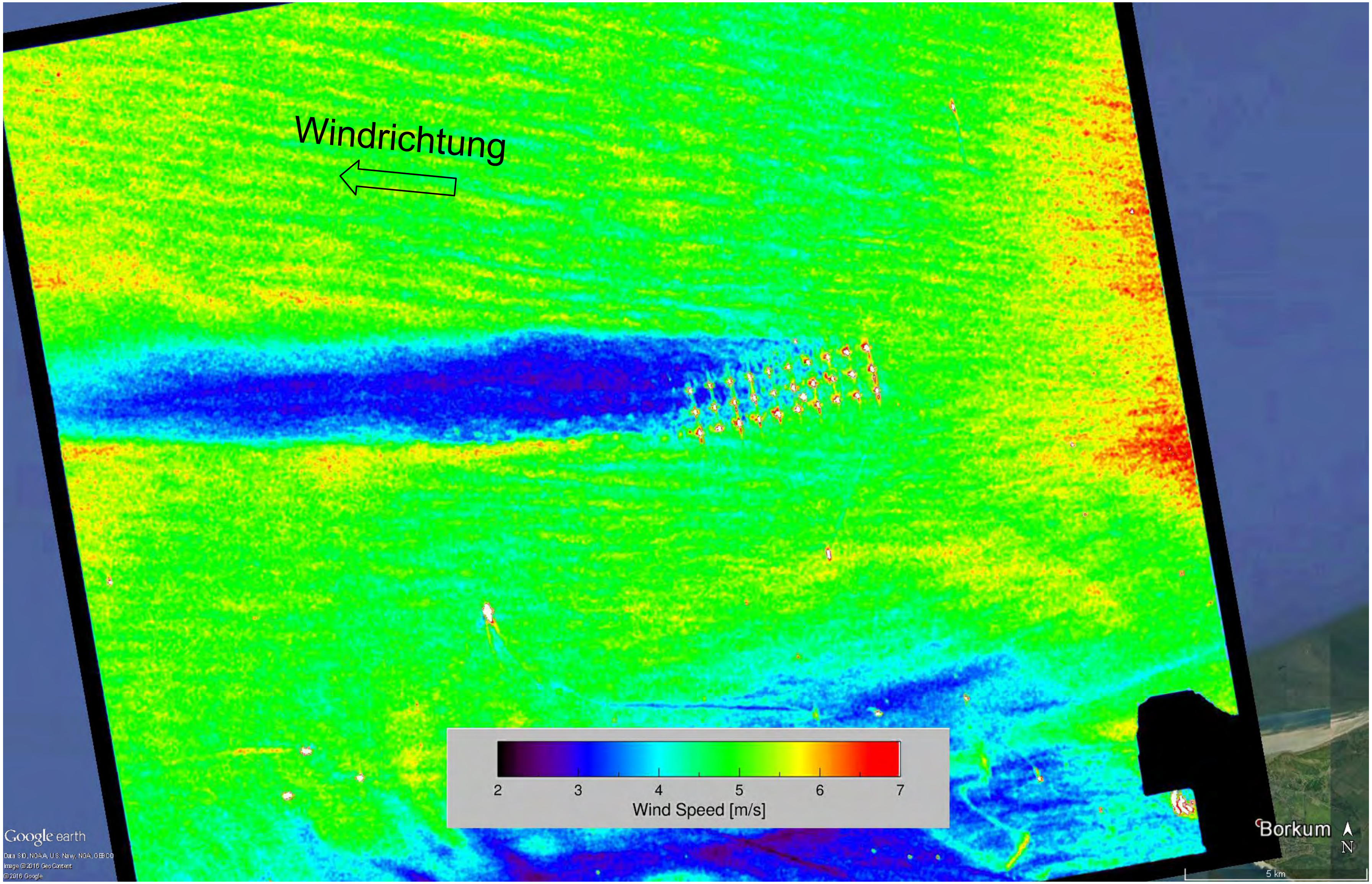






Profile 2
Wind Speed along Profile
Wind Speed u10 [m/s]
Wind Wake Signatures
Distance along Cross-Sectional Profile [km]
Profile1
Profile 2
Profile1
Cross-Sectional Mean Wind Speed
Sliding Average (500m)
Wind Speed u10 [m/s]
Turbine Signatures
Distance Downstream of Wind Park [km]

TS-X StripMap (20150820); Riffgat Windpark vor Borkum



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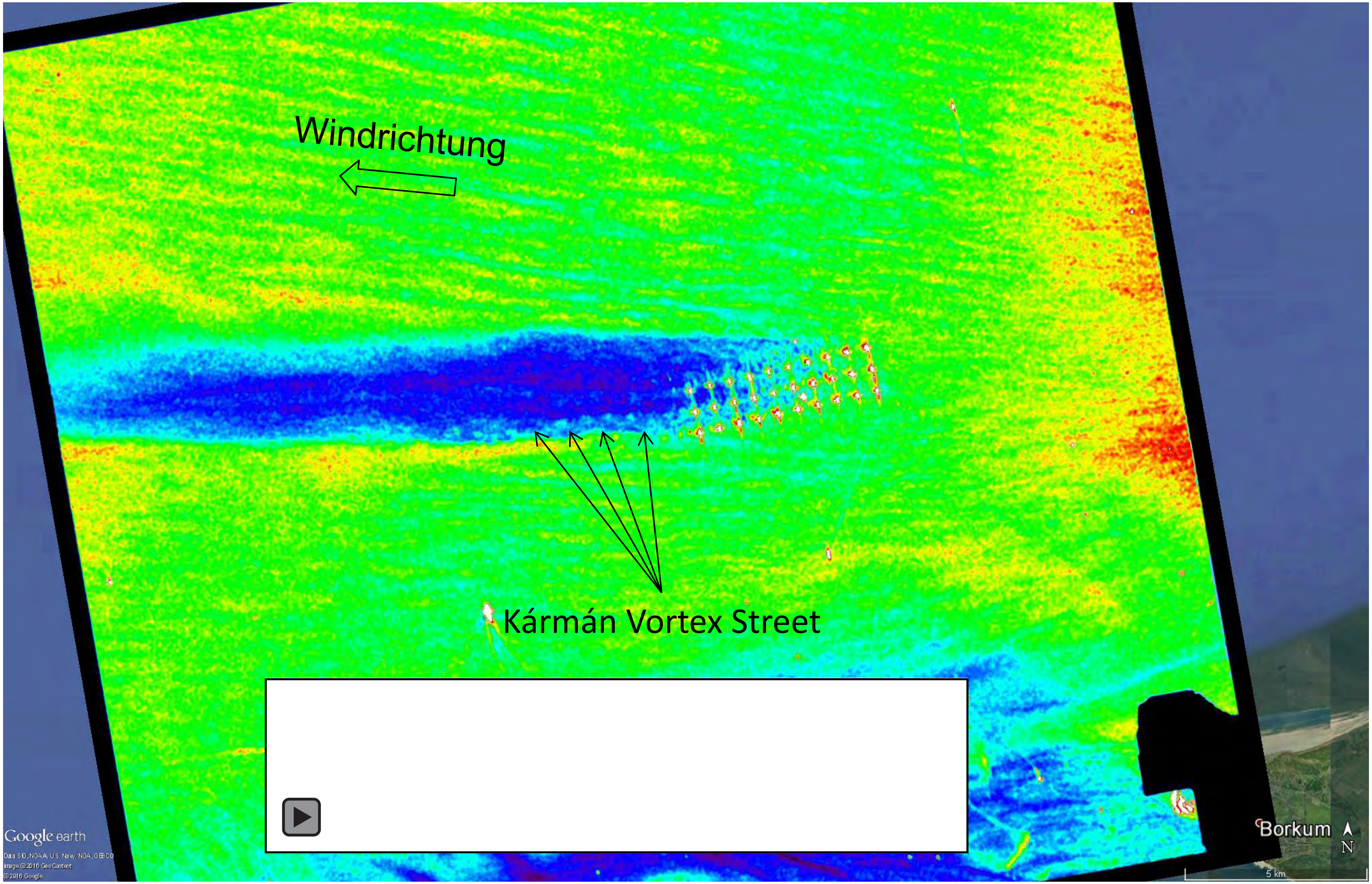
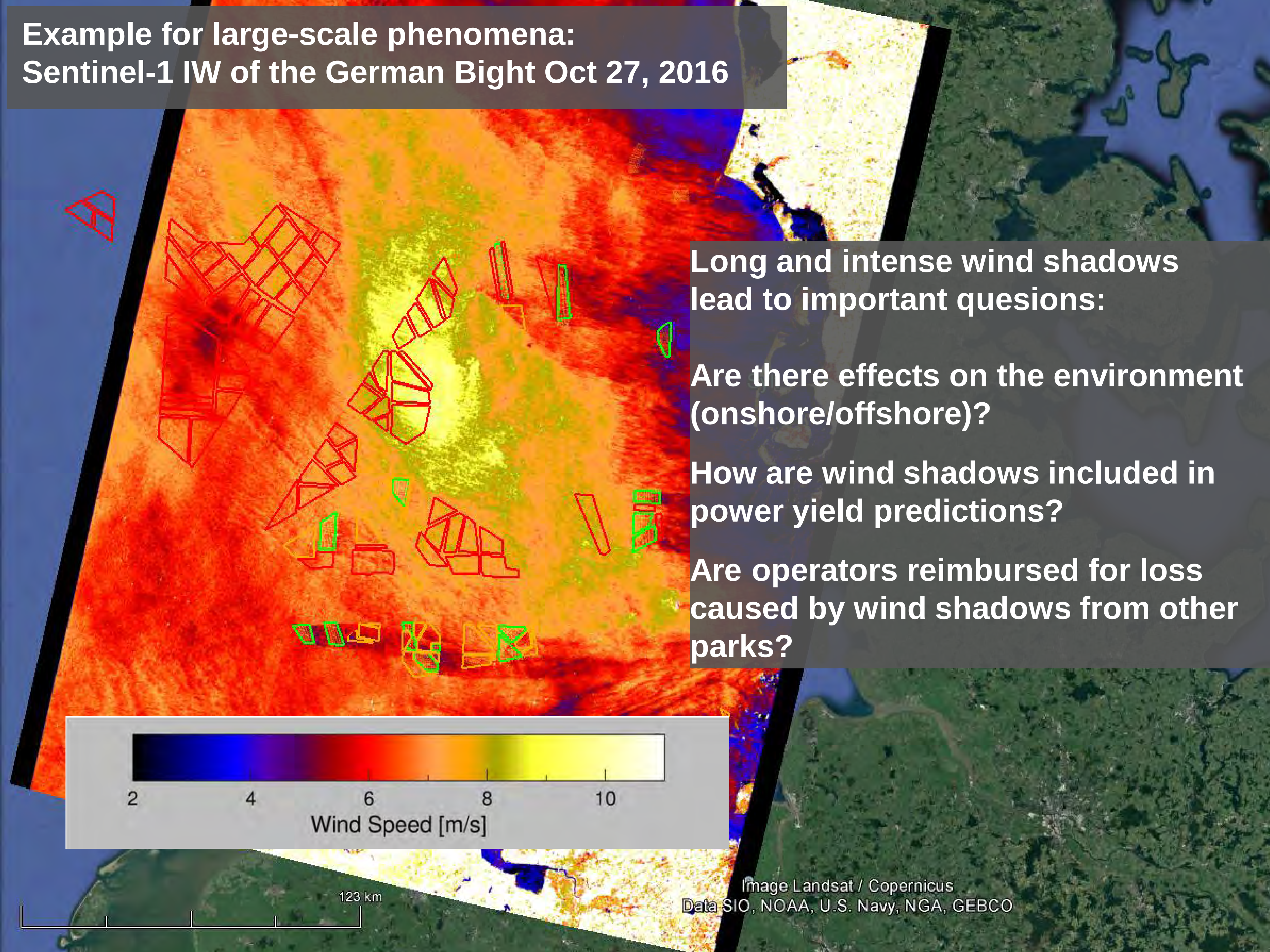


Example for large-scale phenomena:
Sentinel-1 IW of the German Bight Oct 27, 2016



Long and intense wind shadows lead to important quesions:

Are there effects on the environment (onshore/offshore)?

How are wind shadows included in power yield predictions?

Are operators reimbursed for loss caused by wind shadows from other parks?

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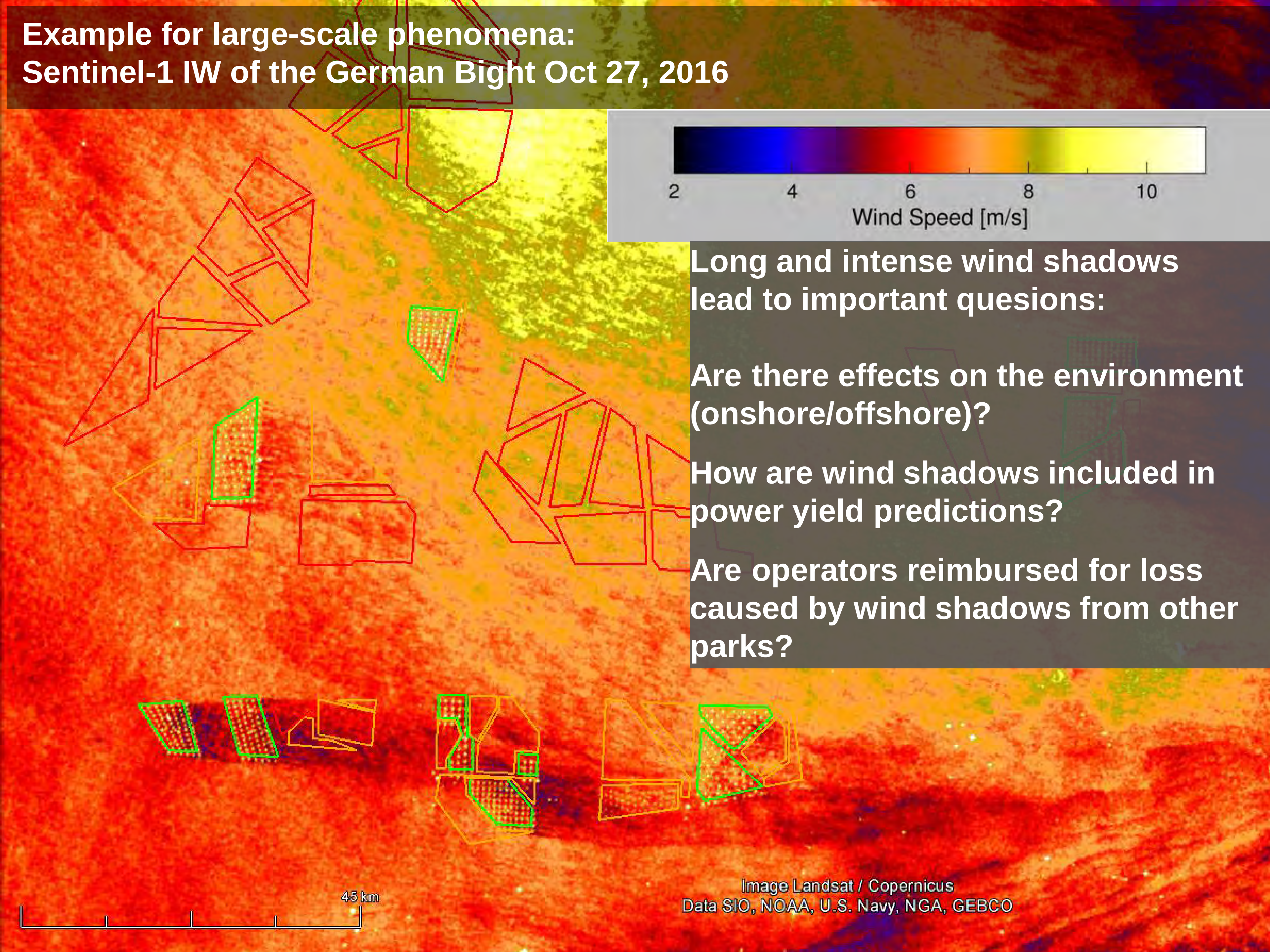

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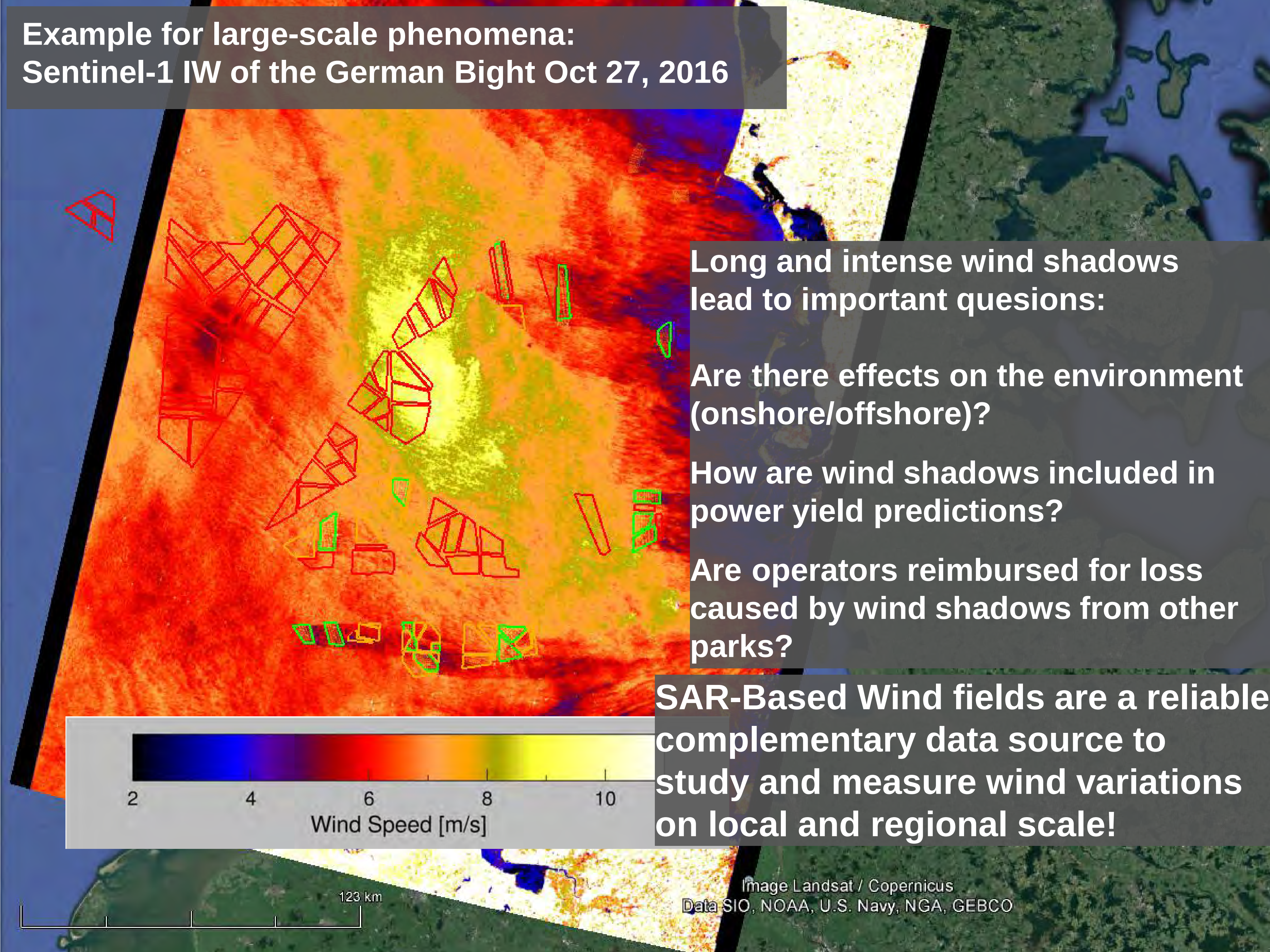

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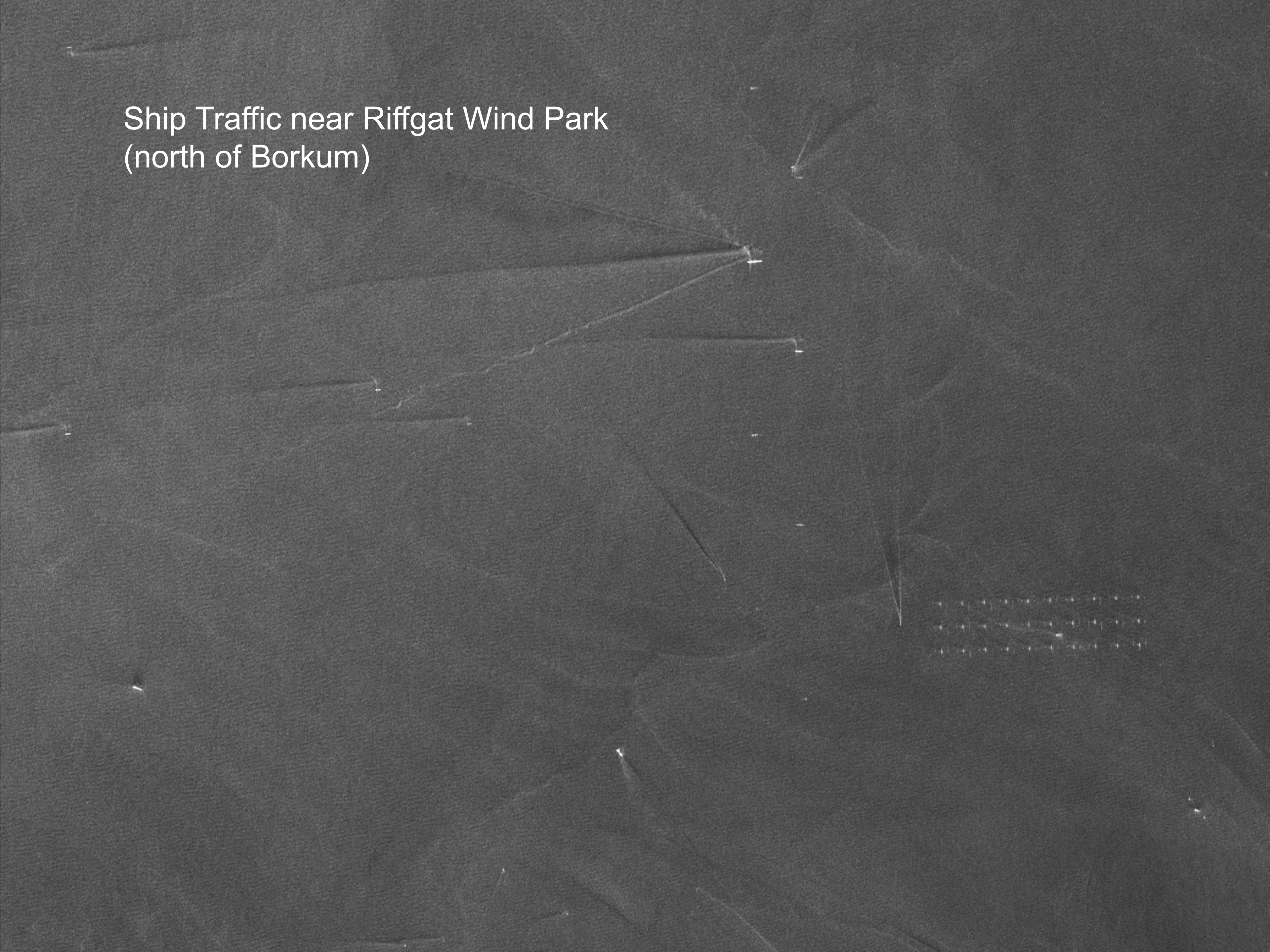
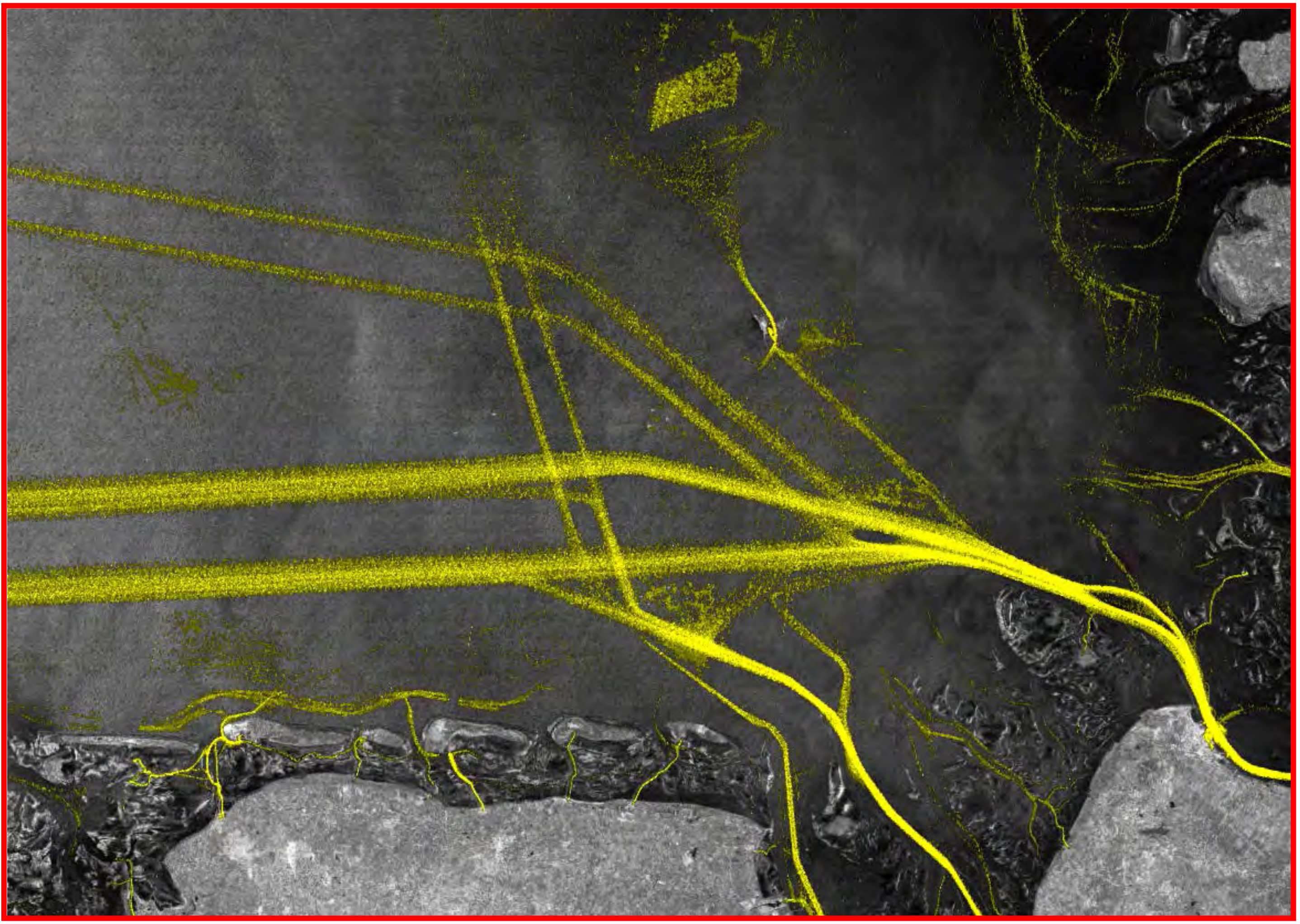
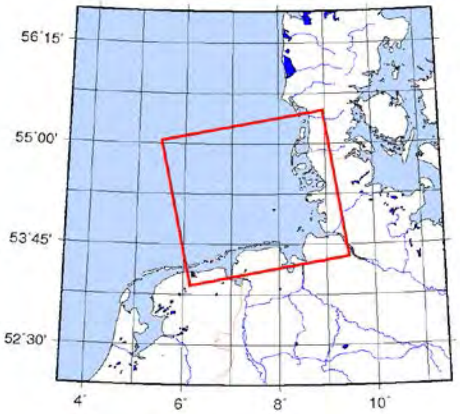
SAR-Based Wind fields are a reliable complementary data source to study and measure wind variations on local and regional scale!


Ship Traffic near Riffgat Wind Park
(north of Borkum)

Ship traffic in the German Bight





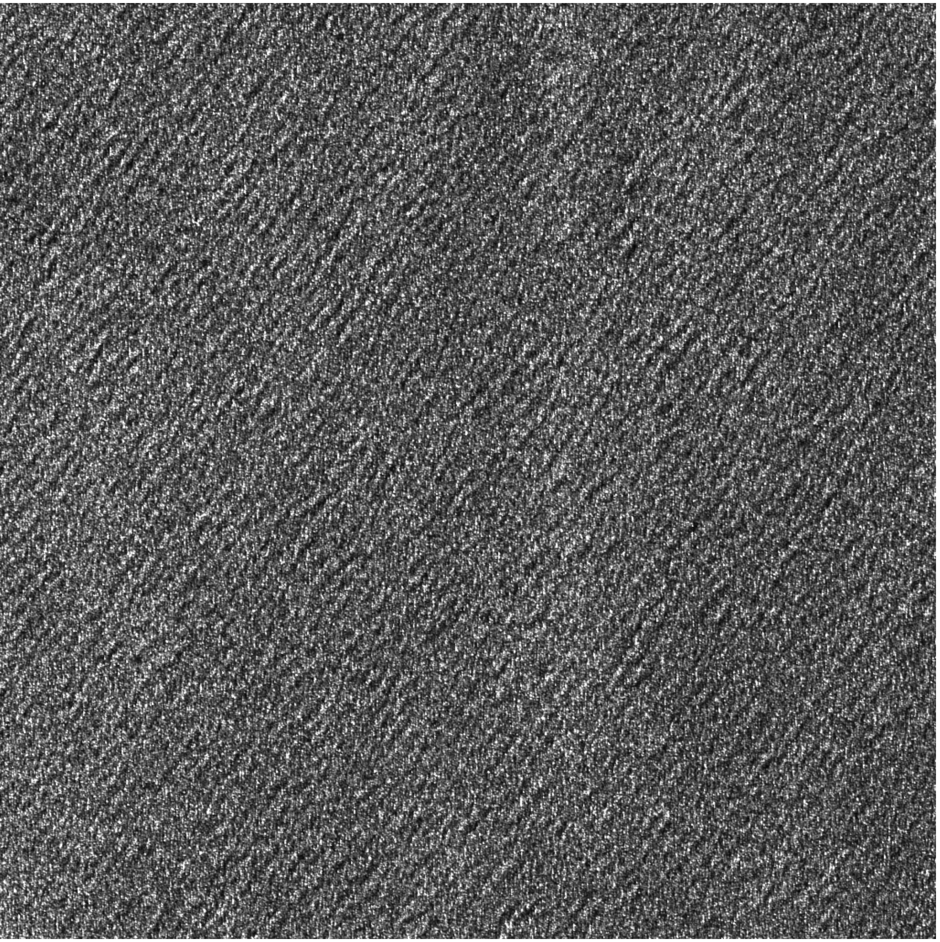
Sea state important for situation awareness and operation planning!

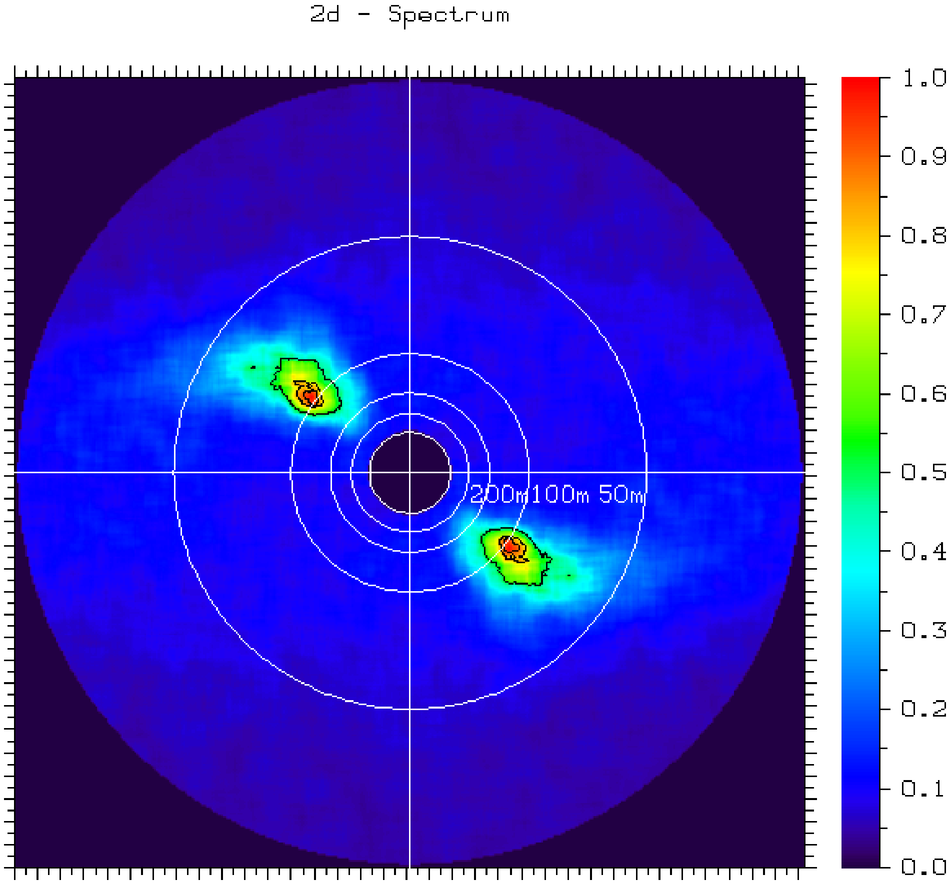
Wave height can be 10-12m during storms

Alpha Ventus:
Offshore Windpark in der Nordsee

DLR

Sea State important for situation awareness and operation planning!





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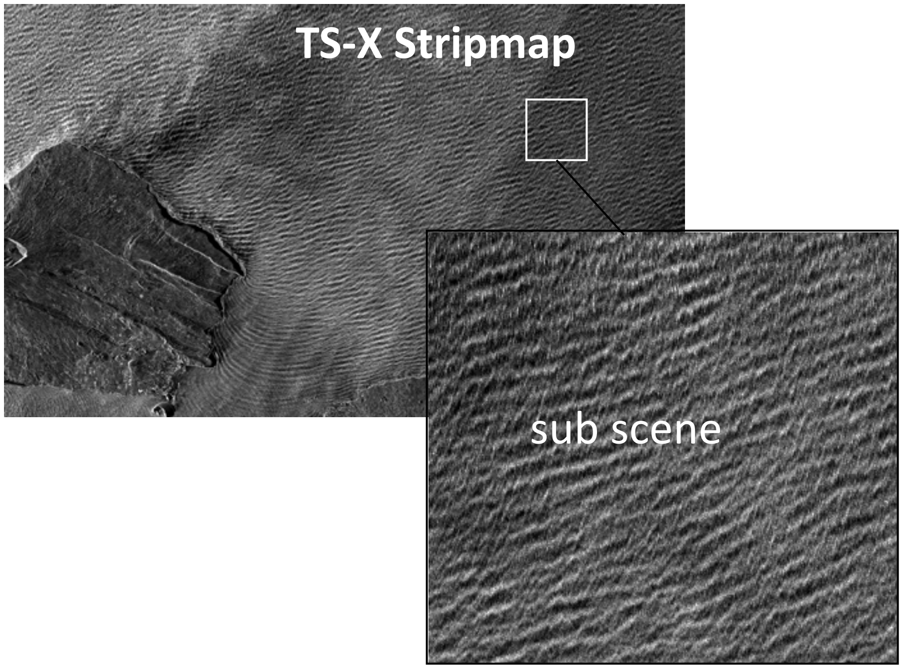
XWAVE empirical algorithm: GMF principle and structure



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

$$S = FFT(m)$$

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

signal intensity *I*

signal modulation ***m***

image spectra ***S***

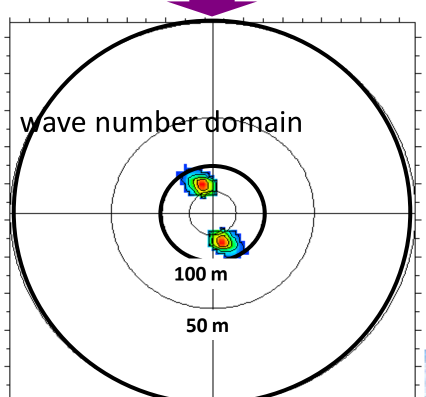
filtering, L_{min}, L_{max}

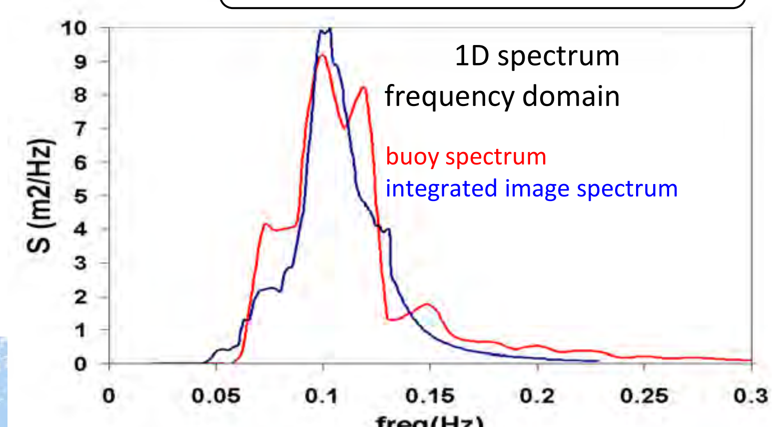
Local Wind (XMOD)

XWAVE GMF function

Parameters: H_s, L_p, T_p…

2D image spectrum





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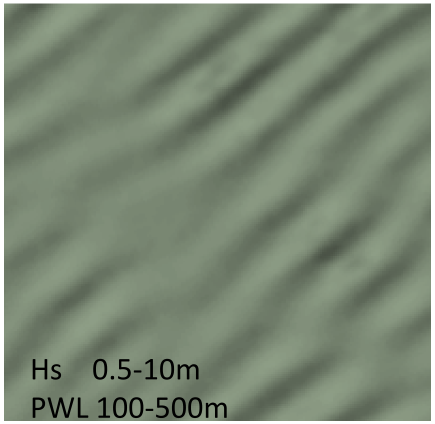
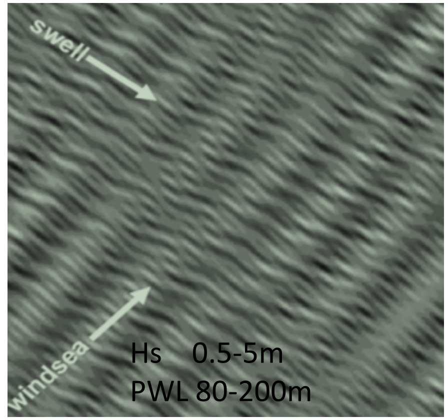
waves: swell, windsea, short windsea in costal areas

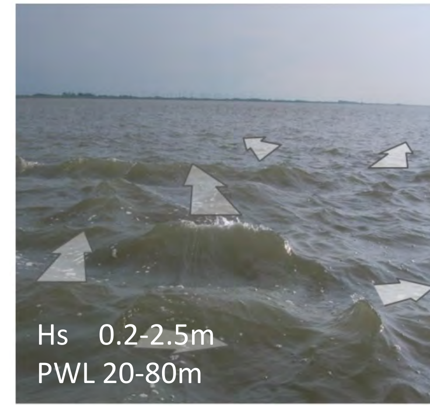
one peak, long waves

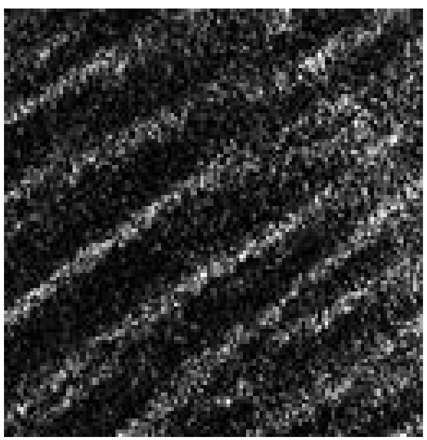


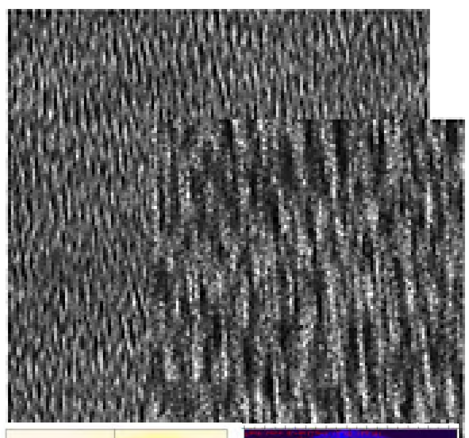
two peaks (two wave systems)

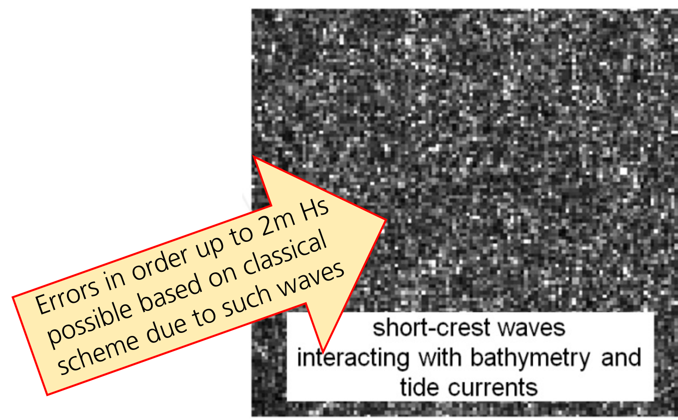


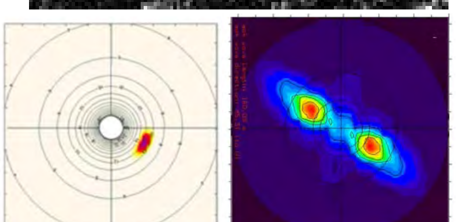
Very short crest waves, current and bathymetry interaction



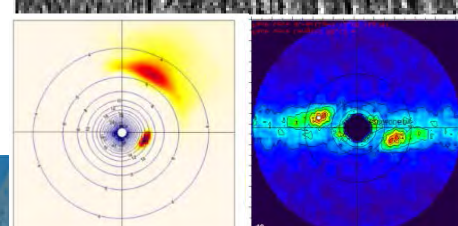


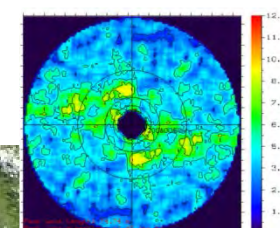






wave spectrum ~ image spectrum

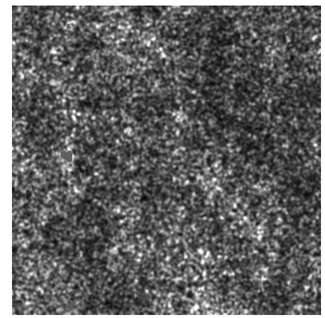


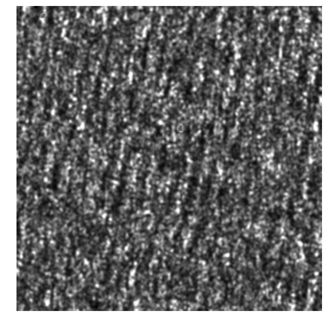


TerraSAR-X X-band and Sentinel 1 C-Band SAR

Differences: resolution and bands

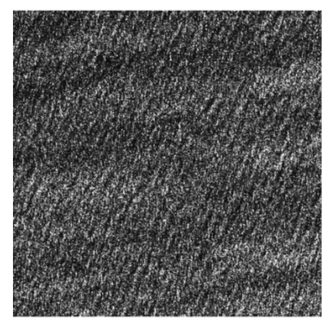
Sentinel-1 A/B IW 250km 10m pixel res.

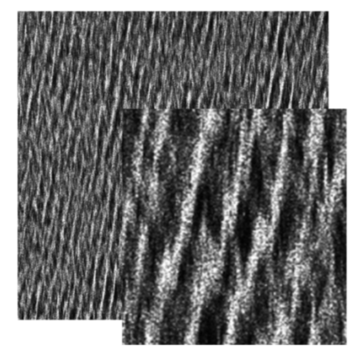




H_s~1.5m
L_p~ 80m

H_s~3.5m
L_p~250m



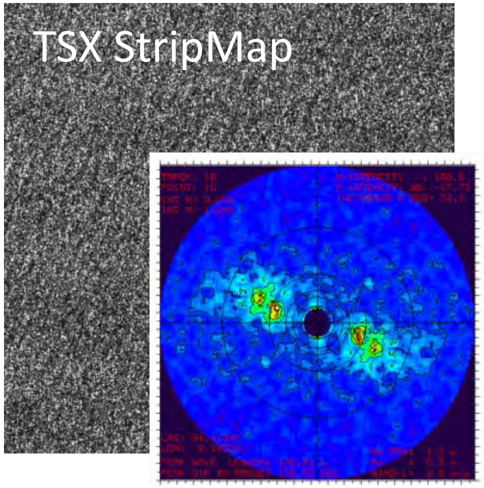


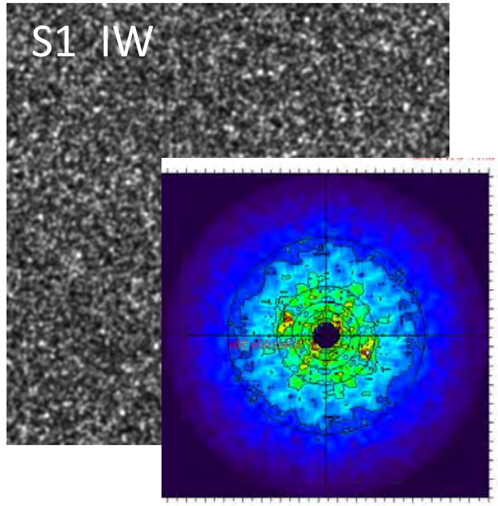
TerraSAR-X StripMap 30km 1.2m pixel res.

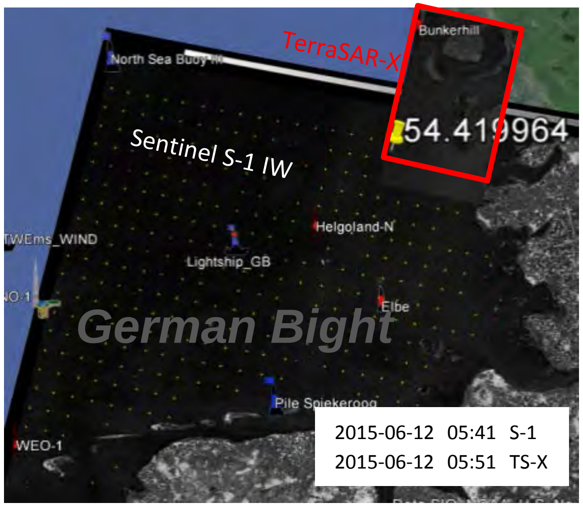
Sea Surface by different Sensors

The same time and location

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

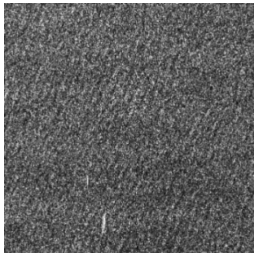






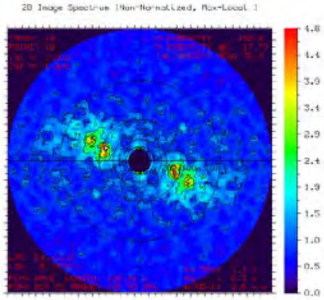
sea state parameters estimation

SAR subscene

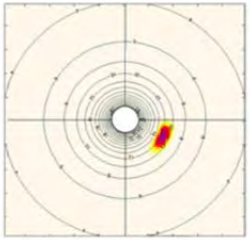


FFT

Image spectra



Transfer functions



integration

Integrated parameters:

Wave height,
mean period,
etc.

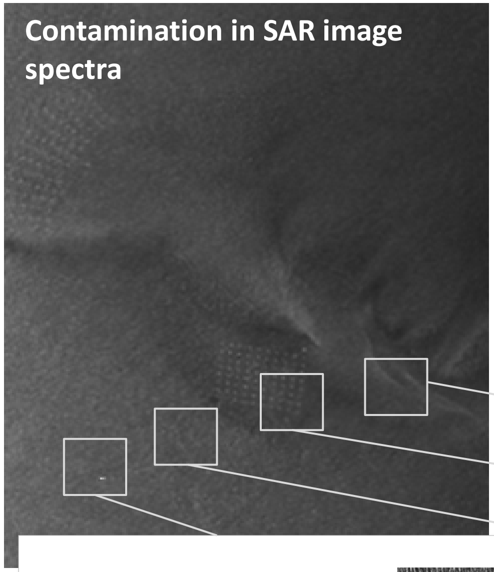
empirical functions
using also local wind information

Image feature analysis **GLCM (Grey Level Co-occurance Matrix)**

Entropy, Contrast, Dissimilarity, etc.,

DLR

Coastal applications: “contamination” impacts spectral analysis



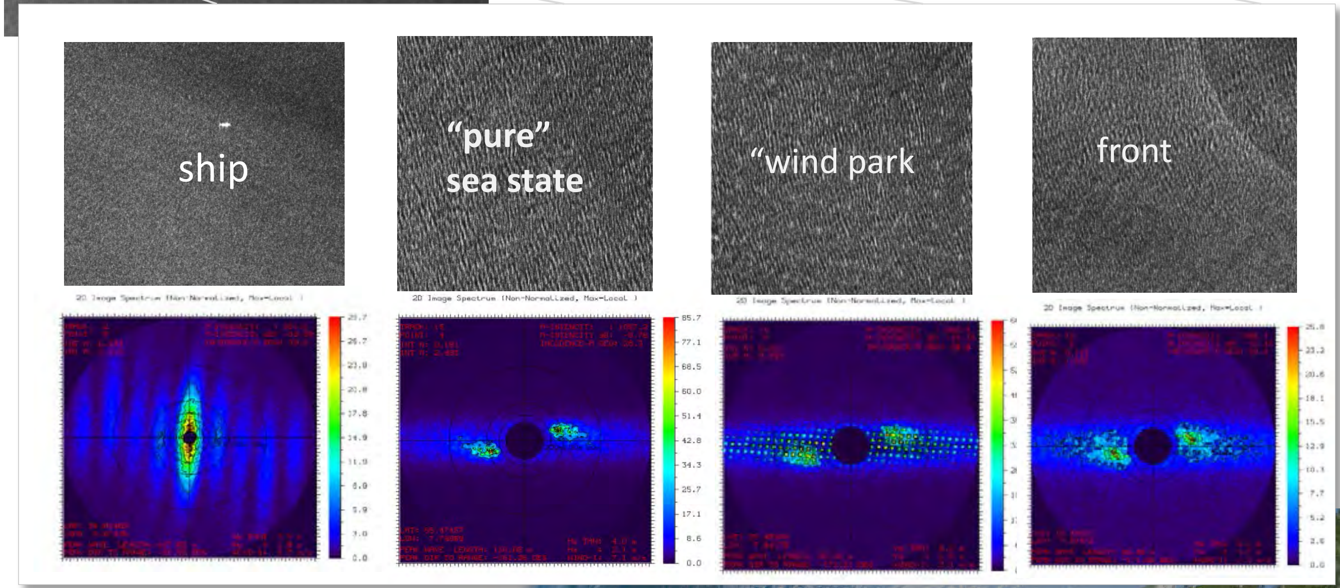
Removing contaminations

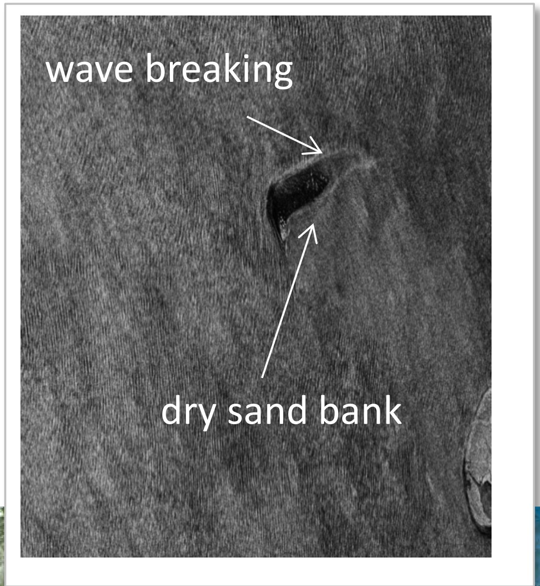
- Sand banks
- Wave breaking
- Ships, Buoys, Wind farms
- Current fronts, ship wakes

1. Before analysis
2. Function term
3. Results control

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

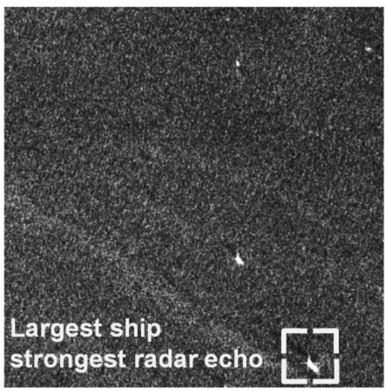
Without pre-filtering Integrated energy and *Hs* can > 10 times overestimate real value





Sea State Processor for SENTINEL-1 and TerraSAR-X

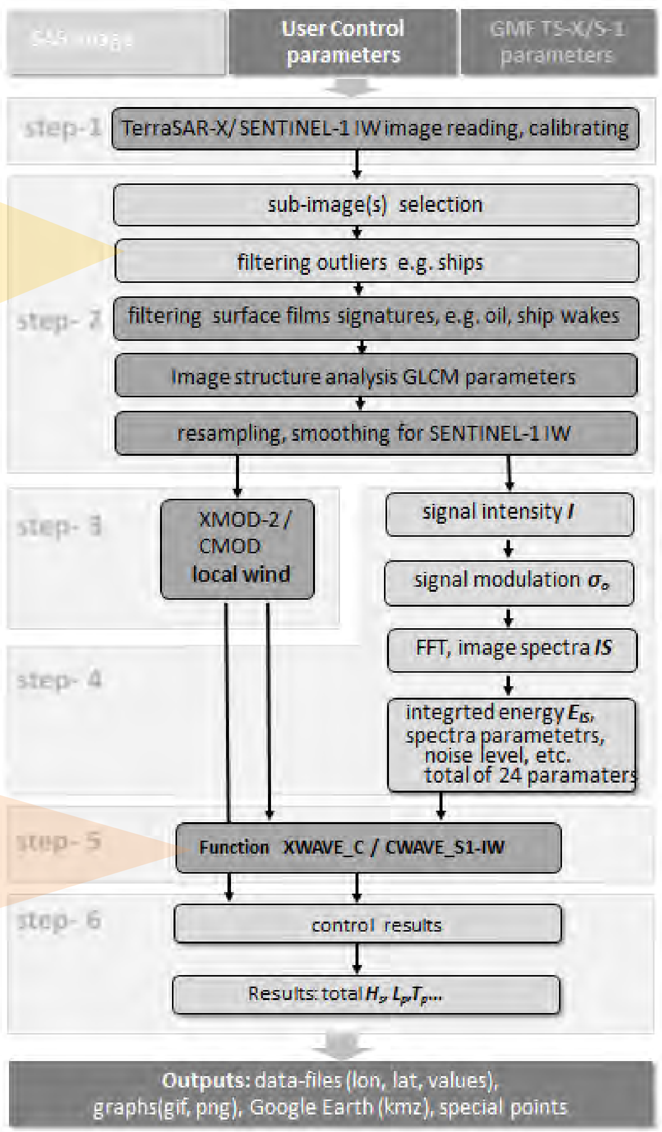
artefact pre-filtering



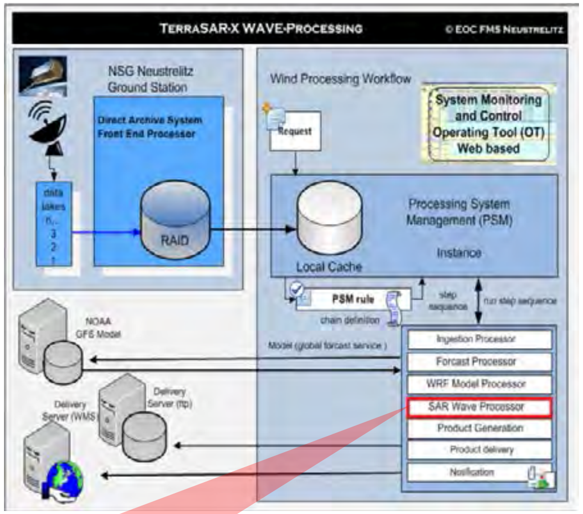
Sea State Functions
TerraSAR-X
Sentinel-1

$$H_S = a_1 \sqrt{B_1 E_{IS}} \tan(\theta) + \sum_{i=2,n}^{n} a_i B_i$$

Sea State Processor



NRT chain, Ground Station Neustrelitz

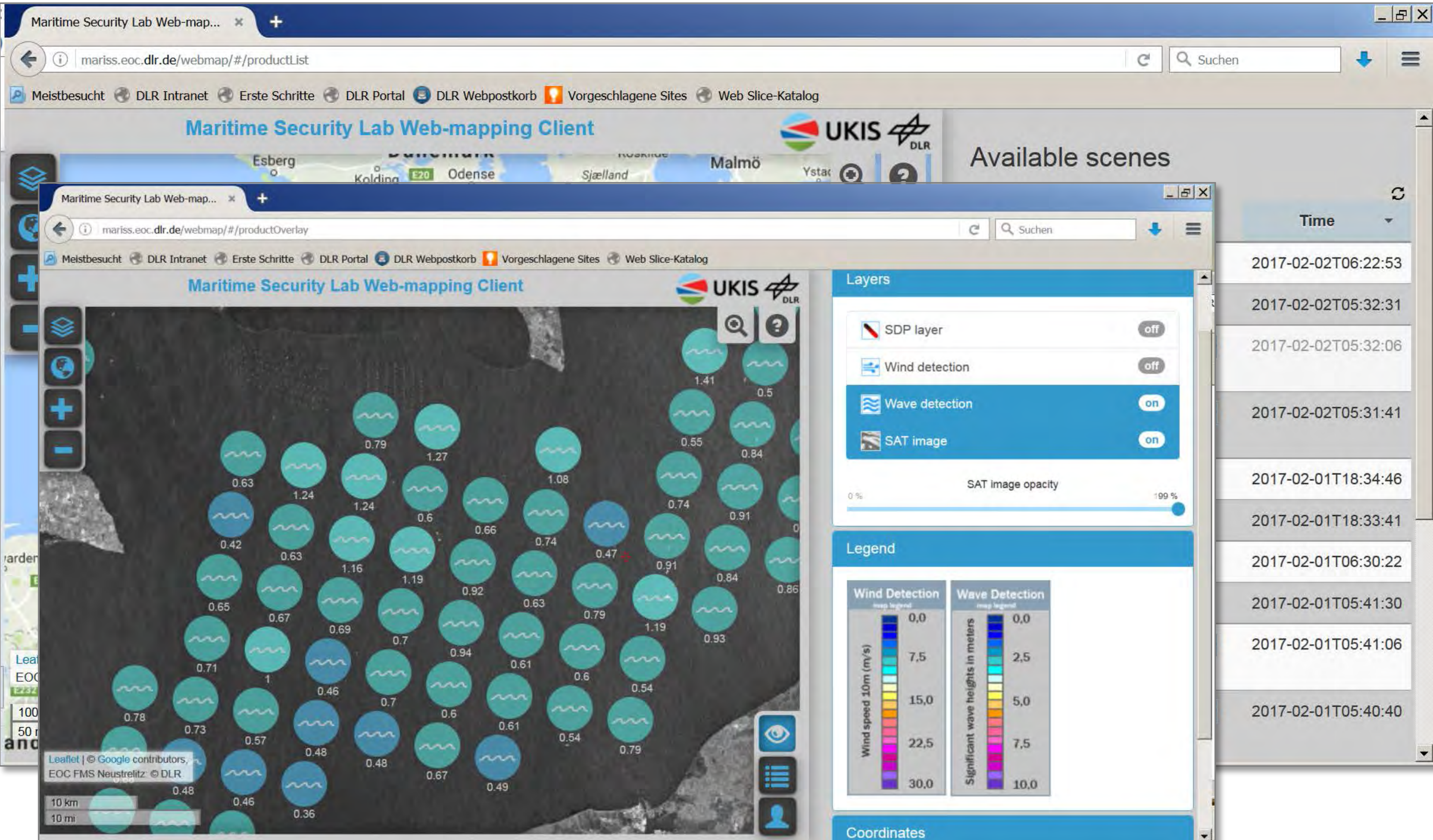


DLR

Maritime situation awareness

NRT services: waves, wind ships

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

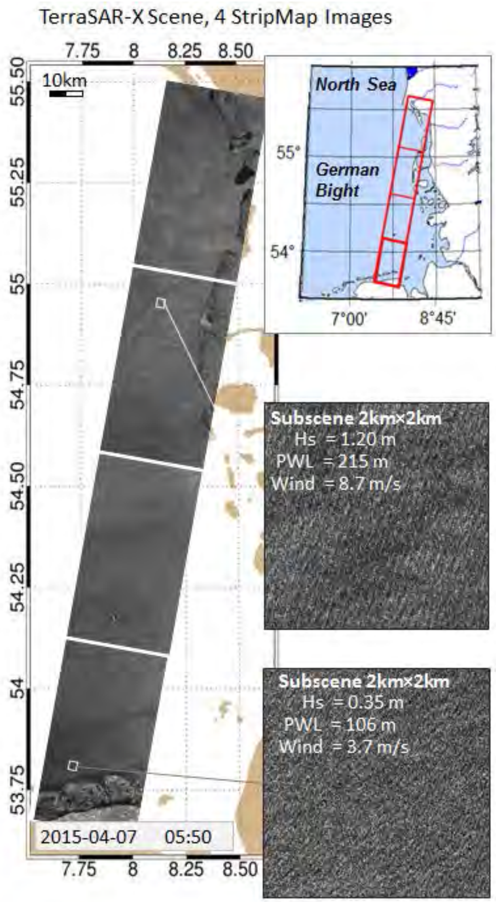


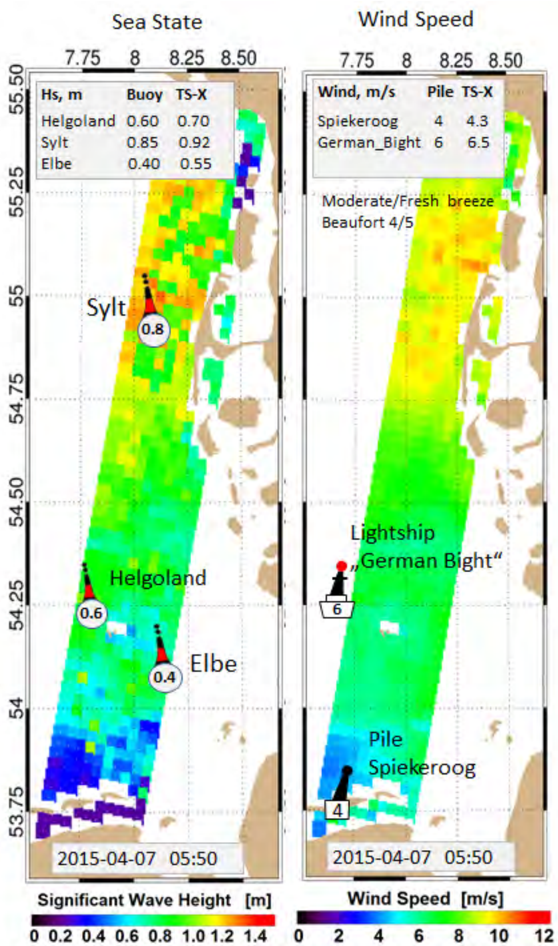
Sea State Processor for TerraSAR-X

Accuracy:
RMSE=0.24m
for total wave height *Hs*
for coastal waters

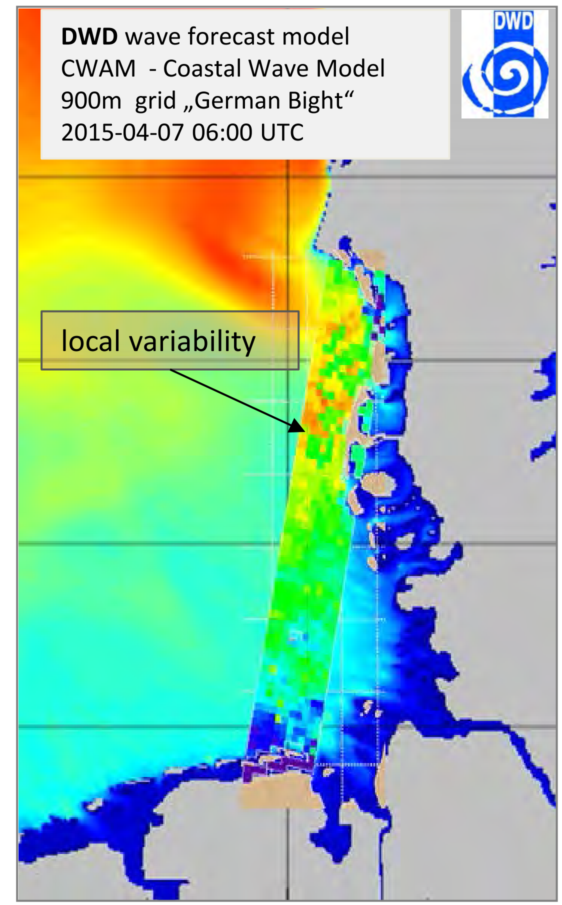
Example: German Bight

TerraSAR-X acquisition 07.04.2015 05:51 UTC





best delivery performance – 10min

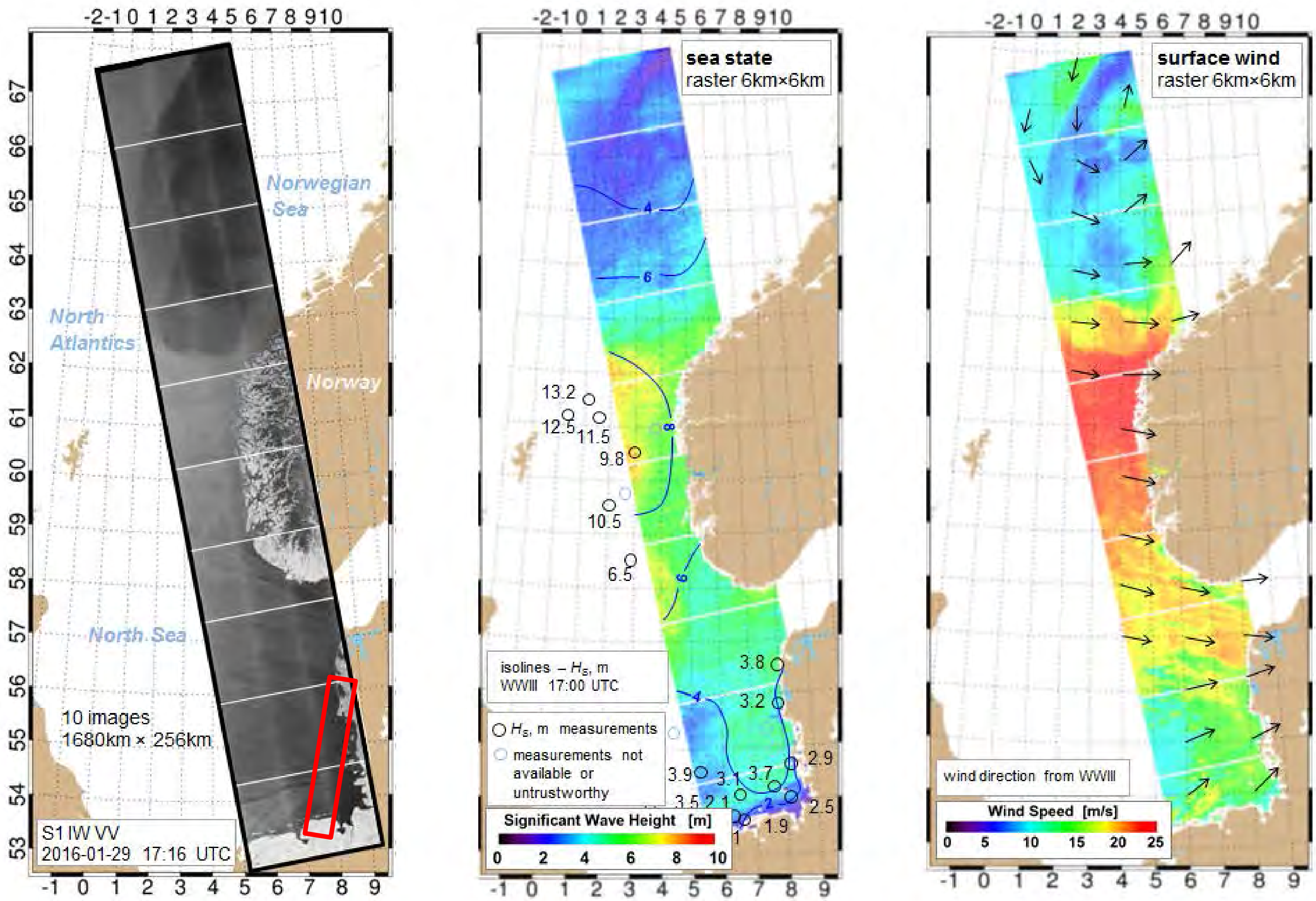


Sea State Processor for Sentinel-1

Example: German Bight

TerraSAR-X acquisition 29.01.2016 17:16 UTC

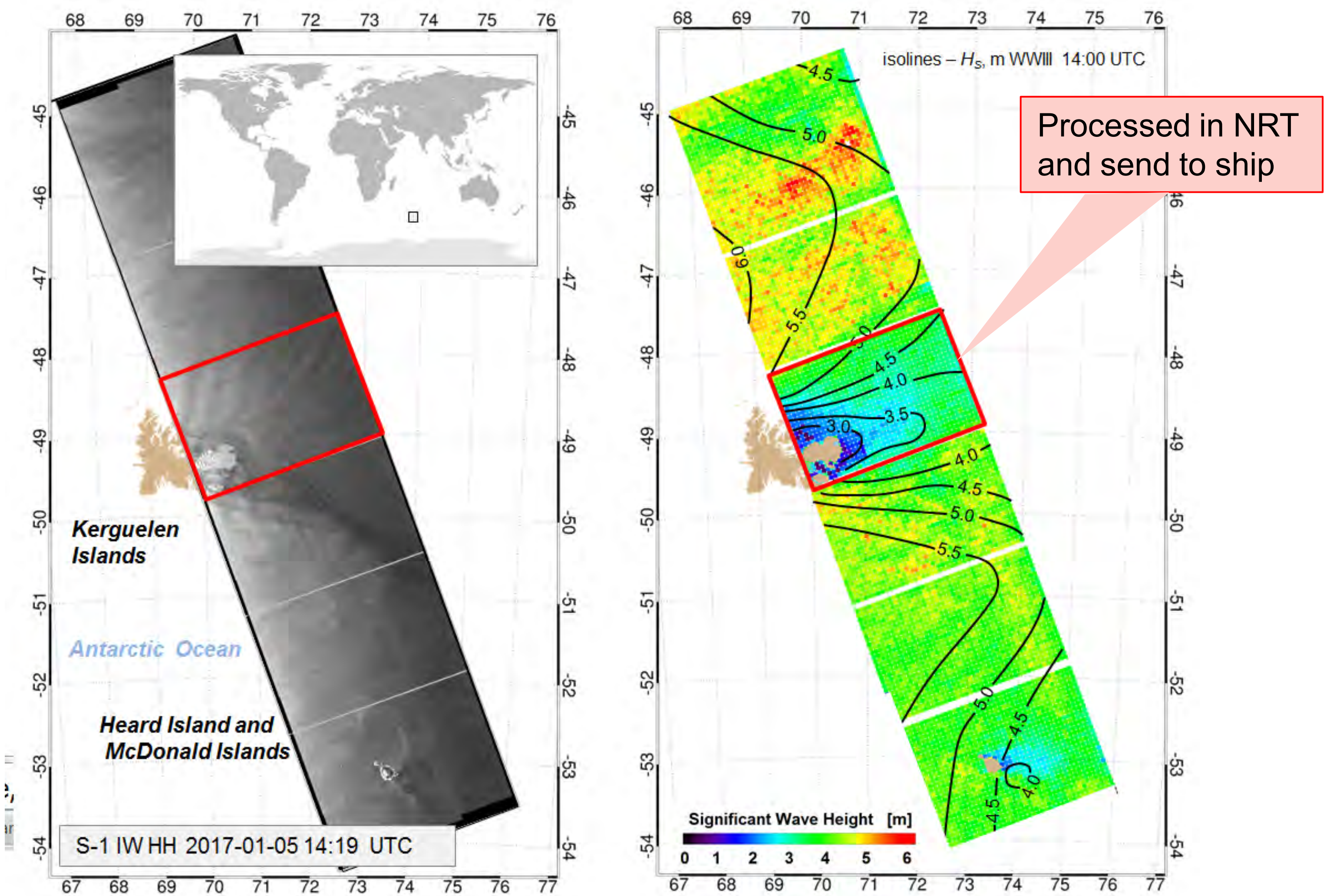
Accuracy:
RMSE=0.80
for total wave height *Hs*
worldwide



Sea State Processor for Sentinel-1

Example: Arctic Sea, 05.01.2017

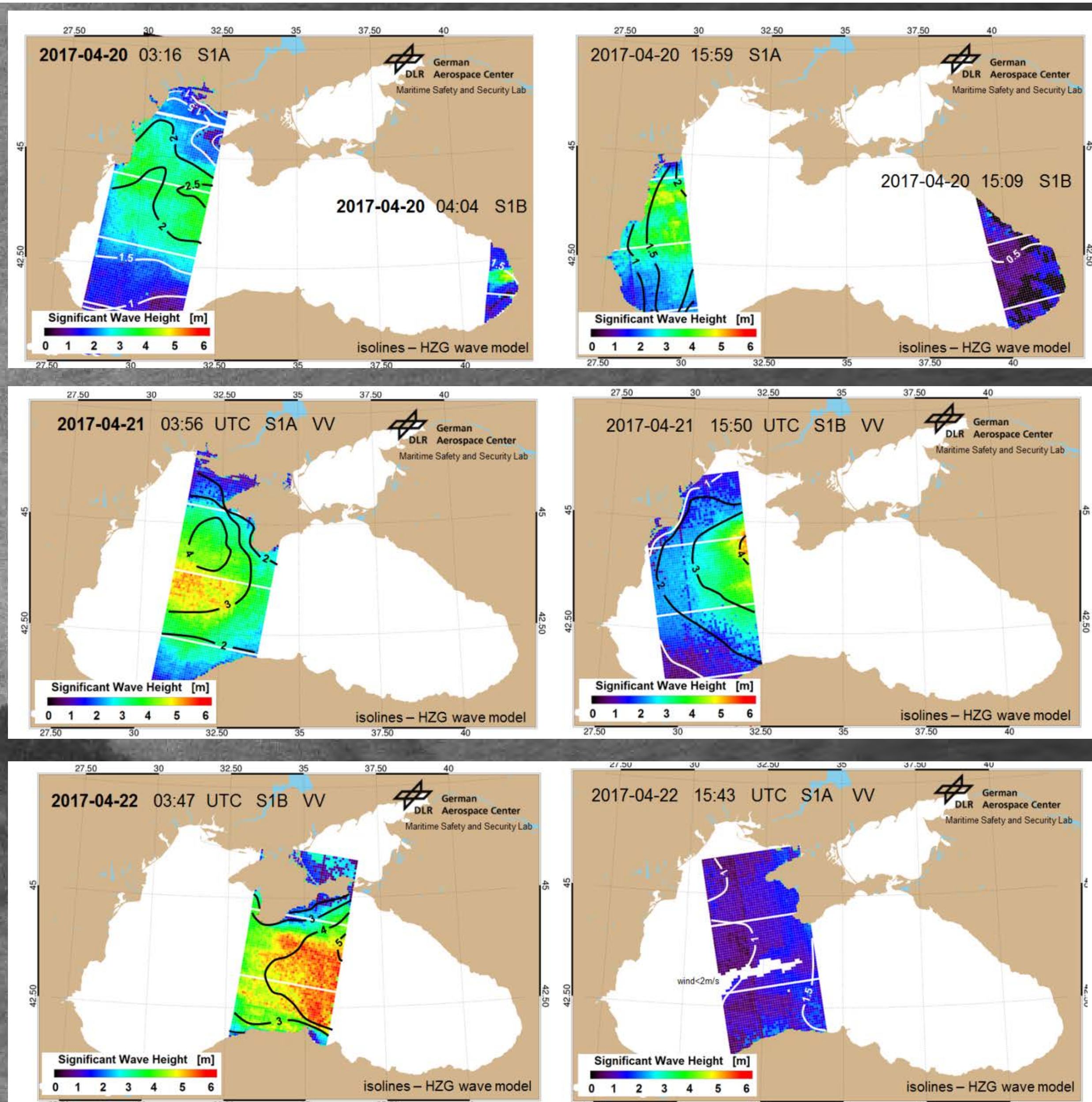
Support of a research cruise



DLR

Following a storm in the Black Sea

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



Conclusions

- SAR-based met-ocean parameters are a reliable source to complement model predictions and buoy data
- Available in Near-Real-Time and for long-term analysis
- Improtant for offshore construction/maintenance operations planning
- Optimize power production estimates for offshore wind farms (including wind shadows and turbulent effects)