Wind Speed and Sea State by TerraSAR-X

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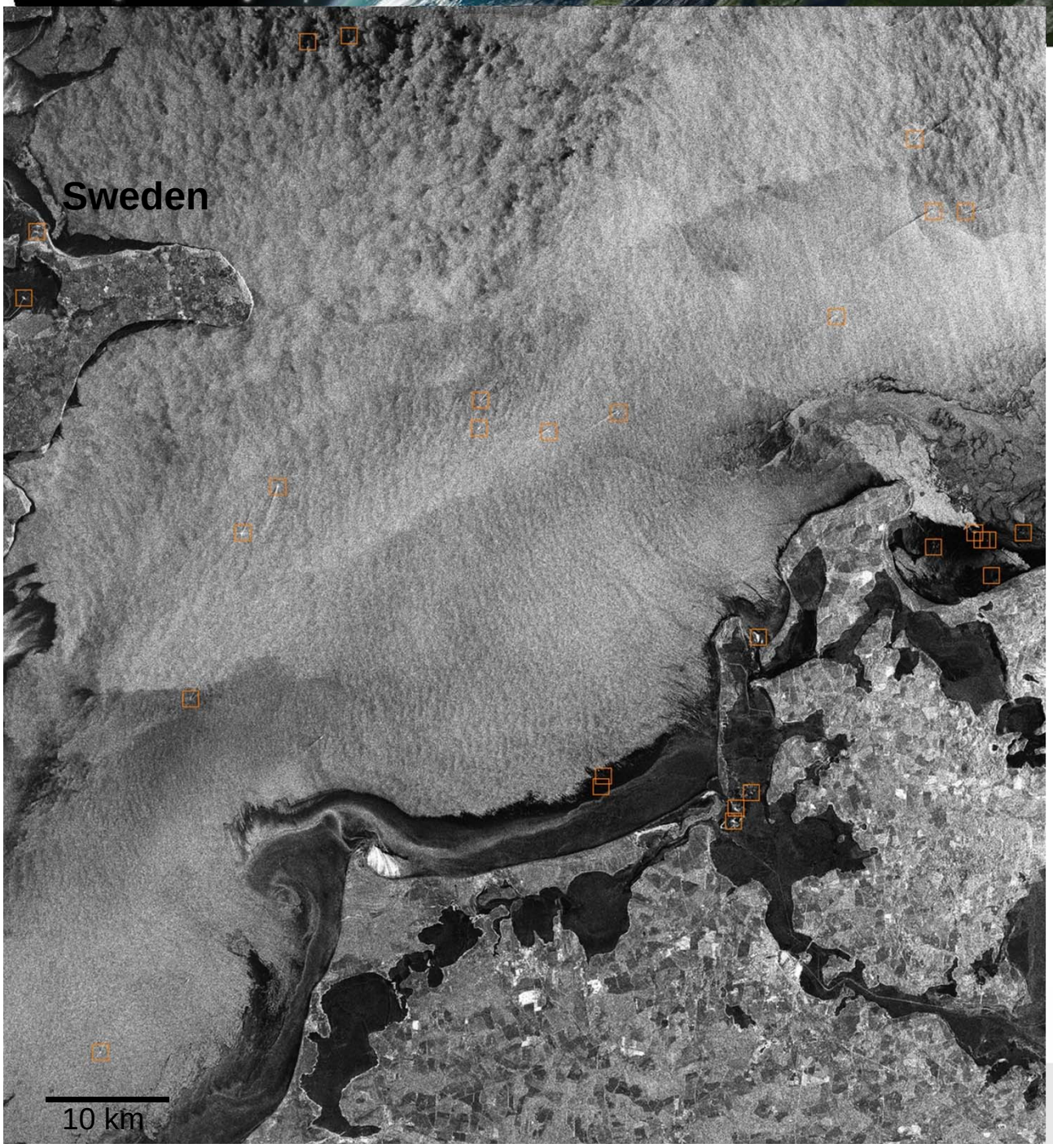
DLR für Luft- und Raumfahrt e.V.
in der Helmholtz-Gemeinschaft



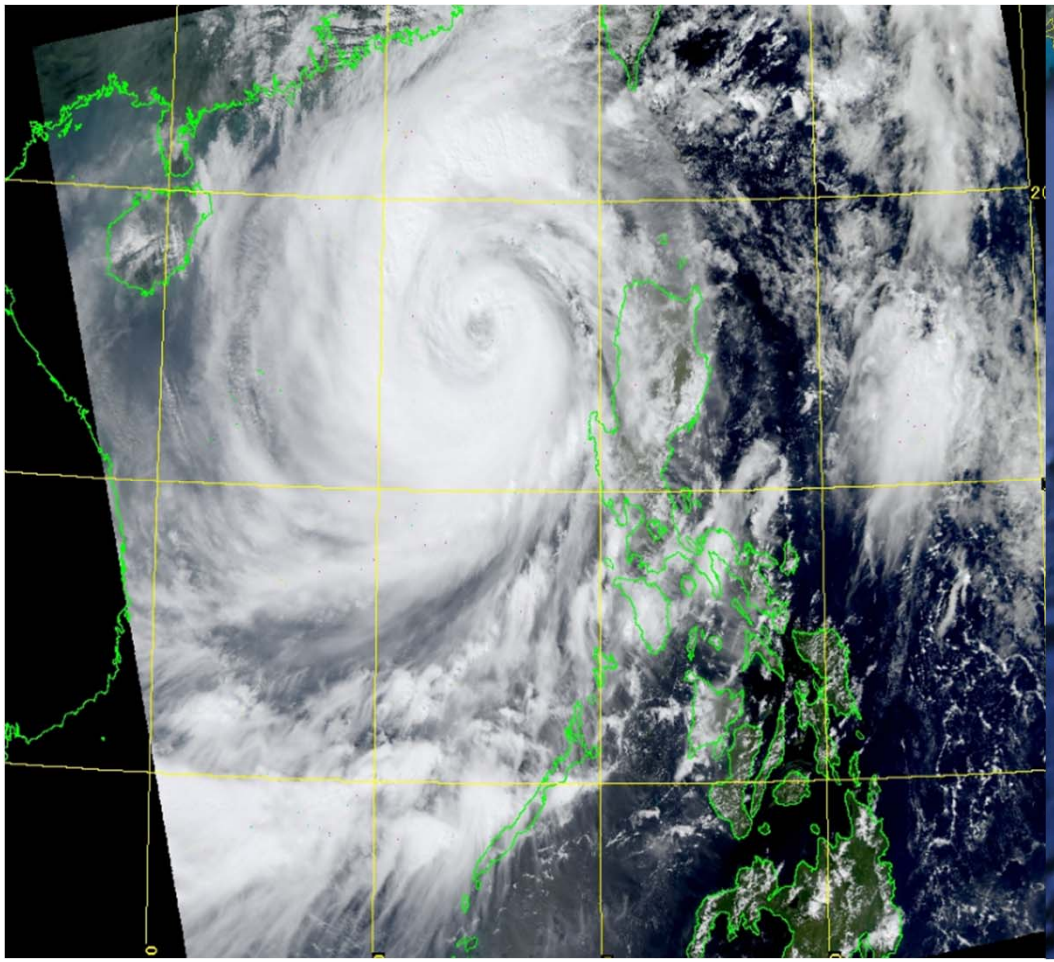
Baltic Sea Observed by SAR:

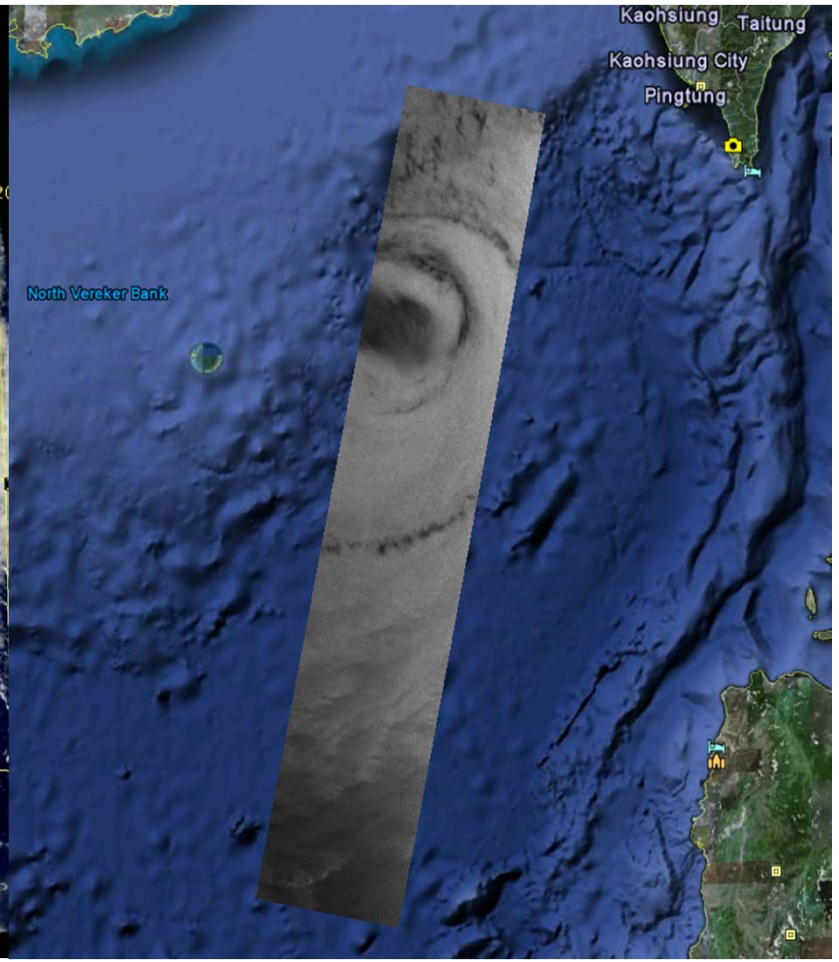
Coastline
Wind field
Sea State
Current
Sea Ice
Ships

ERS 2, Jan 2010, Rügen

since 1991

Why SAR? Watch through clouds, independent of sunlight





Optical: Clouds

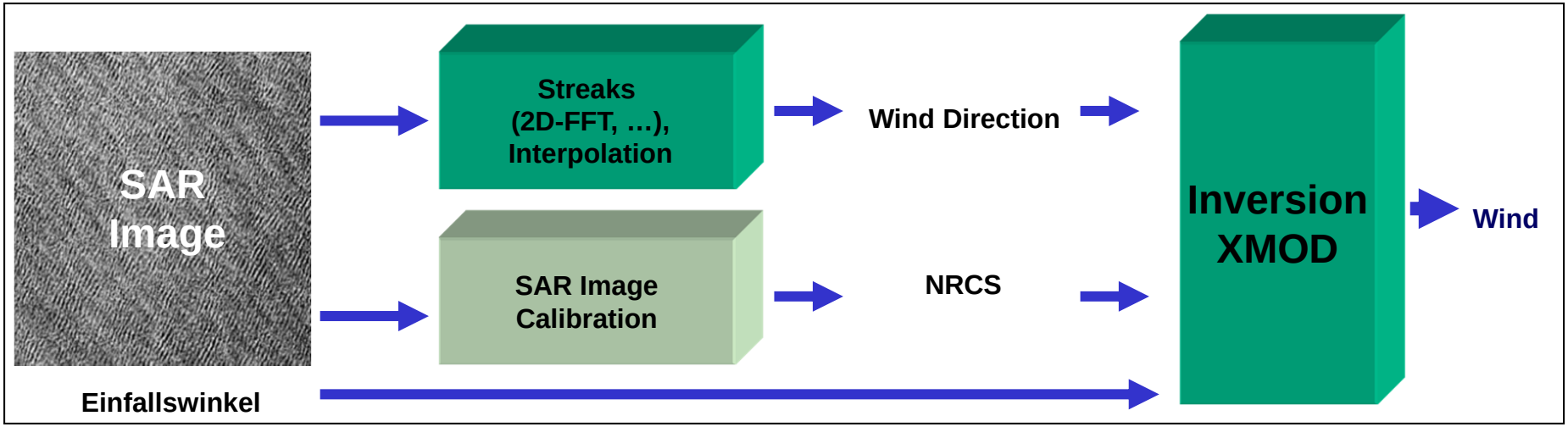
Radar: Sea Surface

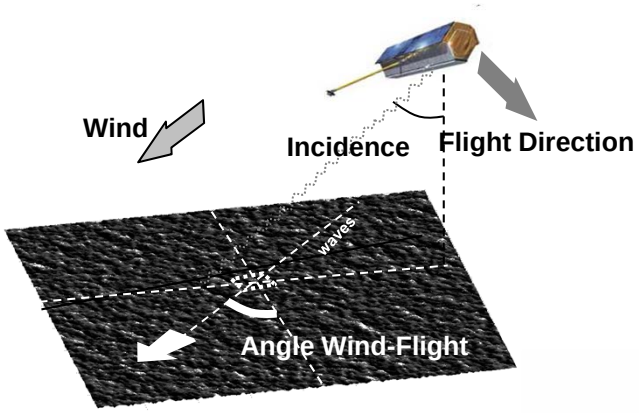
Typhoon MEGI mit MODIS und TS-X, Oct 20, 2010

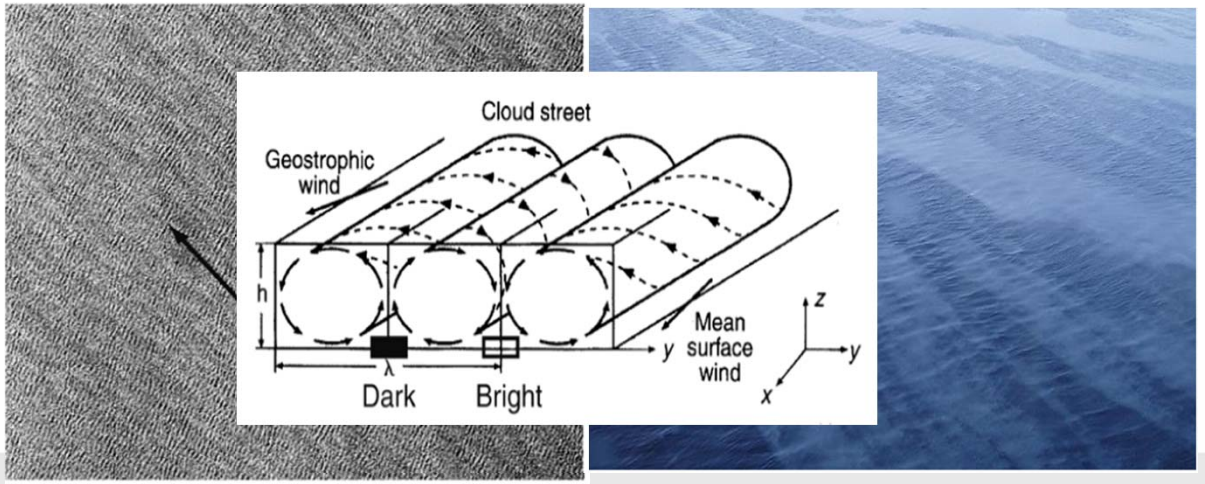
Wind Field: XMOD Algorithm

Geophysical Model Function GMF (Wind ⟷ Roughness of Sea Surface)

Connection between Radar NRCS, Wind Speed, Wind Direction and Incidence Angle







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➢ Development of the X-band GMF for sea surface wind field retrieval

XMOD1, linear inversion

$$\sigma_0(U_{10},\theta,\varphi) = x_0 + x_1 U_{10} + x_2 \sin(\theta) + x_3 \cos(2\varphi) + x_4 U_{10} \cos(2\varphi)$$

XMOD2, non-linear inversion, comparable to CMOD GMF

$$\sigma_0(U_{10},\theta,\varphi) = \sum_{n=0}^{2} (A_n(U_{10},\theta,\varphi)\cos\{n\varphi\})$$

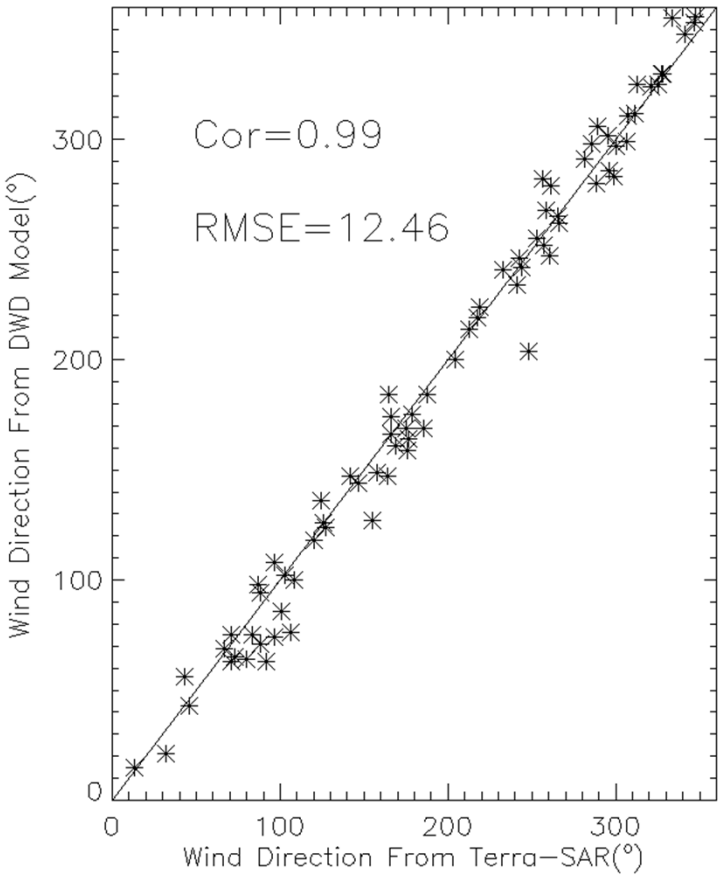
U_{10} — wind speed;

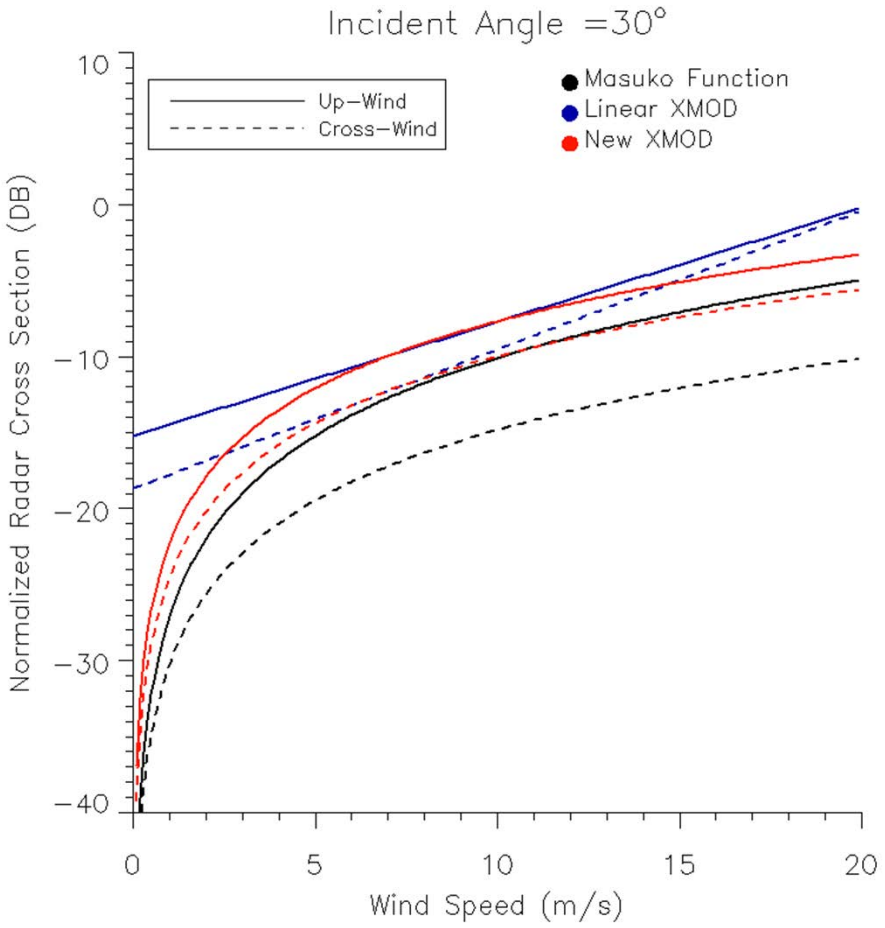
θ — incidence angle;

φ — angle between wind direction and SAR look direction

XMOD1, Y. Ren et al, IJRS, tuning dataset from X-SAR (shuttle mission)
XMOD2, (tuning on TS-X data)

Comparison of Wind Speed Algorithms

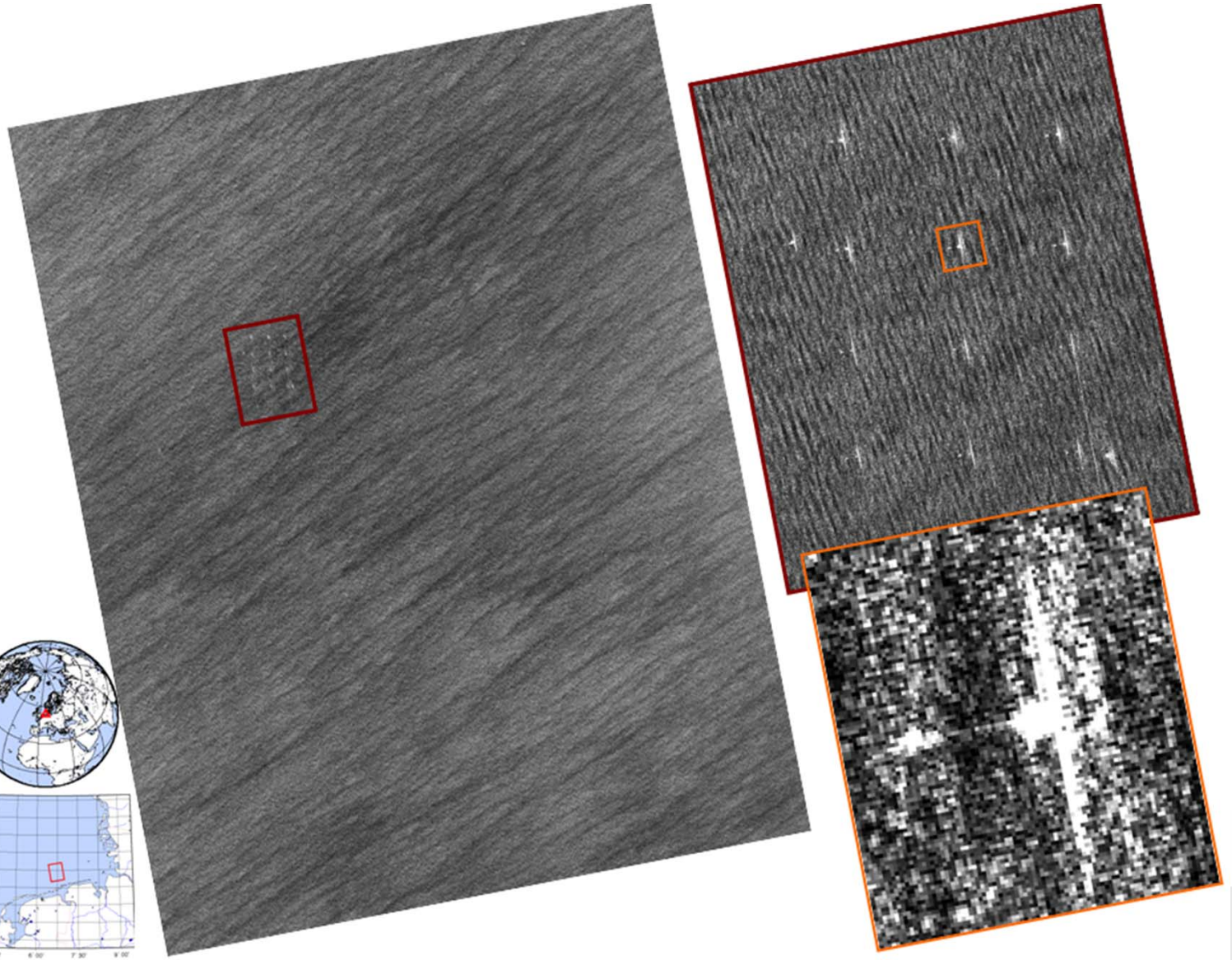




In Germany : High resolution wind field needed for Alpha Ventus, Wind Farm North Sea

TS-X Stripmap
Aug.7, 2011
at 17:18 UTC

VV polarization,
spatial res. 3 m



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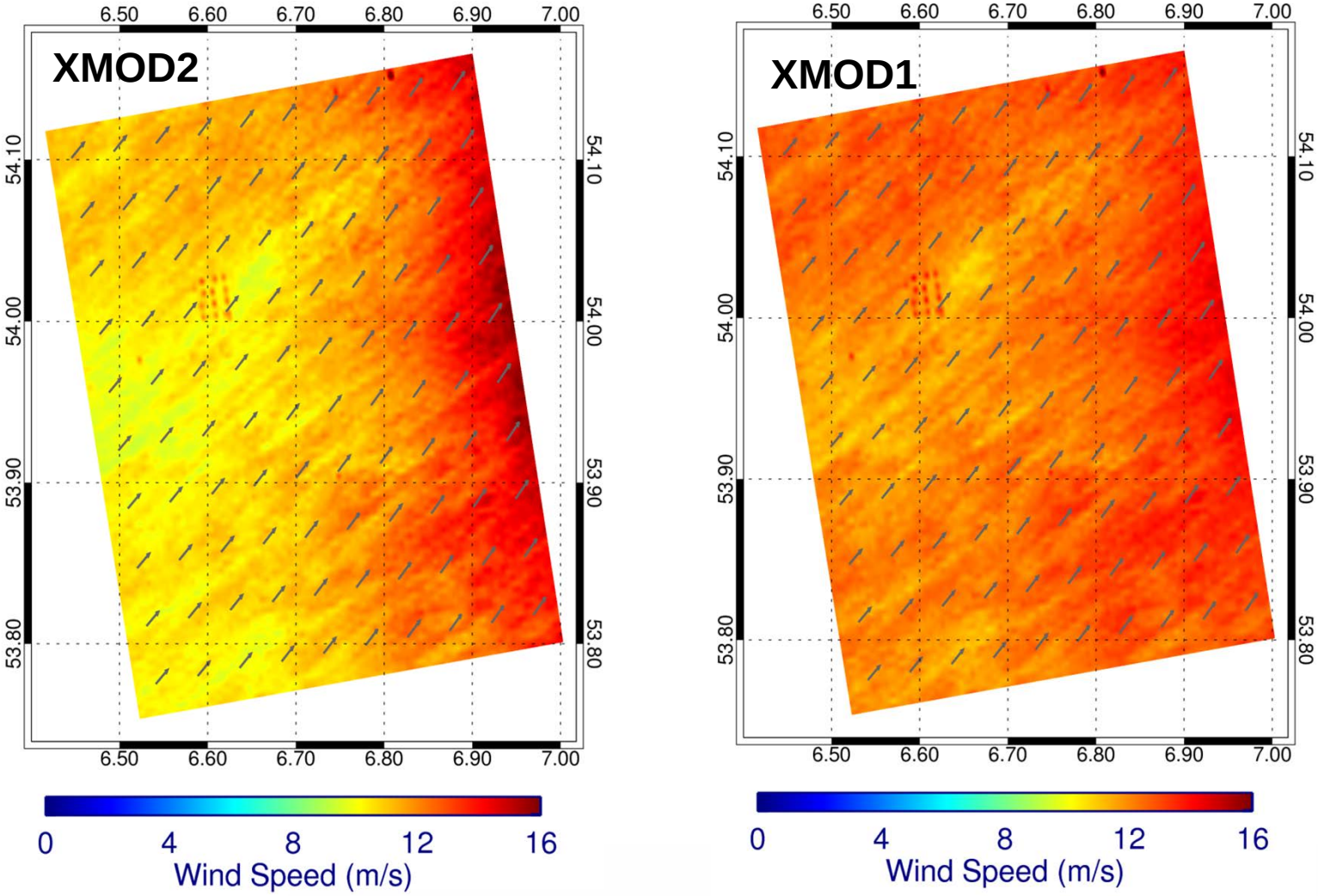
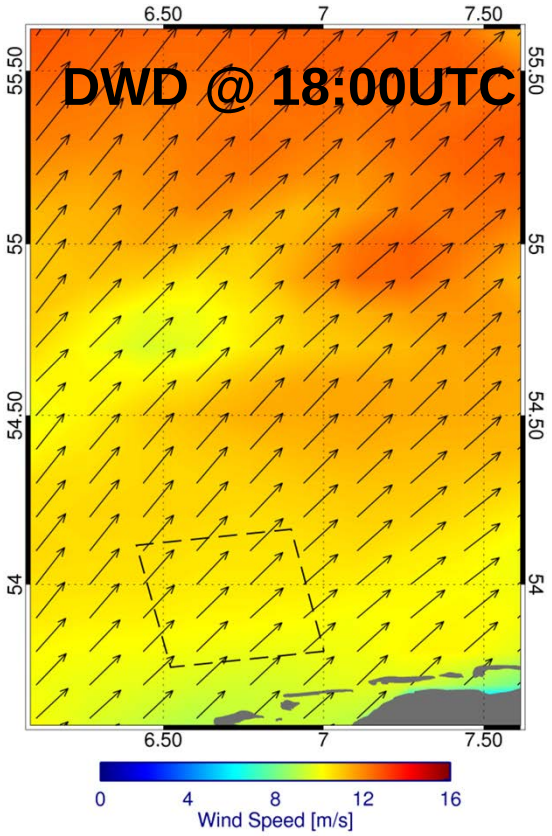
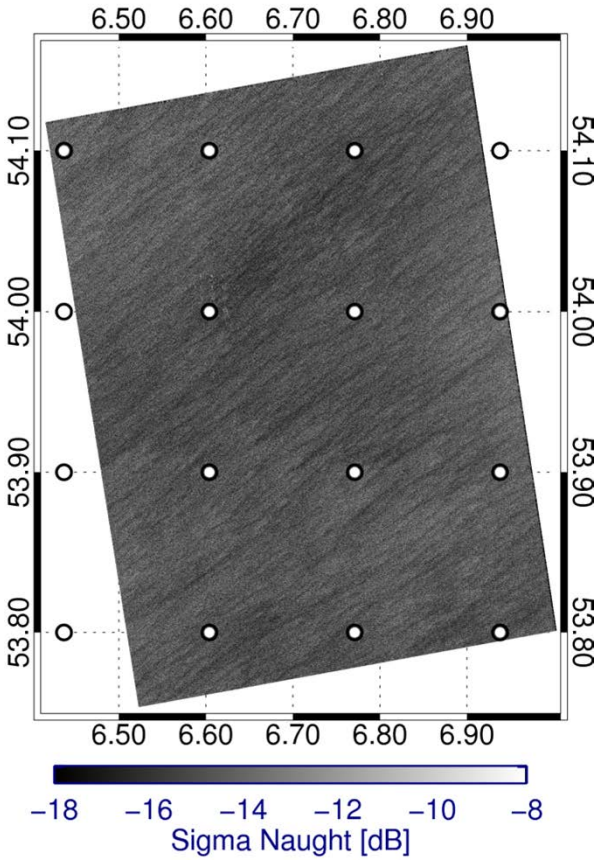
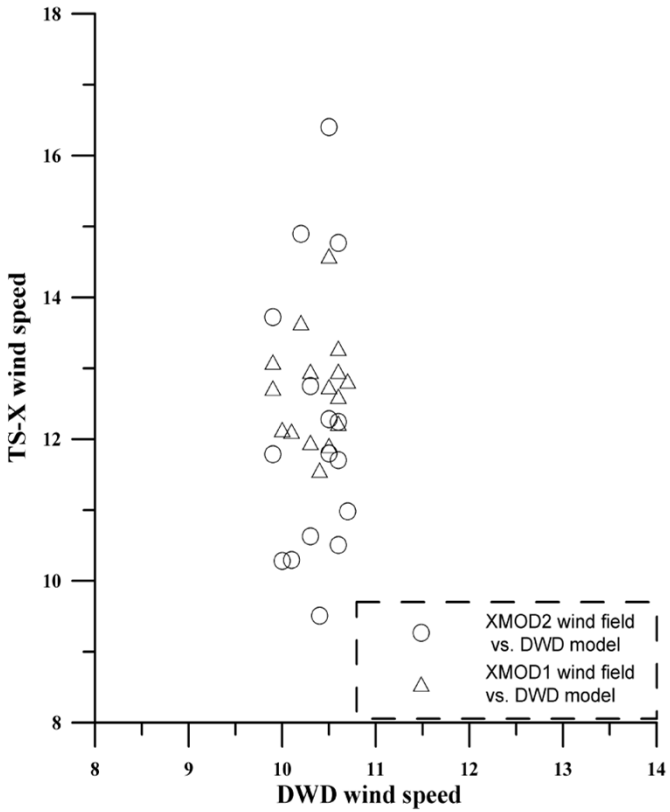
Sea surface wind field derieved from the TS-X data over Alpha Ventus



Comparison of TS-X wind measurements to DWD (global) model

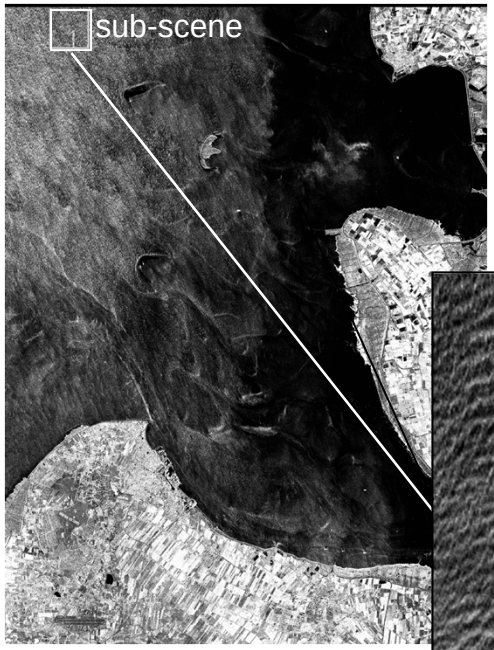






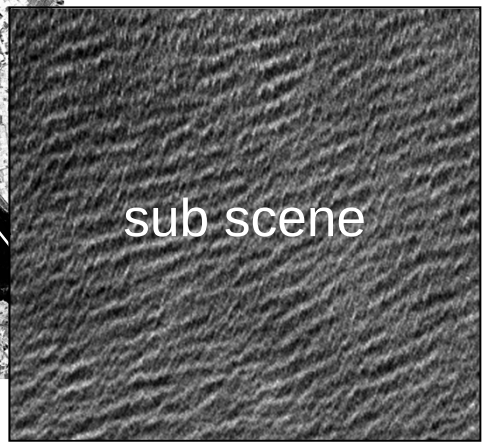
Higher variability in TS-X data

XWAVE: Sea State Parameters from TerraSAR-X Images



TerraSAR-X SM

Elbe estuary



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

$$S = FFT(m)$$

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

signal intensity I

↓

signal modulation ***m***

↓

image spectra ***S***

↓

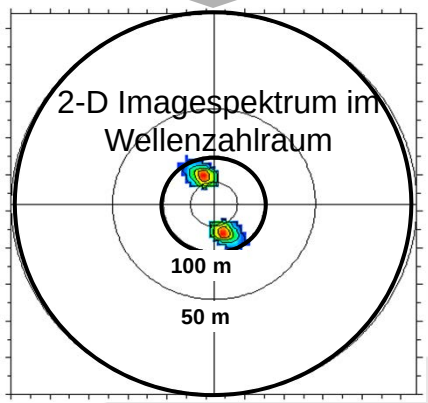
filtering, L_{min}, L_{max}

↓

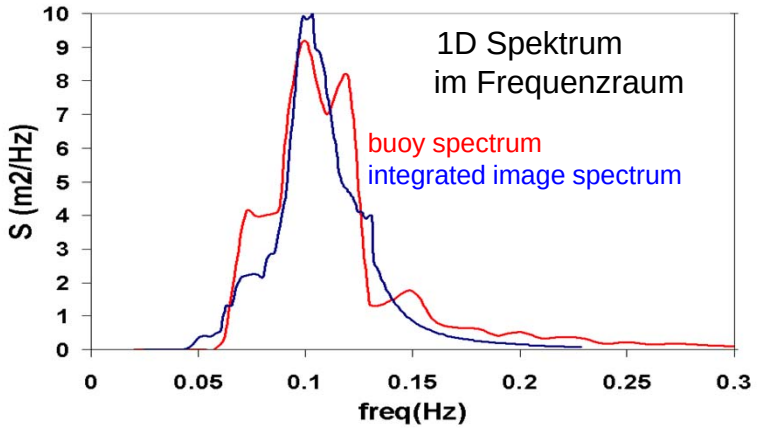
XWAVE function

↓

Parameters: H_s, L_p, T_p…



2D image spectrum



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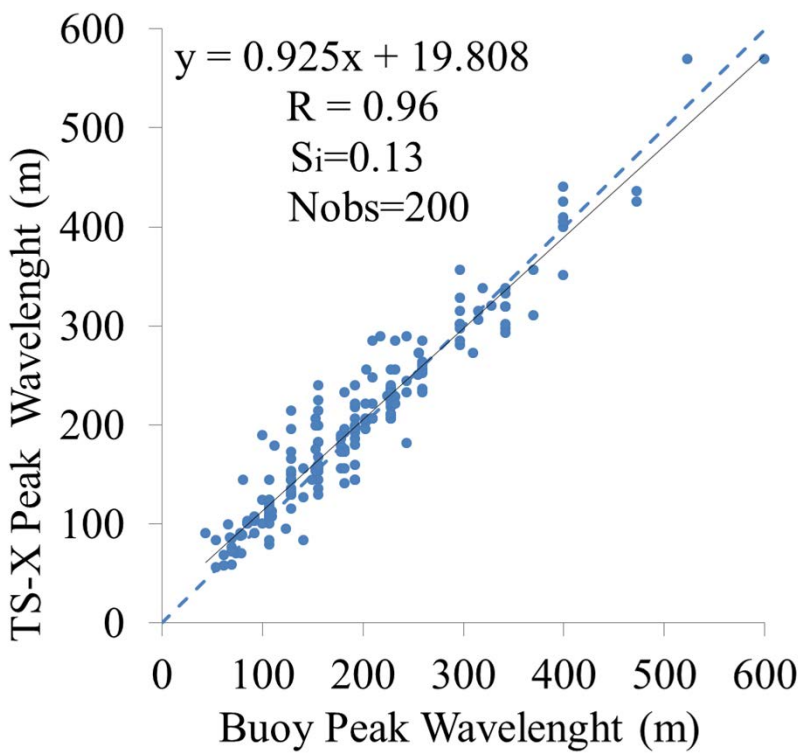
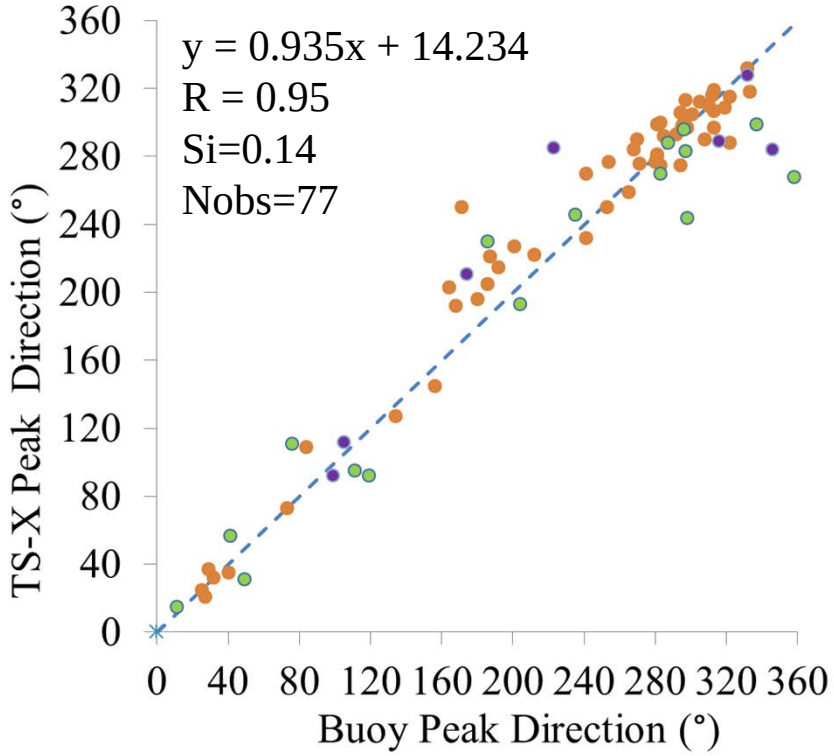
Wave measurements: Verification Peak wavelength and direction

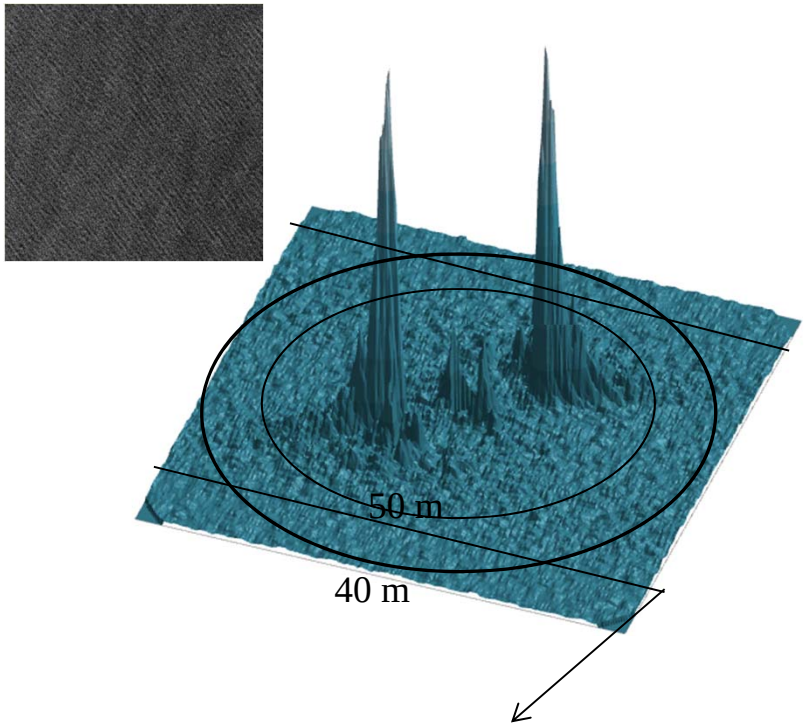




>120 m : Orange
120 -75 m: Green
55 -75 m: Violet

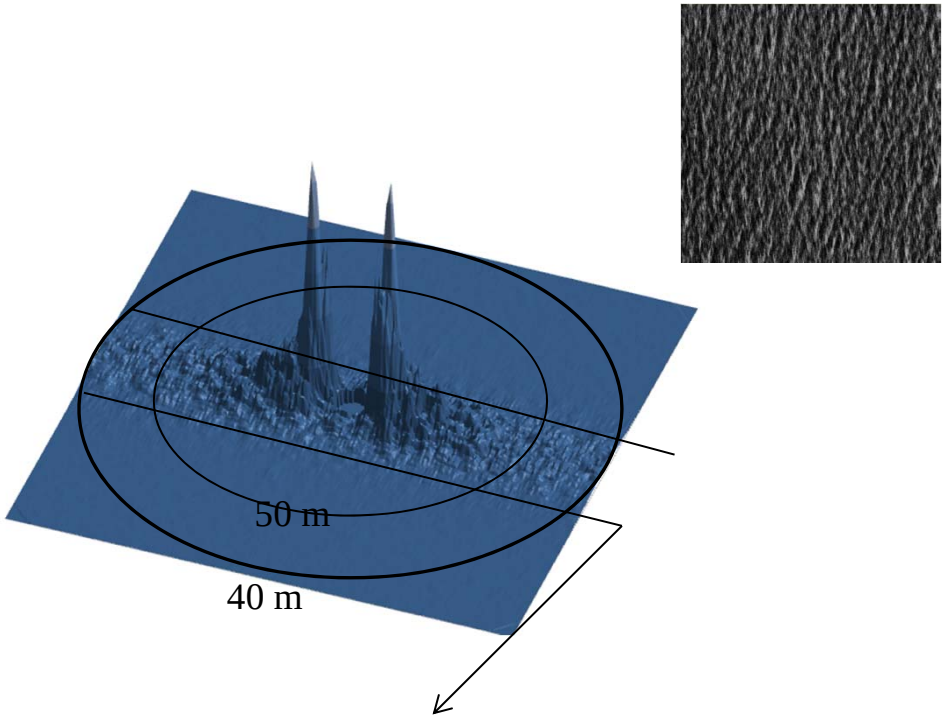
Azimuth Cut-off Wavelength

Buoy Wave height = 0.9 m
Buoy Wind speed =3.2 m/s
TS-X VV pol. collocated data; incidence angle=26.4°



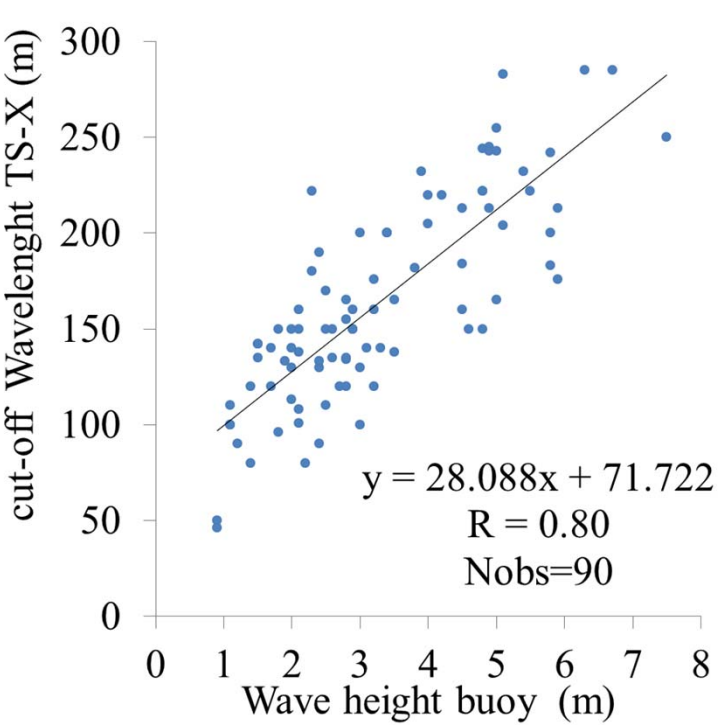
Estimated Cut off wavelength = 46m

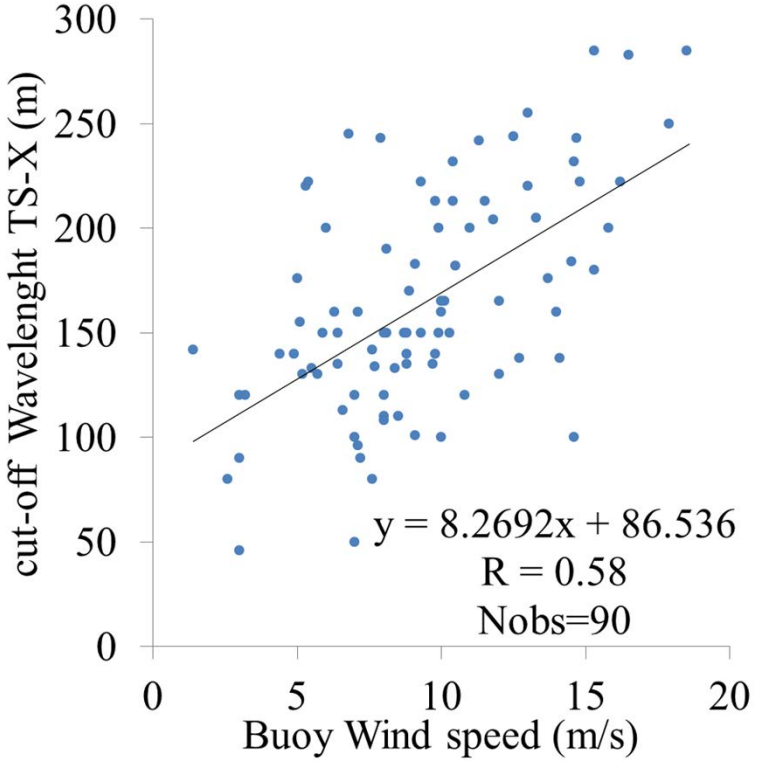
Buoy wave height =5.9 m
Buoy wind speed =5.4 m/s
TS-X VV pol. collocated data: incidence angle=28°



Estimated Cut off wavelength = 160 m

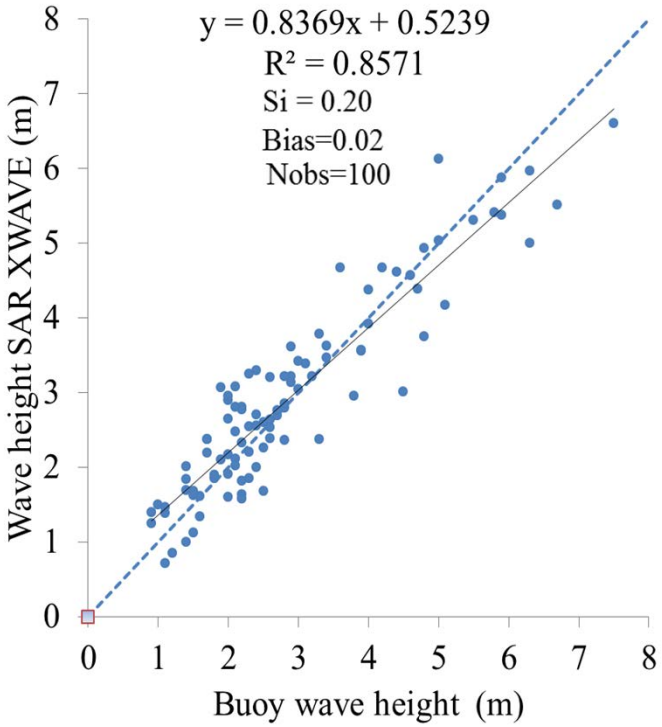
Azimuth Cut-off Wavelength





Only collocated cases with wind measurements

XWAVE algorithm wave height validation results



For an estimated wave height by the cut off wavelength < 4 m

$$H_s = a_1 \cdot \sqrt{E \cdot tan\theta} + a_2 \cdot U10xmod + a_3$$

For an estimated wave height by the cut off wavelength > 4 m

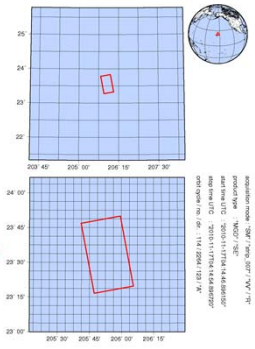
$$H_s = a_4 \cdot \sqrt{E \cdot tan\theta} + \boldsymbol{\nu} \cdot a_5 \cdot U10xmod + a_6 \cdot \cos(\boldsymbol{\alpha}) + a_7$$

($\boldsymbol{\alpha}$) is the relative wave direction to satellite path
and $\boldsymbol{\nu}$ is a unitary coefficient with unit [s],
U10xmod is the wind speed obtained by the XMOD algorithm
θ incidence angle

XWAVE results for *in-situ* NOAA buoy-collocated TS-X Stripmap VV pol. data
Center incidence angle of TS-X acquisitions < 38°

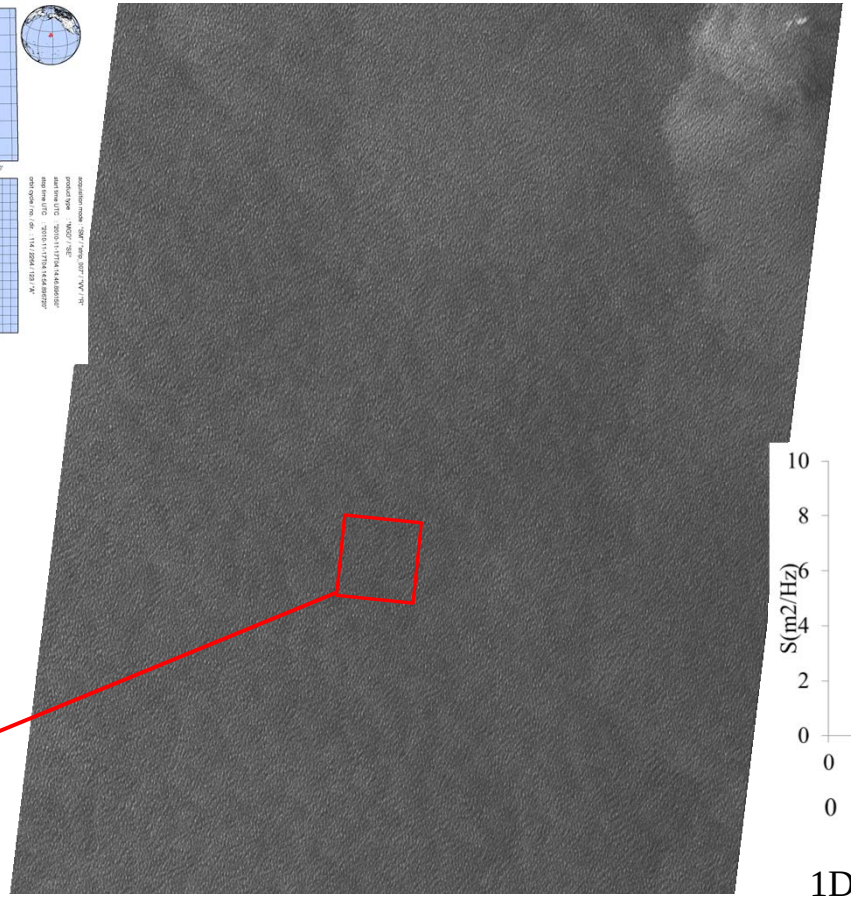
Case over buoys (I) :Range traveling waves

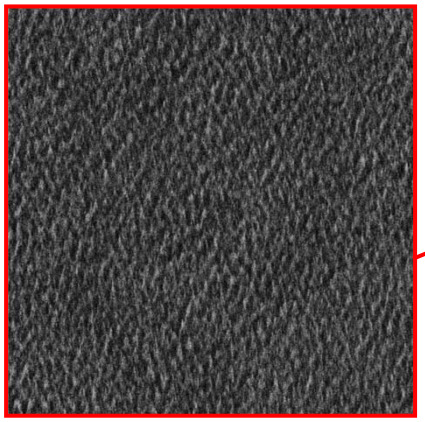
Tandem-X VV pol. image acquired over station 51000 with 31 ° centre incidence angle on November the 17th , 4:15 UTC , 2010.



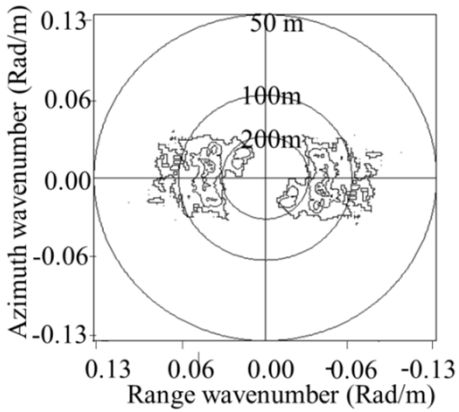
Owned and maintained by National Data Buoy Cente
3-meter discus buoy
AMPS payload
23.546 N 154.056 W (23°32'47" N 154°3'20" W)

Site elevation: sea level
Air temp height: 4 m above site elevation
Anemometer height: 5 m above site elevation
Barometer elevation: sea level
Water depth: 4096.5 m
Watch circle radius: 4275 yards

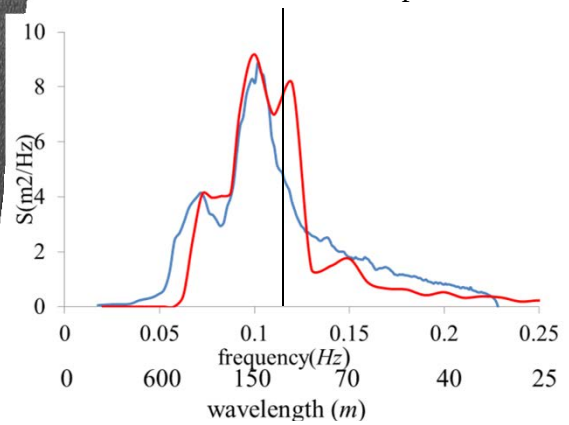




2048 pixel subscene (~4.6km)



2D SAR spectrum

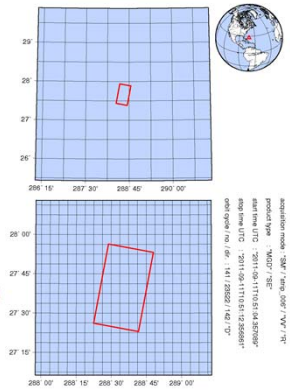


1D spectrum (blue SAR, red buoy)

	$H_{s\,(m)}$	$T_{p\,(s)}$	$L_{(m)}$	$dir_{(°)}$	$U_{(m/s)}$
buoy	2.8	10.0	156	73	3.2
TS-X	2.8	10.0	156	74	3.9

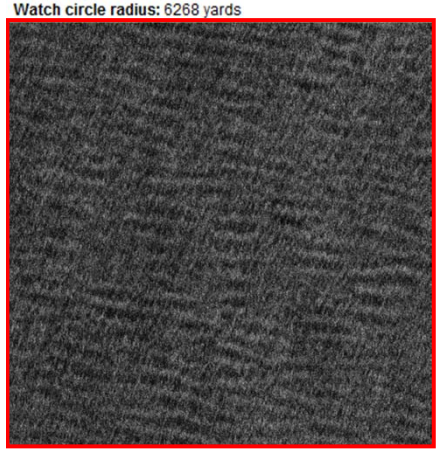
Case over buoys (II): Azimuth traveling waves

TS-X image VV pol. acquired near station 41047 with 28.8° centre incidence angle on September the 11th at 10:51 UTC, 2011

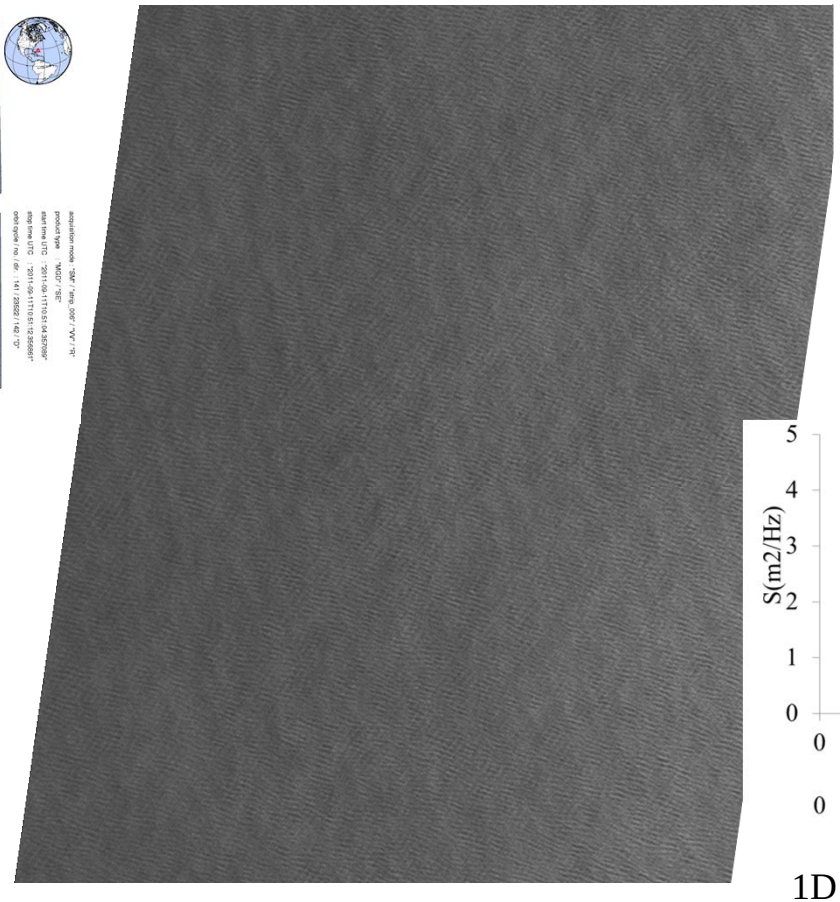


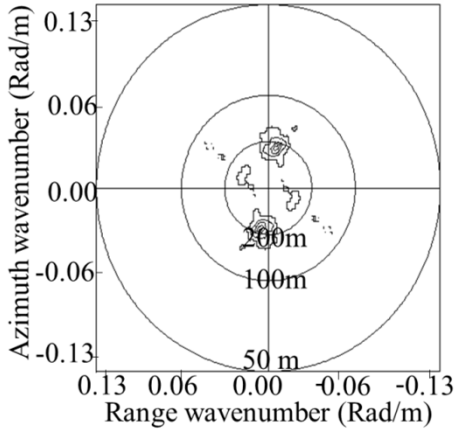
Owned and maintained by National Data Buoy Cent
3-meter discus buoy
AMPS payload
27.517 N 71.483 W (27°31'0" N 71°29'0" W)

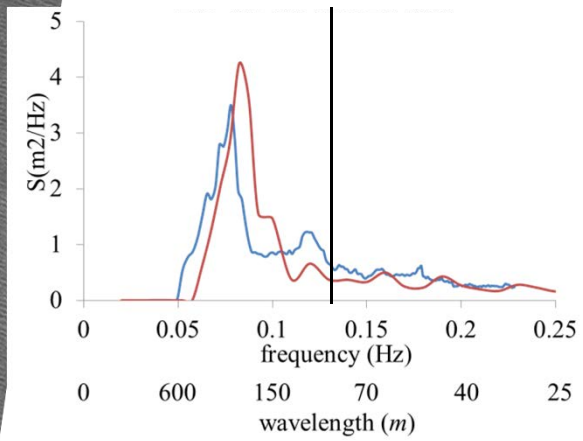
Site elevation: sea level
Air temp height: 4 m above site elevation
Anemometer height: 5 m above site elevation
Barometer elevation: sea level
Sea temp depth: 0.6 m below site elevation
Water depth: 5221 m
Watch circle radius: 6268 yards



2048 pixel subscene (~4.6km)





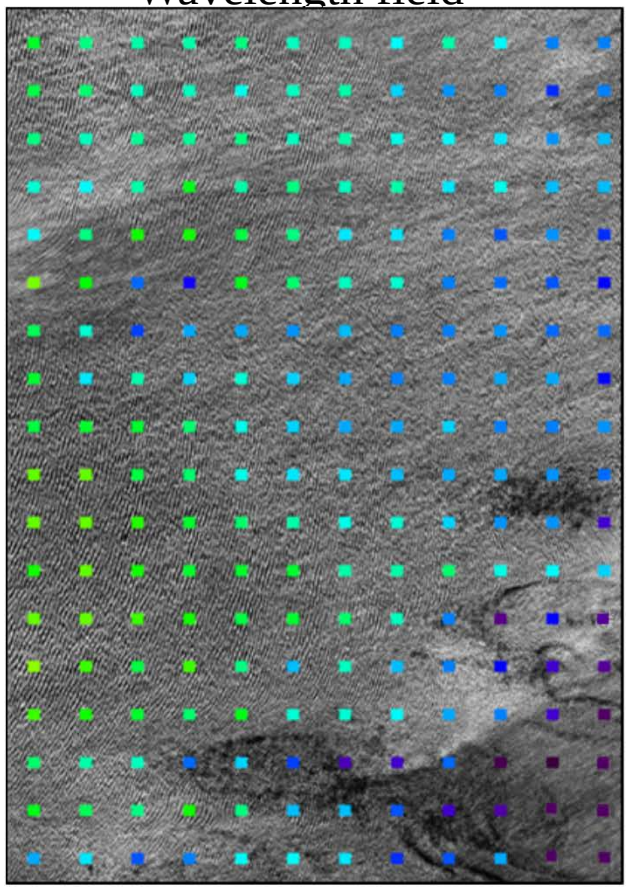


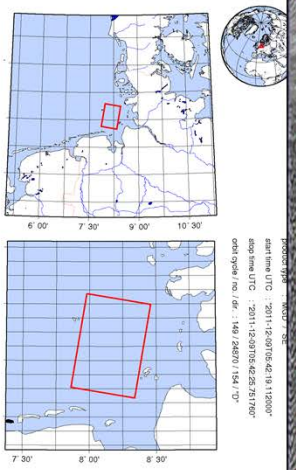
1D spectrum (blue SAR, red buoy)

	$H_{s\,(m)}$	$T_{p\,(s)}$	$L_{(m)}$	$dir_{(°)}$	$U_{(m/s)}$	$U_{10dir(°)}$
buoy	1.6	12.1	229	27	5.7	143
TS-X	1.4	12.2	221	21		

Coastal Sea state characterization

Wavelength field

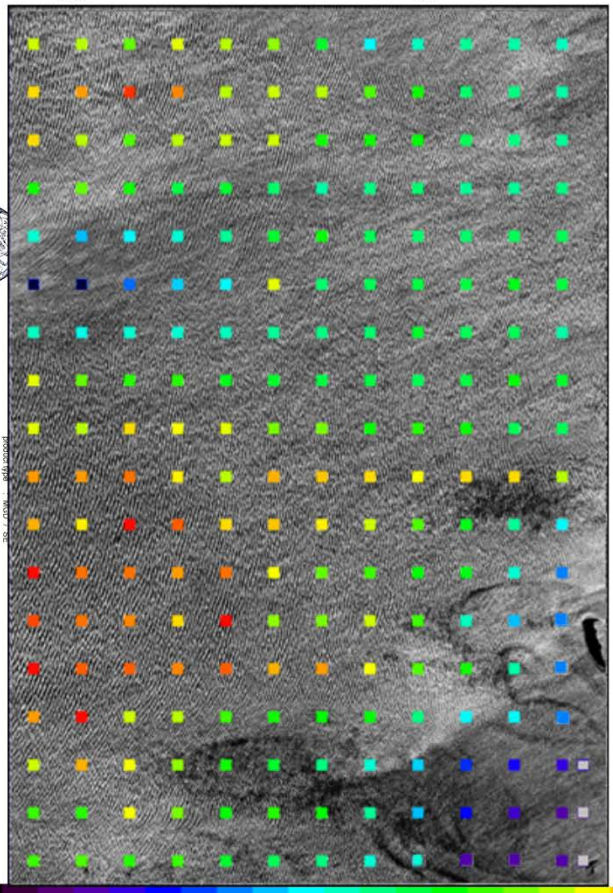




40 65 130 195 300

Wavelength (m)

Significant wave height field



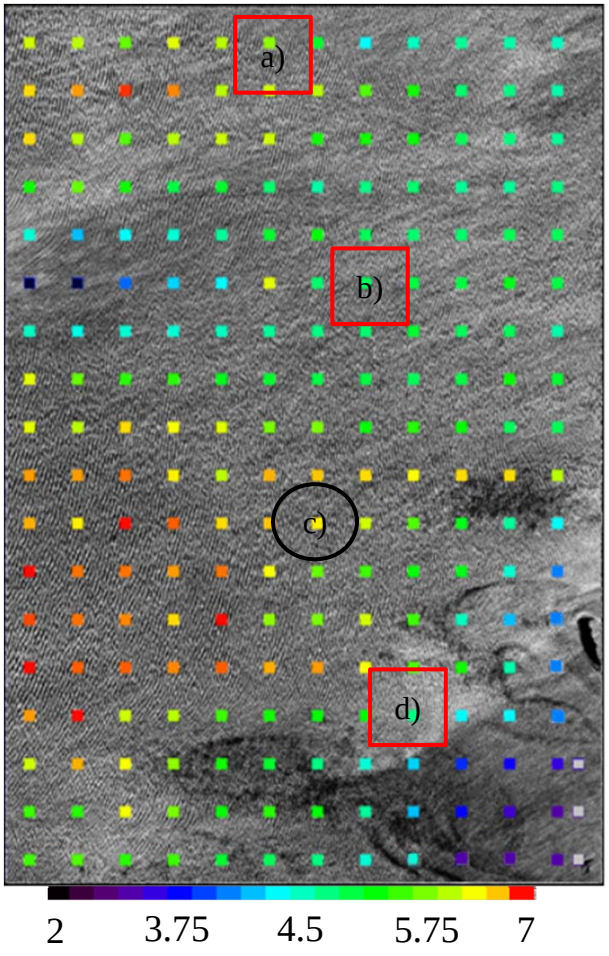
2 3.75 4.5 5.75 7

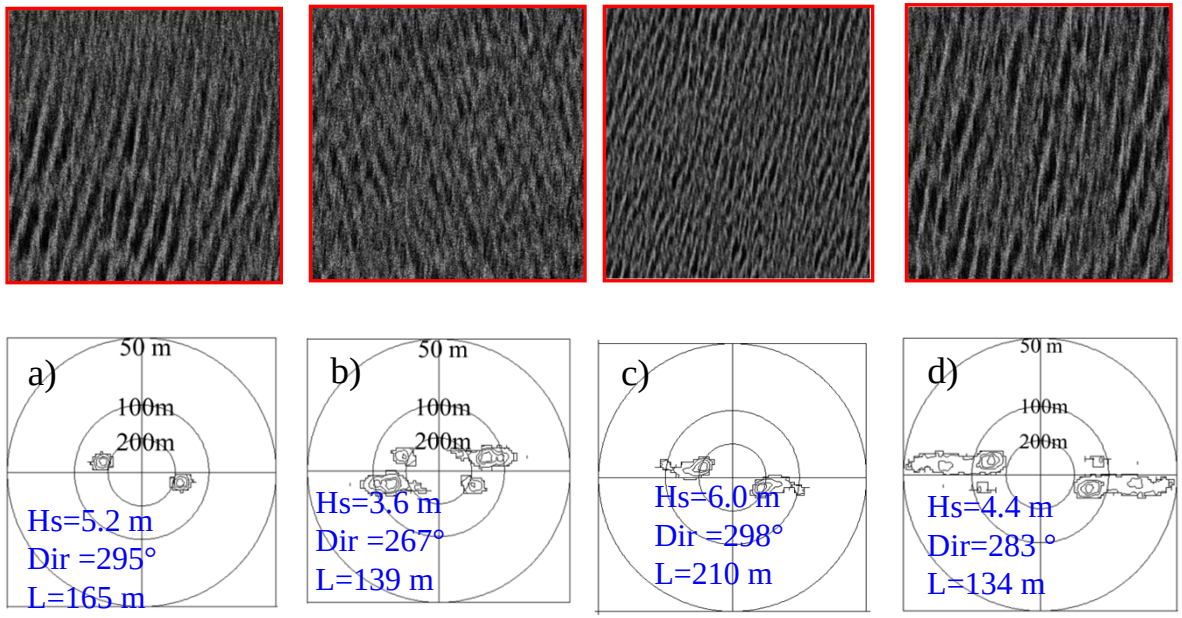
Wave height (m)

Wave analyses on a 1024 pixel box ~2.4 km

Coastal Sea state characterization

TS-X Stripmap VV pol. acquired on Dezember, the 9th , 2011 5:42 UTC near Elbe Estuary





	Hs (m)	*Tp* (s)	*Λp* (m)	*Dir* (°)	*U* (m/s)	*Udir* (°)
DWD	4.1	13.5	285	307	18.5	261
buoy	5.7	11.1	195	-	-	-
TS-X	6.0	11.6	210	298	16.6	260

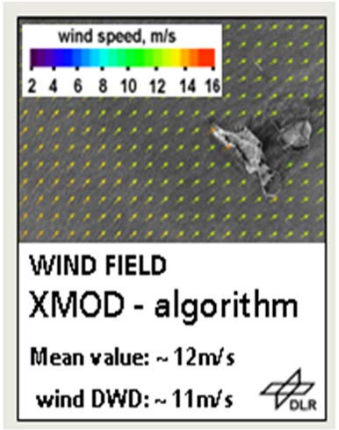
Use of Parameters Derived from SAR for Numerical Wave Modelling

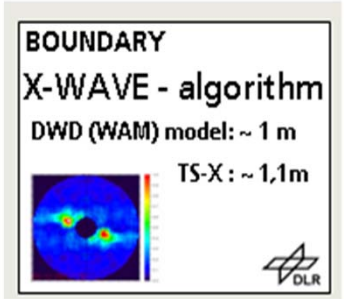
TerraSAR-X Scene

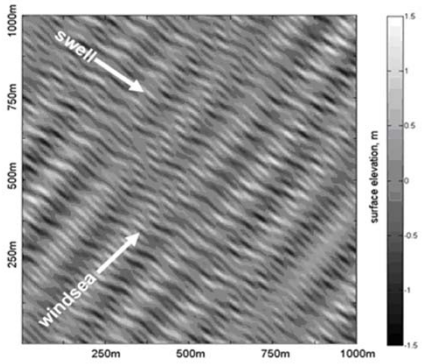
Wind and boundary conditions

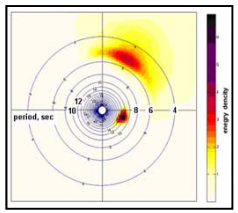
Topography and wave model

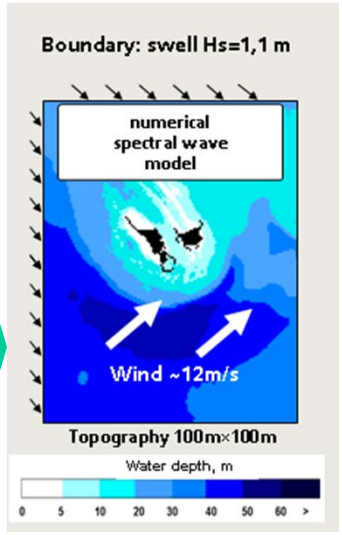
Results of wave model

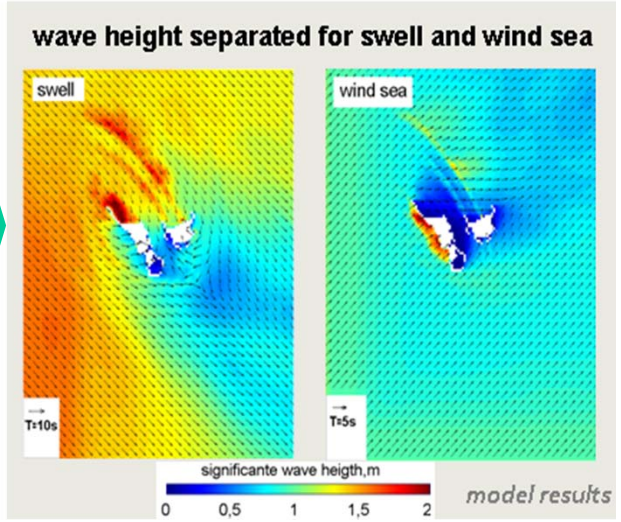












Boundary spectrum, composed of two parts:
- Swell (XWAVE)
- Wind sea (JONSWAP)

Wind field: XMOD Algorithmus
Sea state: XWAVE Algorithmus

Summary

- Derivation of Coastal Wind and Wave Fields using TS-X
- XMOD1, linear tuned on X-SAR
- XMOD2, CMOD type GMF, tuned on 200 TS-X data
- Application for Offshore Wind Farms
- TS-X Peak wave length and direction SI<14 %
- XWAVE tuned on 200 TS-X scenes, up to 7 meters HS, SI 20%
- Used for boundary conditions of coastal wave models