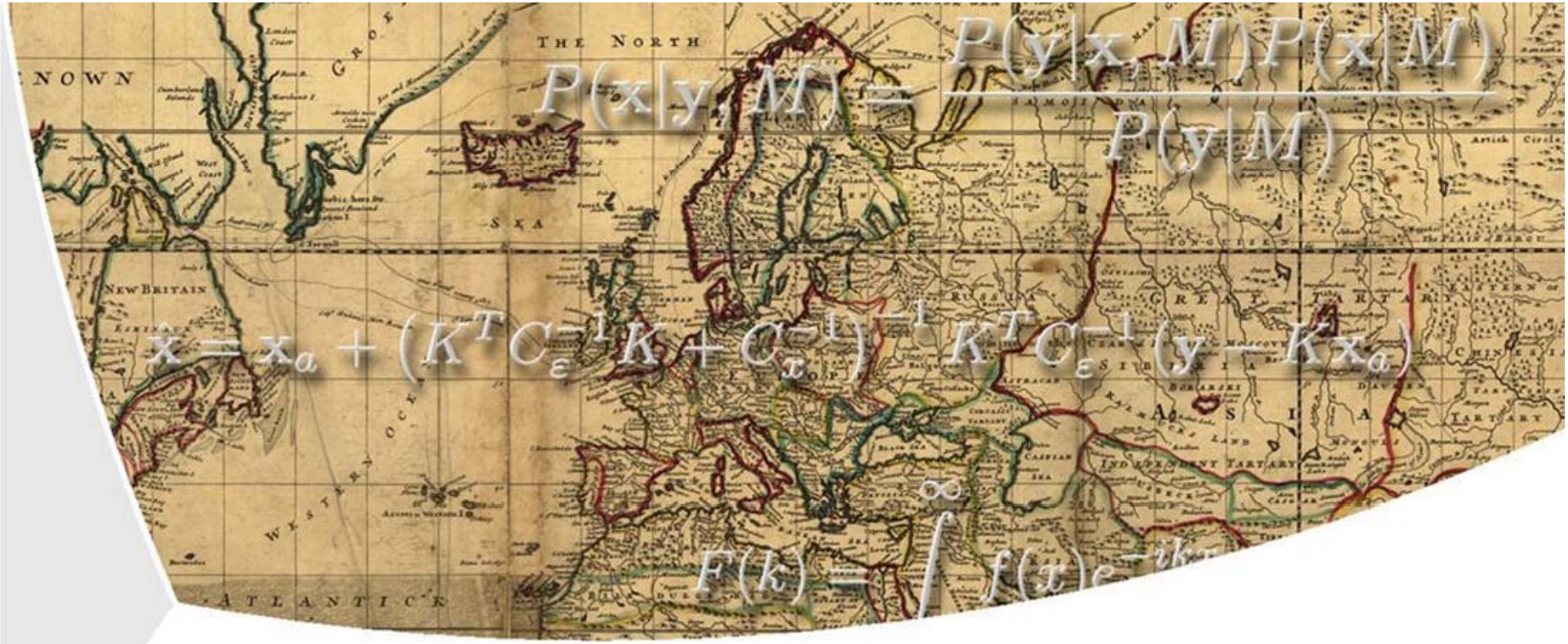


Sea State Measurement using Synthetic Aperture Radar Data

Lehner, Susanne
Pleskachevsky, Andrey
Li, Xioming
Brusch, Stephan

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

German Aerospace Center, Remote Sensing Technology Institute

Institut für Methodik der Fernerkundung

Outline

- Satellites
  - ENVISAT (ASAR)
  - TerraSAR-X
- Algorithms for sea state estimation
  - sea state parameters global: ENVISAT ASAR CWAVE_ENV
  - sea state parameters local: TerraSAR-X XWAVE
- Applications
  - ***wave tracing***: underwater topography by observation of long wave refraction in coastal areas and energy flux along the wave track
  - ***implementation*** of SAR information into numerical modelling

1.1 CWAVE for Envisat

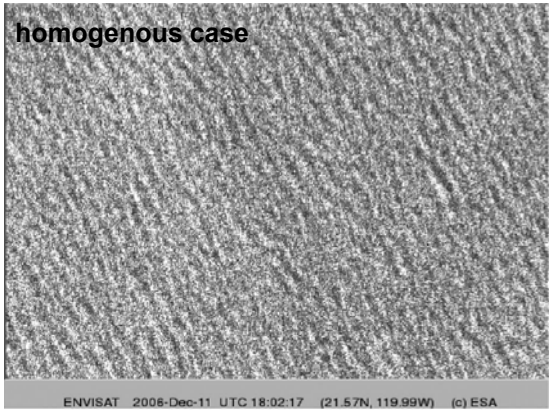
ASAR images covering 6/10km×5km acquired along the orbit every 100 km.

CWAVE_ENV (CWAVE for ENVISAT)

- for **A**dvanced **SAR** (ASAR) wave mode data based on the **CWAVE** approach developed for ERS-2 SAR wave mode data
  non-linear geophysical model function from CWAVE applied and tuned

- **Validation conducted by**
  ***in situ* buoy measurements,**
  ECMWF reanalysis,
  WAM-wave model results
  Altimeter measurements
- without needing input of prior information

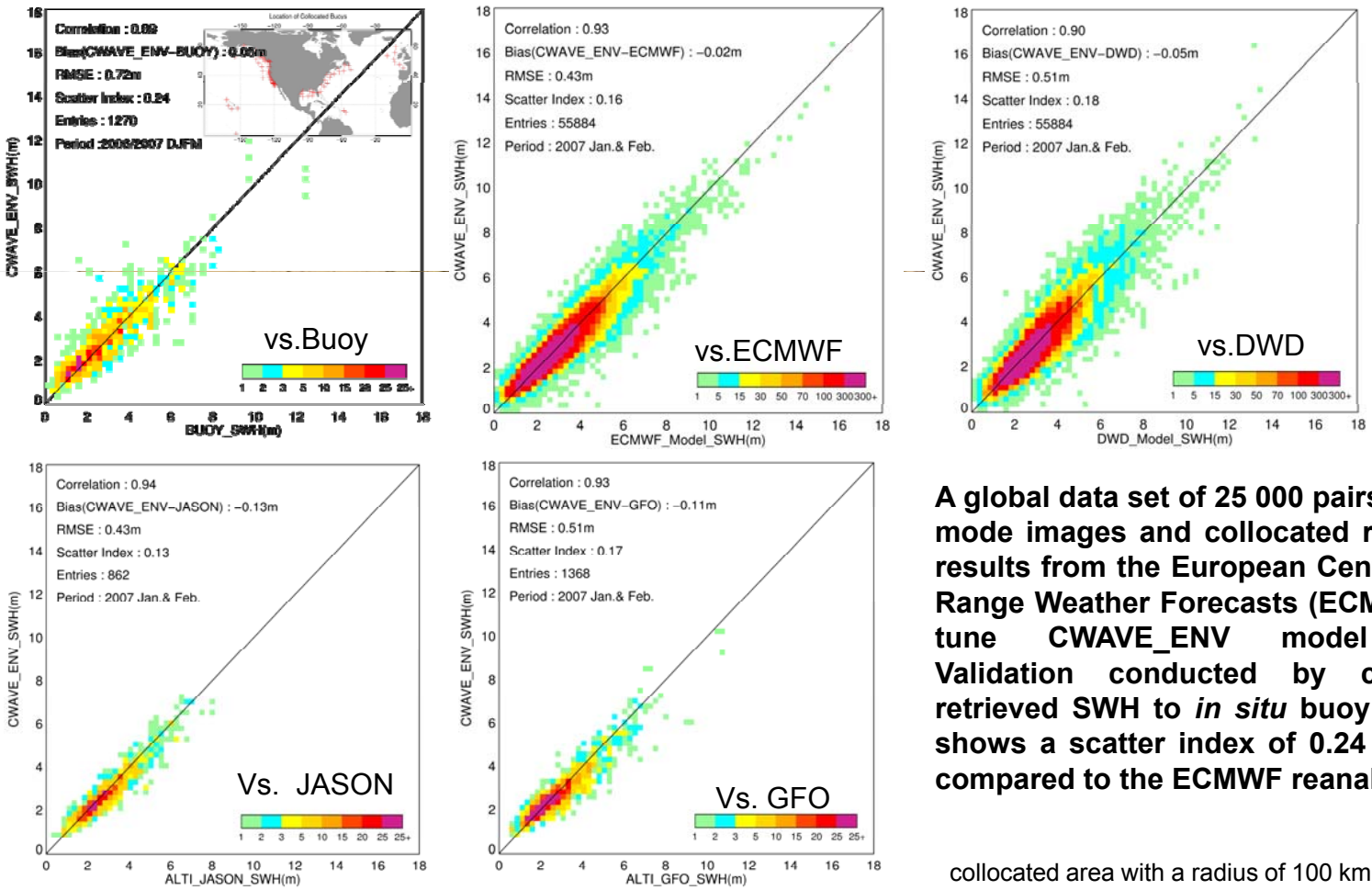
- **makes SAR an independent instrument measuring integrated wave parameters like SWH and mean wave period to altimeter quality.**



Publication: Li, X.-M., Lehner, S., Bruns, Th.
Ocean wave integral wave parameter Measurements using Envisat ASAR wave mode data
IEEE TGRS, 2010. DOI:10.1109/TGRS.2010.2052364.

1.2 CWAVE for Envisat: *comparisons*

New technique (CWAVE_ENV) developed for deriving significant wave height from ASAR wave mode data under severe weather situations.



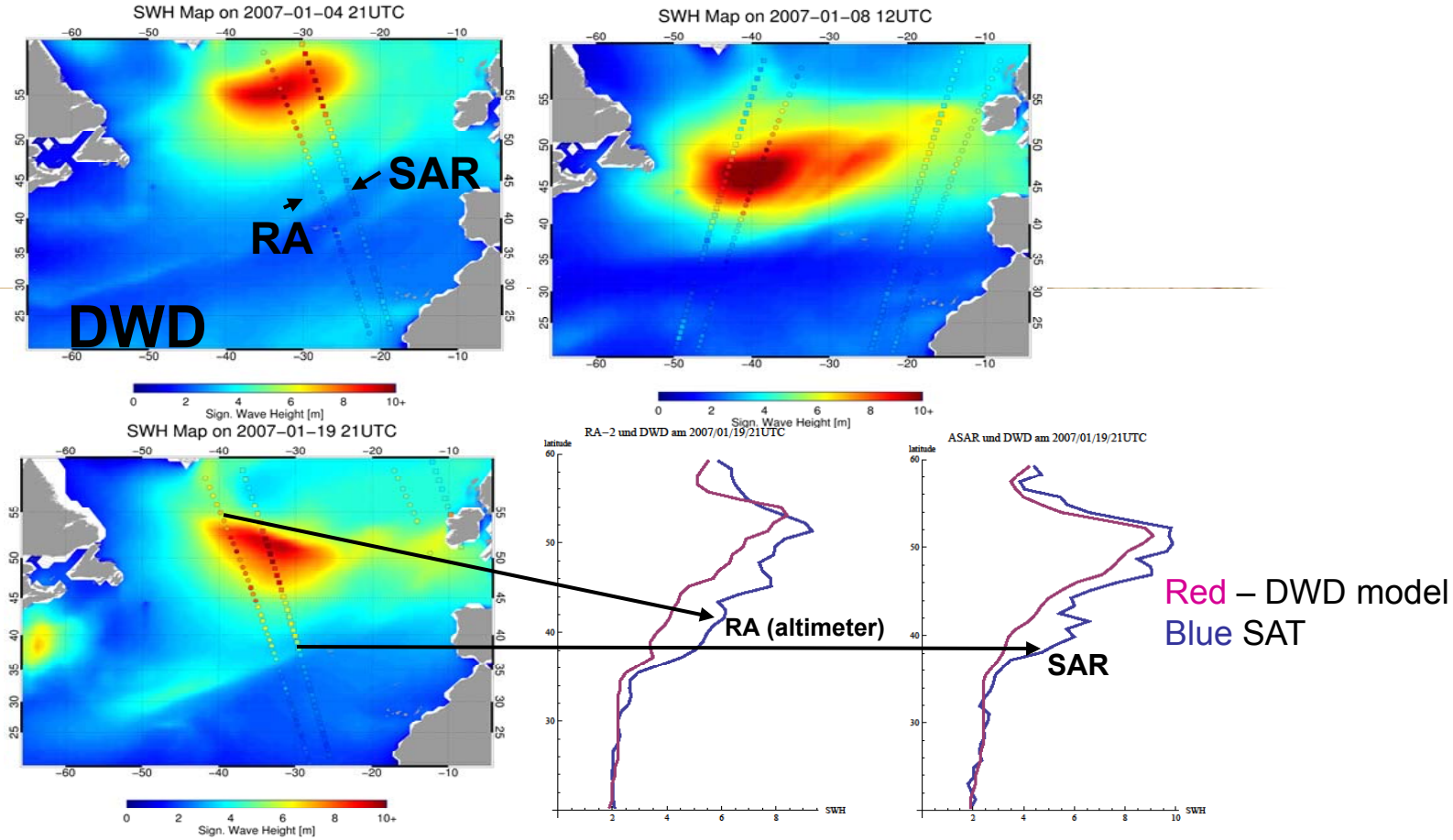
A global data set of 25 000 pairs of ASAR wave mode images and collocated reanalysis WAM results from the European Centre for Medium-Range Weather Forecasts (ECMWF) is used to tune CWAVE_ENV model coefficients. Validation conducted by comparing the retrieved SWH to *in situ* buoy measurements shows a scatter index of 0.24 and 0.16 when compared to the ECMWF reanalysis WAM.

collocated area with a radius of 100 km, +/-3h

Publication: Li, X.-M., Lehner, S., Bruns, Th.
Ocean wave integral wave parameter Measurements using Envisat ASAR wave mode data
IEEE TGRS, 2010. DOI:10.1109/TGRS.2010.2052364.

1.3 CWAVE for Envisat: *validation of wave models*

An underestimation of wave height in wave-model forecasting especially during storms



two independent measurements show underestimation by wave model (DWD)

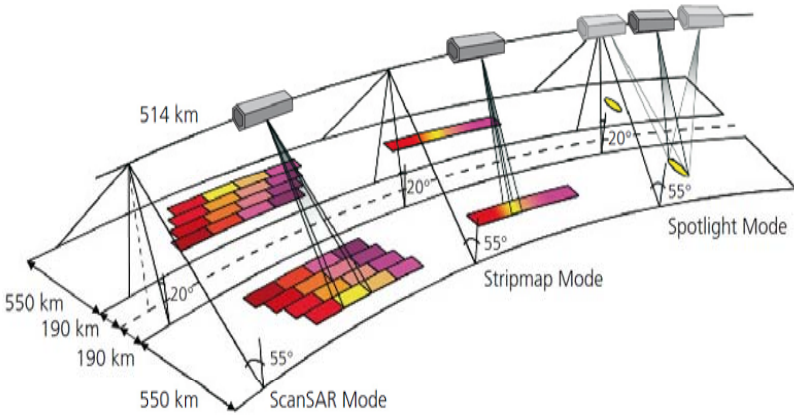
Publication: Li, X.-M., Lehner, S., Bruns, Th.
Ocean wave integral wave parameter Measurements using Envisat ASAR wave mode data
IEEE TGRS, 2010. DOI:10.1109/TGRS.2010.2052364.

2.1 TerraSAR-X satellite

- 514 km altitude,
- ground speed 7km/s, 15 orbits/day, repetition 11 days
- sensor: high frequency X-band SAR
  (Synthetic Aperture Radar)
  wavelength 31mm, frequency 9,6GHz

Basic modes and resolution:

- **Spotlight, 10km x 10**km, of **1-2**m
- **Stripmap, 30**km wide strips at a resolution between **3,3 (azimuth) and 6**m,
- **ScanSAR 100**km wide strips at a resolution of **18**m

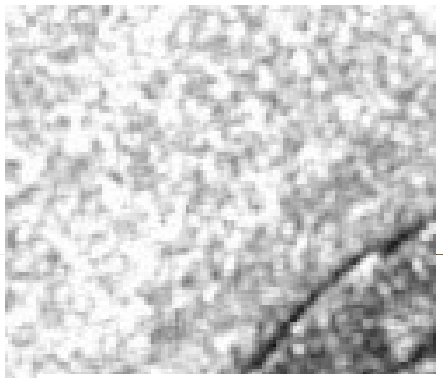


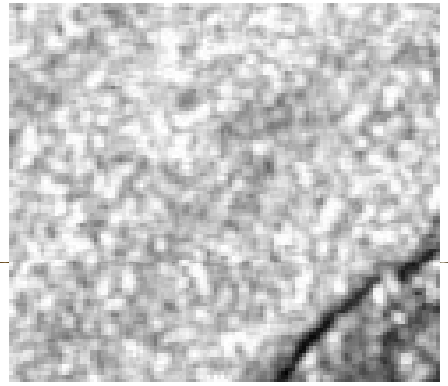
Main application and algorithms

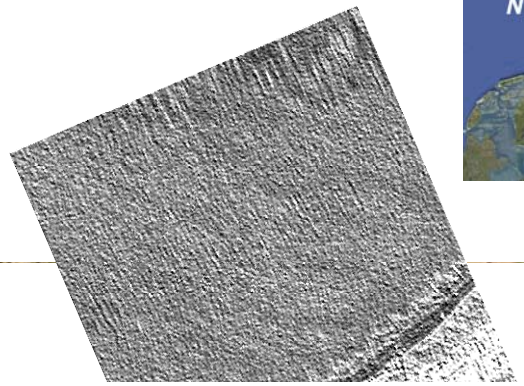
- Wind Field Generation
- Sea State Parameters
- Coastlines and Morphodynamics
- Ship Detection
- Underwater topography estimation

2.2 TerraSAR-X: *effect of the achieved higher resolution (1)*

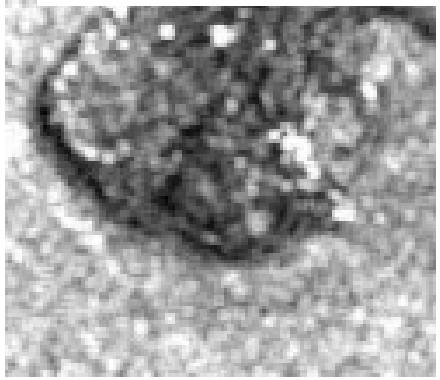
Acquired over the **German island of Norderney**, 2x7 km subscene.

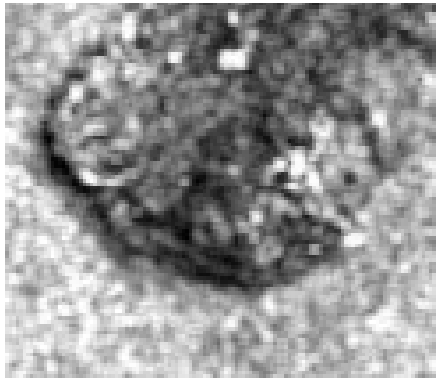


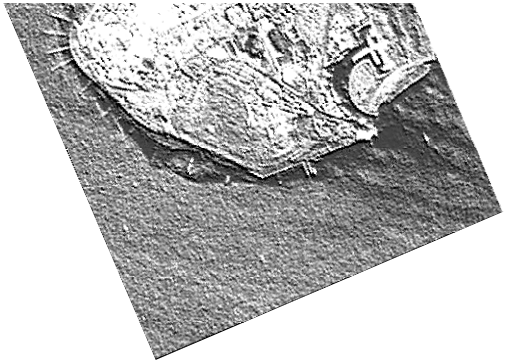




TerraSAR-X: lover altitude (514km against 800km by ENVISAT) and ground speed → reduced Doppler-shift of facets, moving to sensor, reduced cut-off of azimuth travelling waves



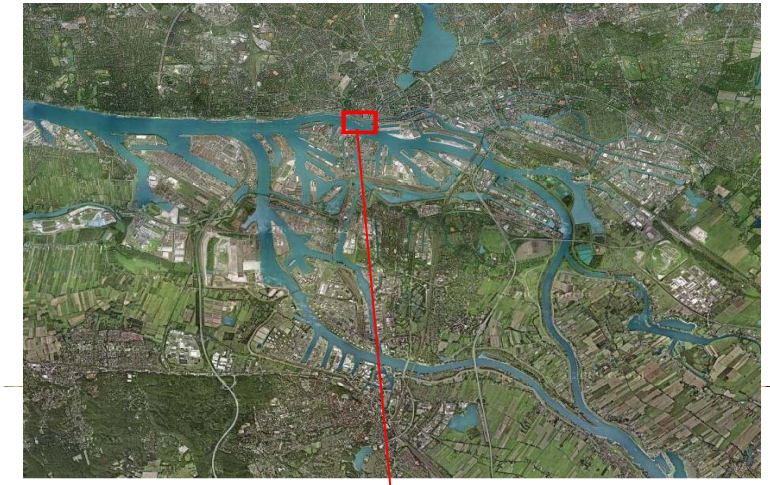


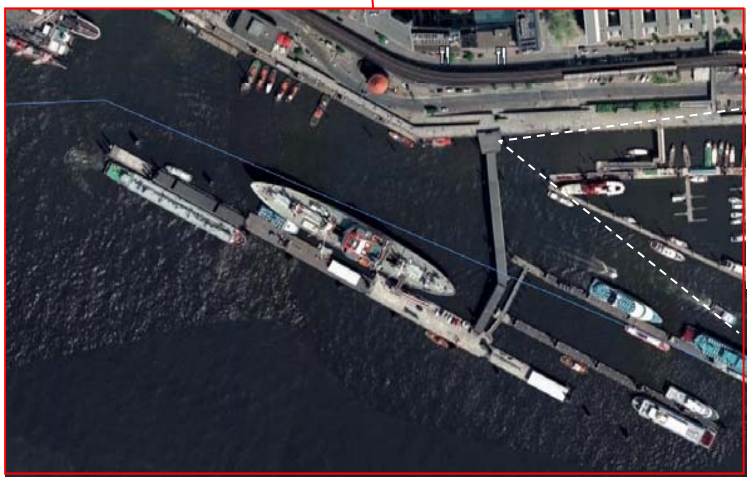


ERS April 4, 2004 *ENVISAT* *TerraSAR-X Stripmap* August 27, 2007

pixel size of 12 meters

2.2 TerraSAR-X: *effect of the achieved higher resolution (2)*



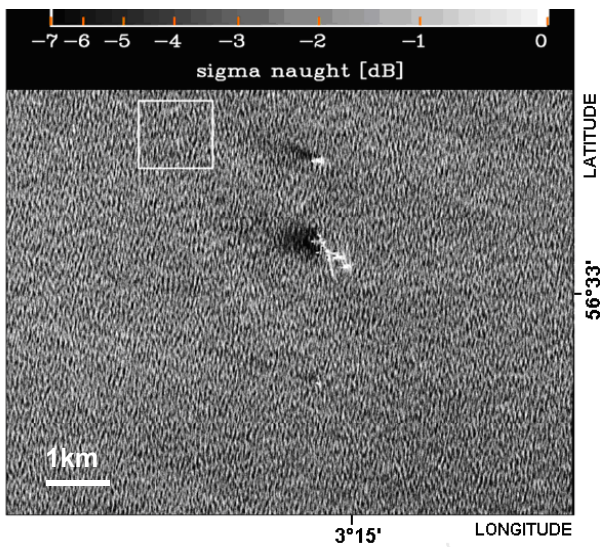


2.3 TerraSAR-X: *X-WAVE to obtain integrated wave parameters*

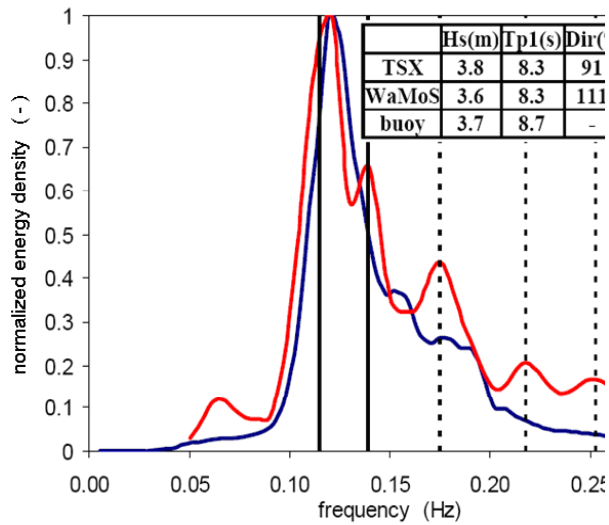
preliminary results published:

- **Using Satellite Spectral Wave Data for Wave Energy Resource Characterization**
  Pontes,M. T., Bruck, M. Lehener, S. A. and Kabuth
  In: **ICOE 2010**: 3rd International Conference on Ocean Energy, 6 October, Bilbao

- **Extraction of wave field from TerraSAR-X data**
  Bruck, M., Li,X.-M., and Lehner,S
  In: **SEA-SAR-2010**, Advances in SAR Oceanography from ENVISAT, ERS and ESA third party missions



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

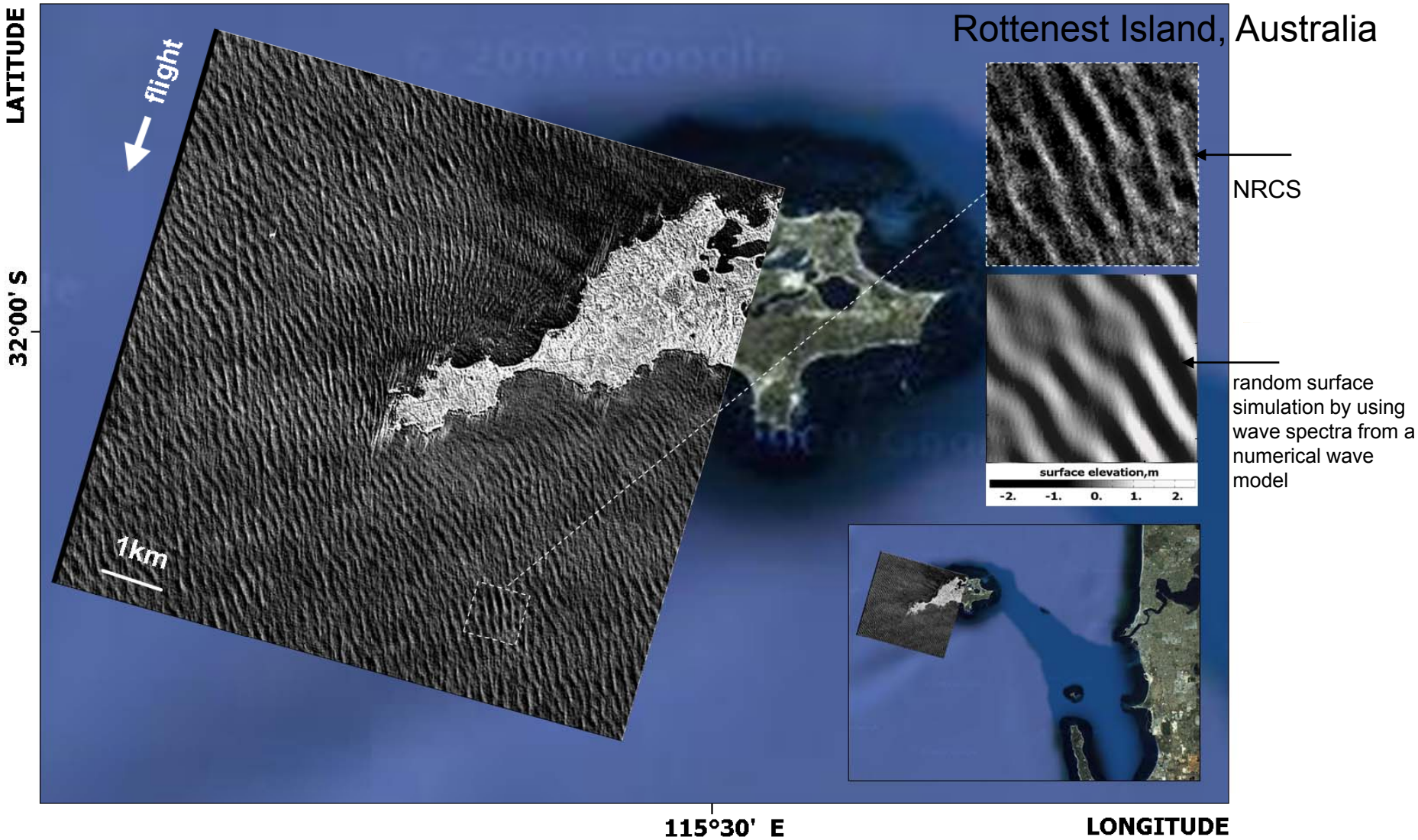


	Hs(m)	Tp1(s)	Dir(
TSX	3.8	8.3	91
WaMoS	3.6	8.3	111
buoy	3.7	8.7	-

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

wave height obtained by the buoy located at Ekofisk oil platform shows a correlation of **0.83.**

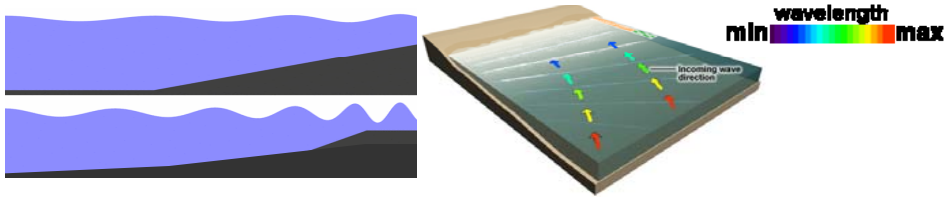
3.1 TerraSAR-X applications: *tracking and implementation into modelling*

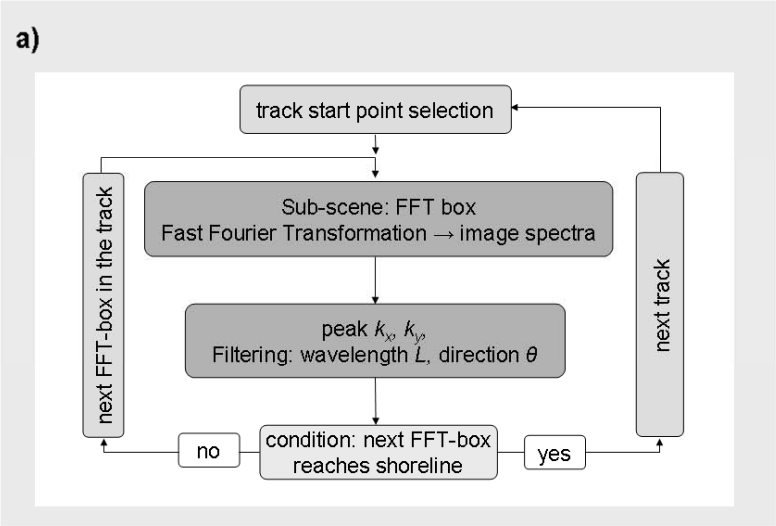


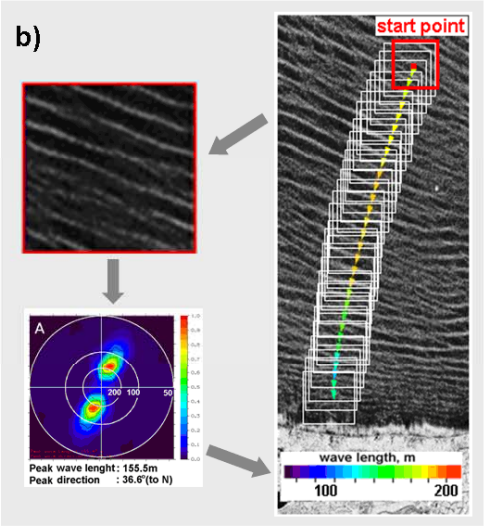
3.2 TerraSAR-X applications: *wave tracing*

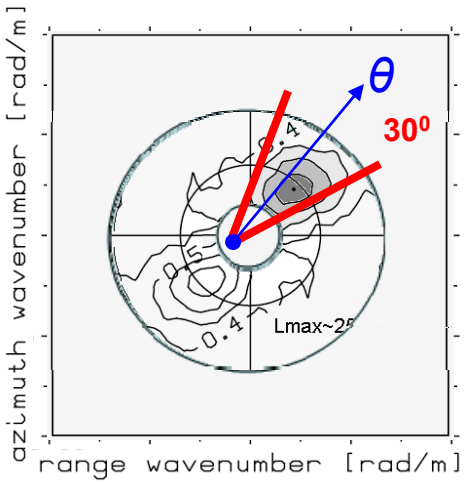
refraction of swell in shallow water (depth < 70m, 80m<*L*<300m)

Changing of wavelength depending on water depths









Data used: TerraSAR-X Spotlight mode, 10x10km scenes, 1pixel 0.75m

3.3 TerraSAR-X applications: *wave tracing → underwater topography (1)*

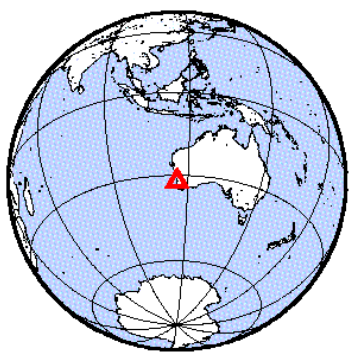
wave length L → wave number k (from TerraSAR-X)

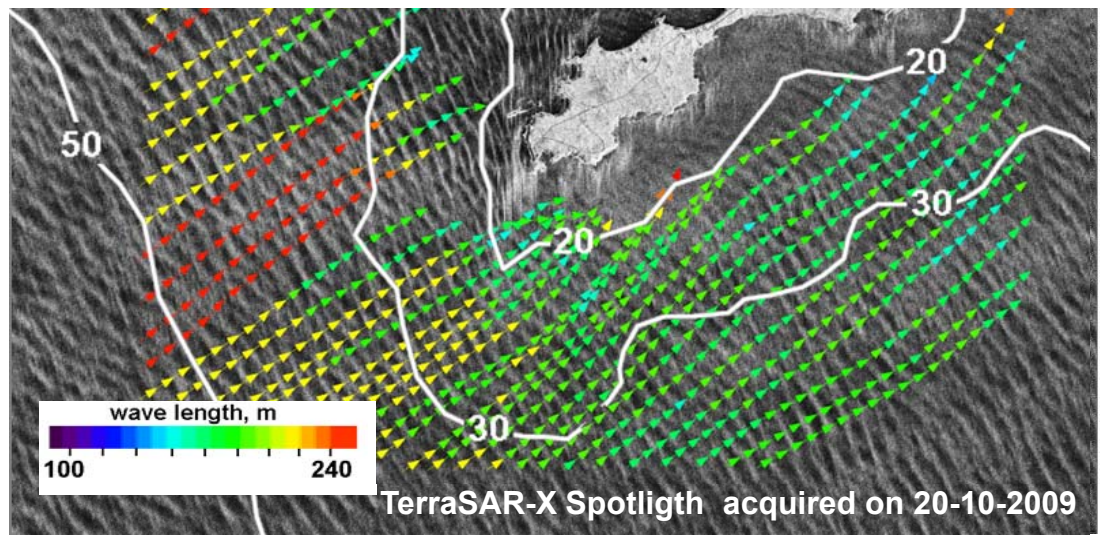
Dispersion relation: $\omega^2 = k \cdot g \cdot \tanh(k \cdot d)$ → depth d

period T → angular frequency ω (e.g. from wave model)

$10m < d < 60m$
$80m < L$

effect of shallow on wavelength by swell





3.3 TerraSAR-X applications: *wave tracing → underwater topography (2)*

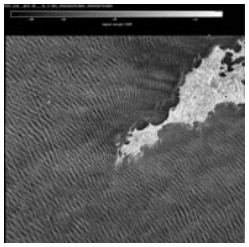
3-D dept field derived from TeraSAR-X

deepView

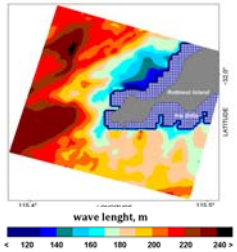
DEEPVIEW project

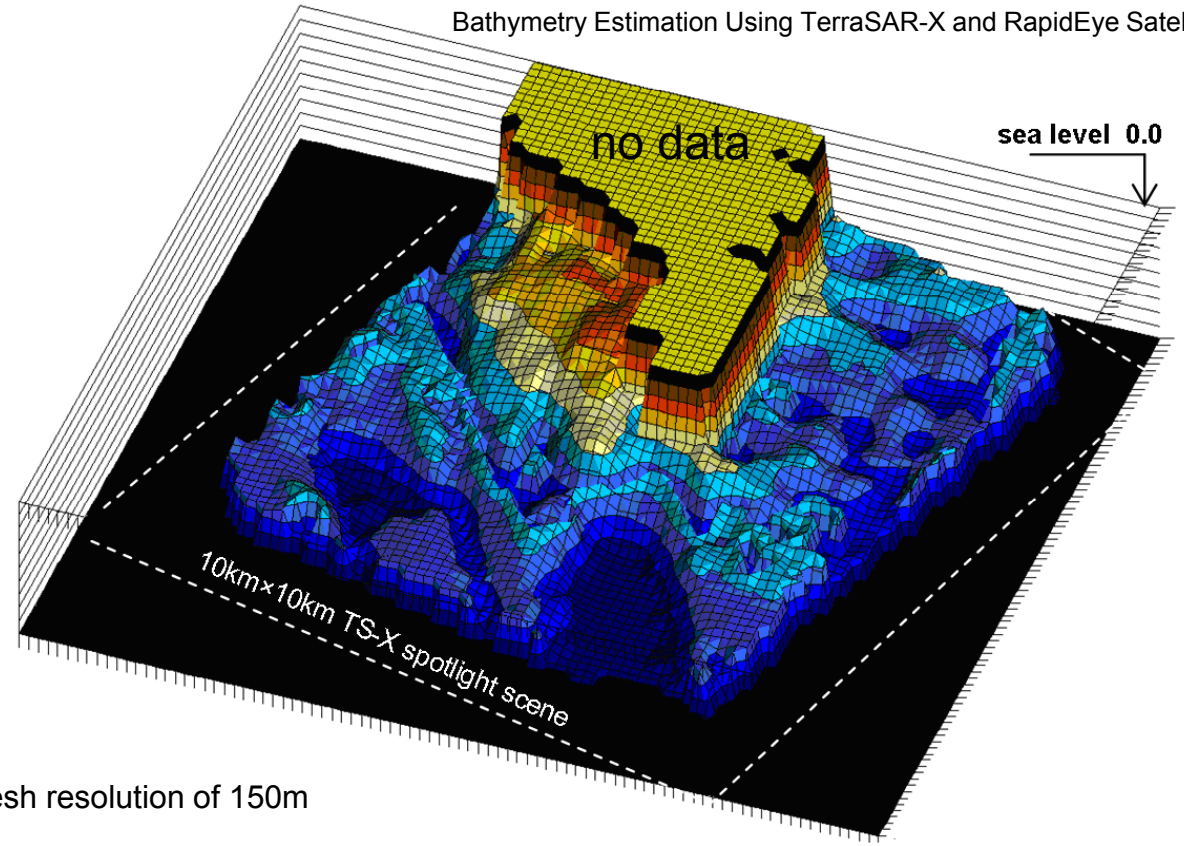
Bathymetry Estimation Using TerraSAR-X and RapidEye Satellite Data

SAR image: Spotlight



Wavelenght field



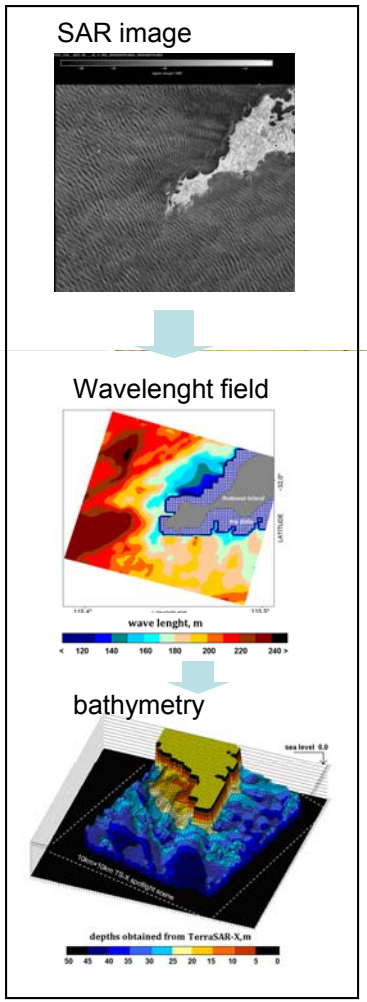


uniform mesh resolution of 150m

depths obtained from TerraSAR-X,m

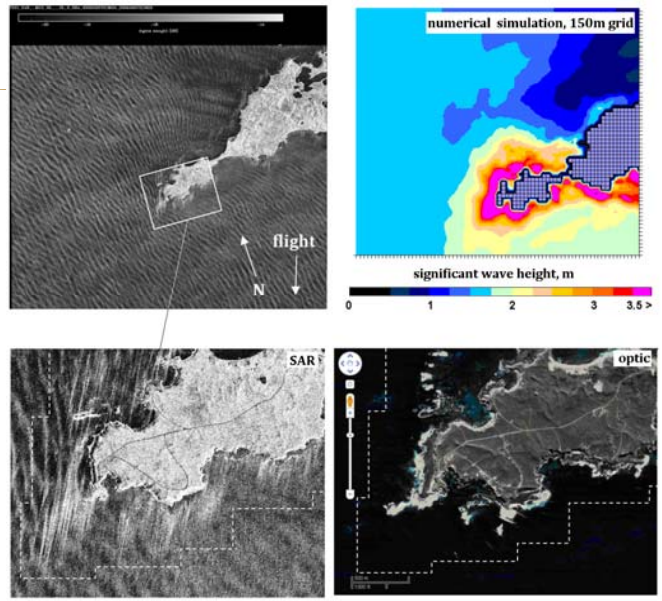
50 45 40 35 30 25 20 15 10 5 0

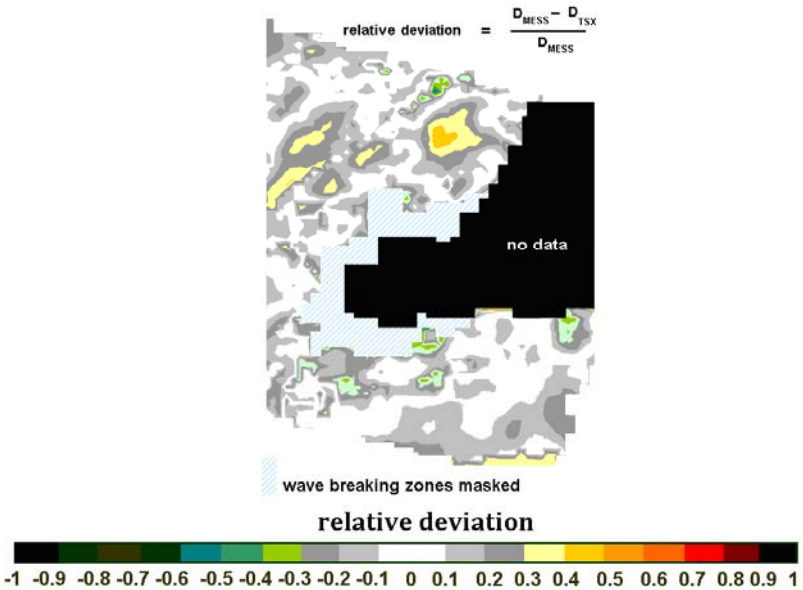
3.3 TerraSAR-X applications: *wave tracing → underwater topography (3)*



Comparison with echo-sounding data

(different measurements, no errors are known)

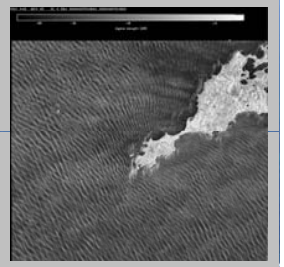




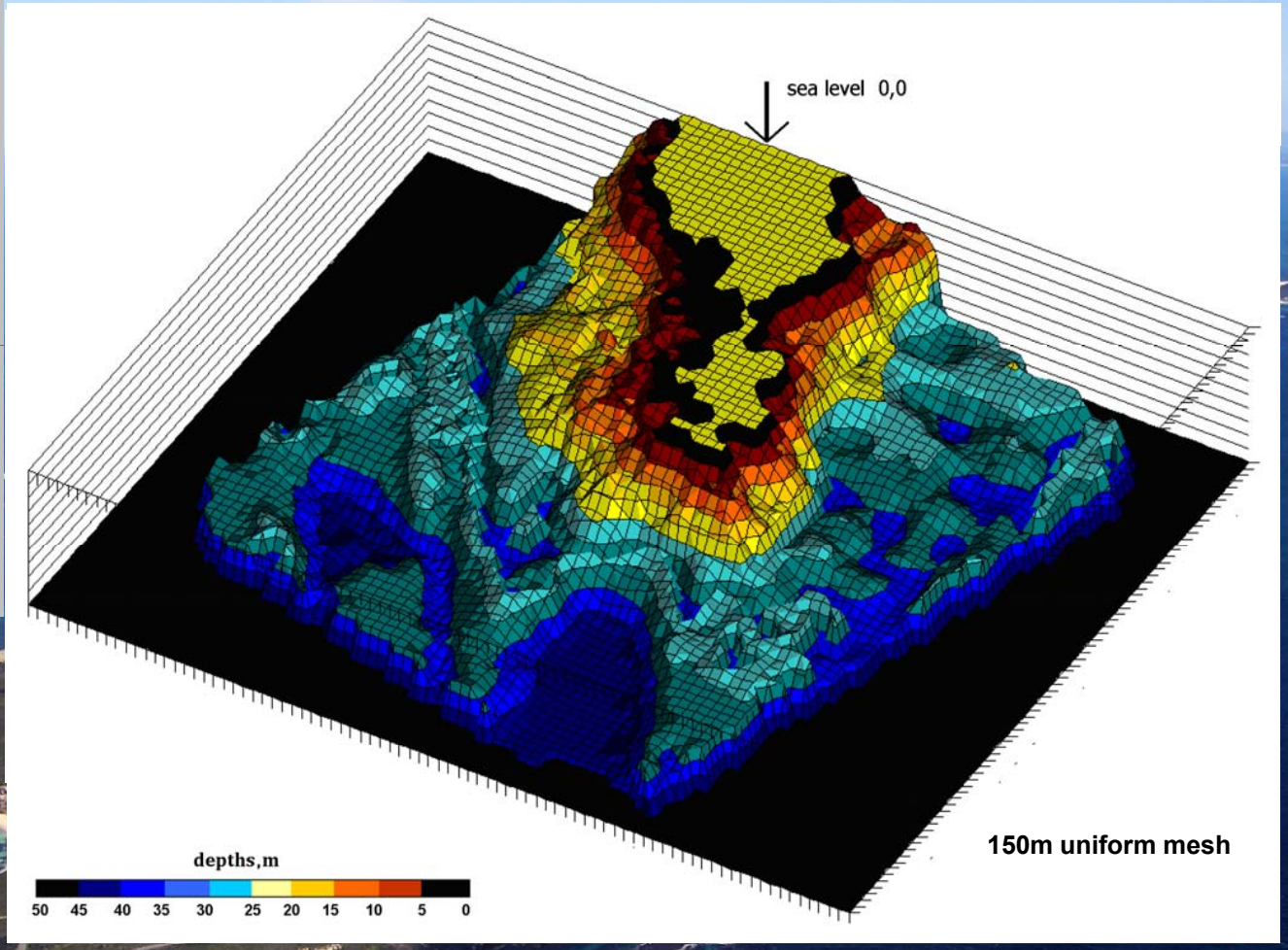
3.3 TerraSAR-X applications: *wave tracing → underwater topography (4)*

Synergy SAR (TerraSAR-X) and optical information (QuickBird)

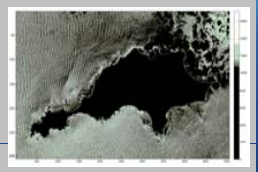
TerraSAR-X



Depth estimation in domain 70-15m



QuickBird



Depth estimation in domain 0-25m

EOMAP

Publication: ***(in preparation)***

Synergy and Fusion of Optical and Synthetic Aperture Radar Satellite Data for Underwater Topography Estimation in Costal Areas

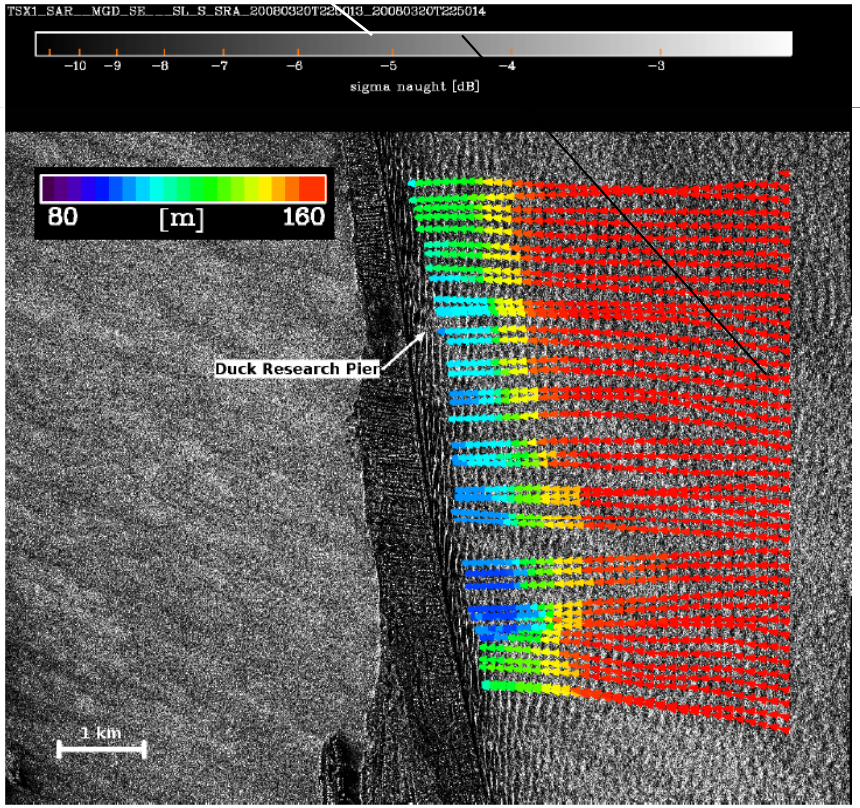
Pleskachevsky, A., Lehner, S. Heege, T., and C. Mott

3.3 TerraSAR-X applications: *wave tracing → underwater topography (5)*

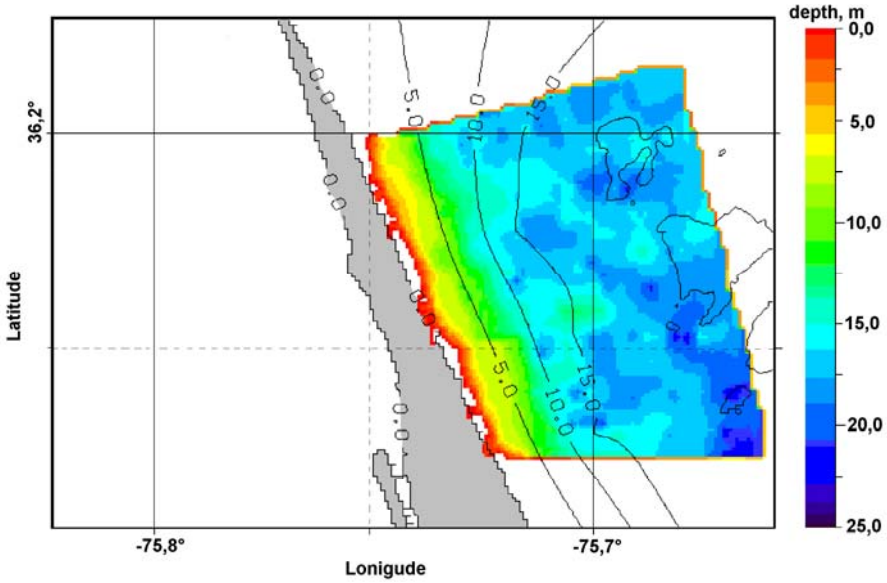
Duck Research Pier

Publication:

Underwater Bottom-Topography in coastal areas from TerraSAR-X data,
Brusch,S., Held,P., Lehner,S., Rosenthal,W., and A.Pleskachevsky
International Journal of Remote Sensing (*in print*)



Topography obtained from TerraSAR-X data [m]



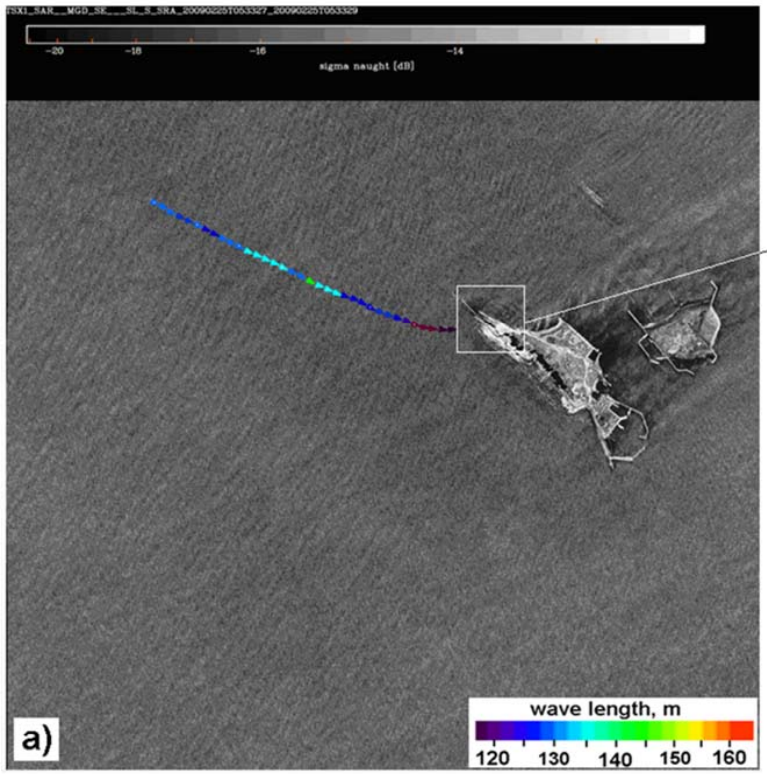
3.4 TerraSAR-X applications: *wave tracing → energy flux by swell waves*

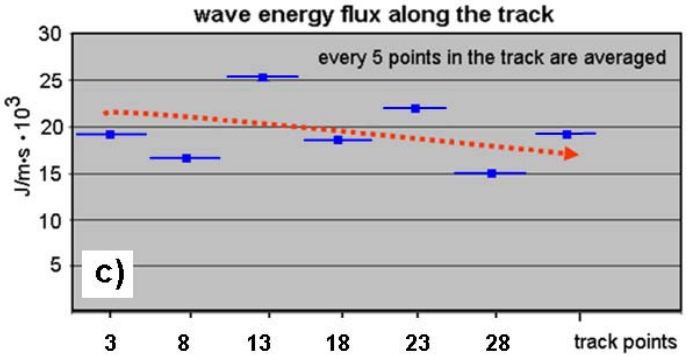
Wave energy flux $FLUX = E \cdot C_g$ [J/m·s]

$E = f(H_s^2)$ wave energy density per unit horizontal area
$C_g = f(T,L)$ wave group velocity

TerraSAR-X Spotlight: 25-02-2009

Heligoland Island



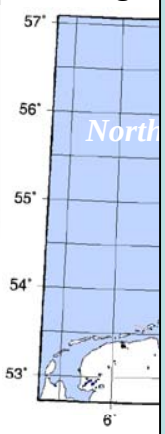


3.5 TerraSAR-X applications: *SAR data into wave modelling (1)*

boundary and wind field derived from SAR → numerical spectral wave model

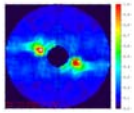
SAR

Heligo



Wave height

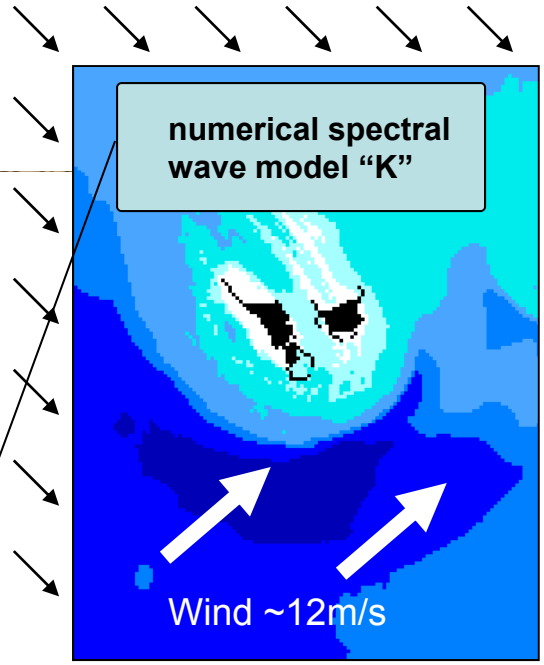
derived from SAR



XWAVE - algorithm

Mean value: ~ 1m

Boundary spectra include
swell part (from XWAVE) and
wins-sea part (using JONSWAP by wind data)



Topography 100x100m

The K-model is a discrete spectral wave model adapted to shallow waters and strong bottom gradients

The K-model calculates the distribution of energy density *E* in the wave number domain (*k*,*θ*), *θ* is the wave direction

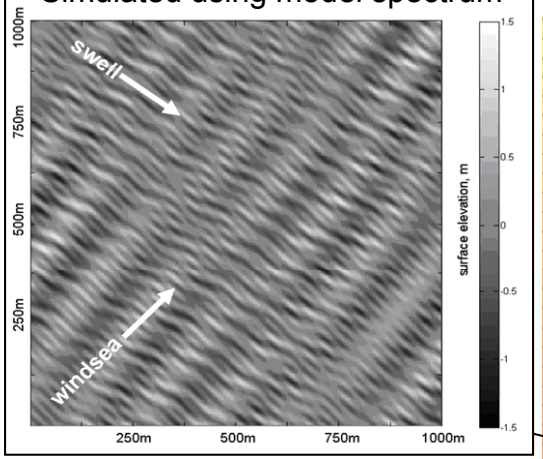
Being an offspring of the WAM-Model, it contains some different source terms

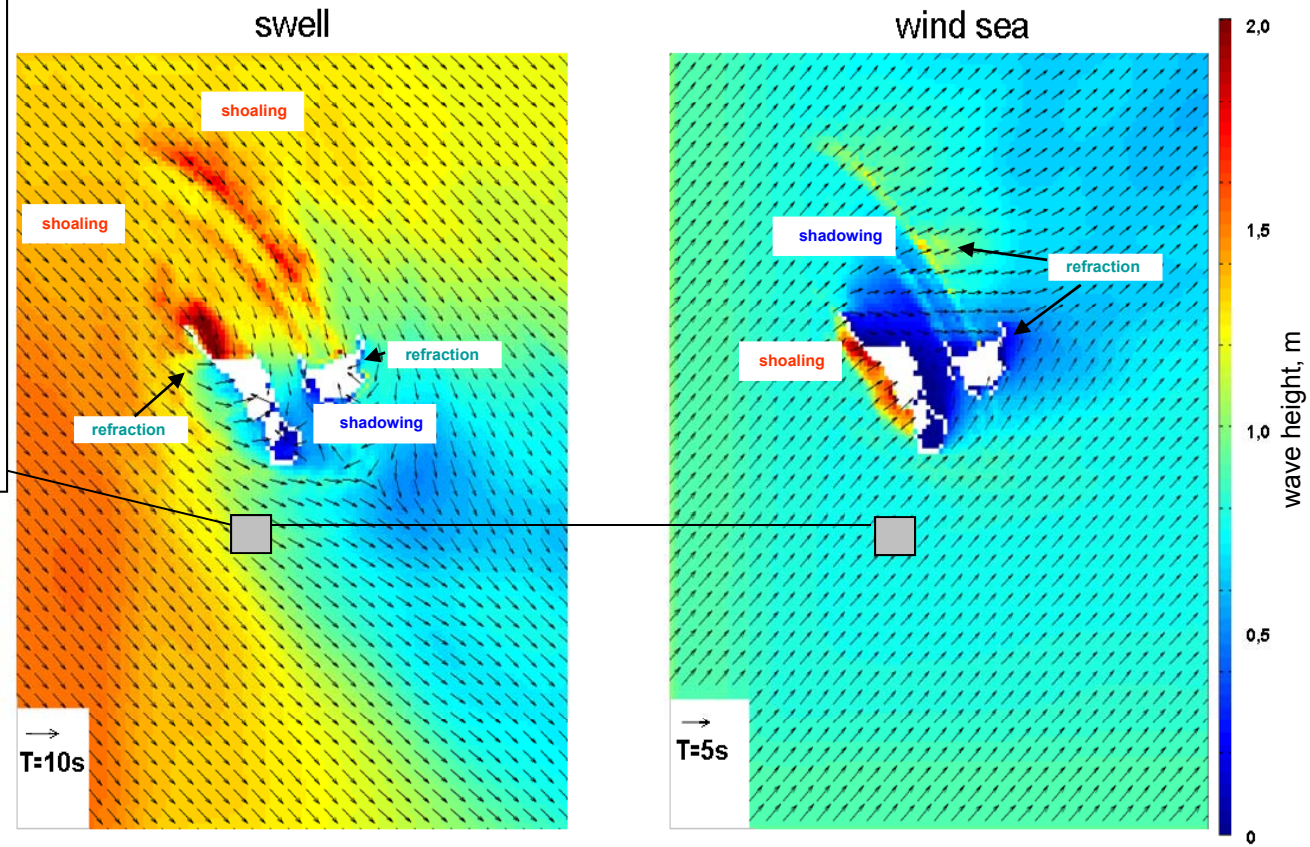
The wave breaking effect is implicitly considered in the model via adequate energy loss due to non-linear dissipation (Kitaigorodski-scaling)

3.5 TerraSAR-X applications: *SAR data into wave modelling (2)*

boundary and wind field derived from SAR → numerical spectral wave model

random sea surface elevation
Simulated using model spectrum





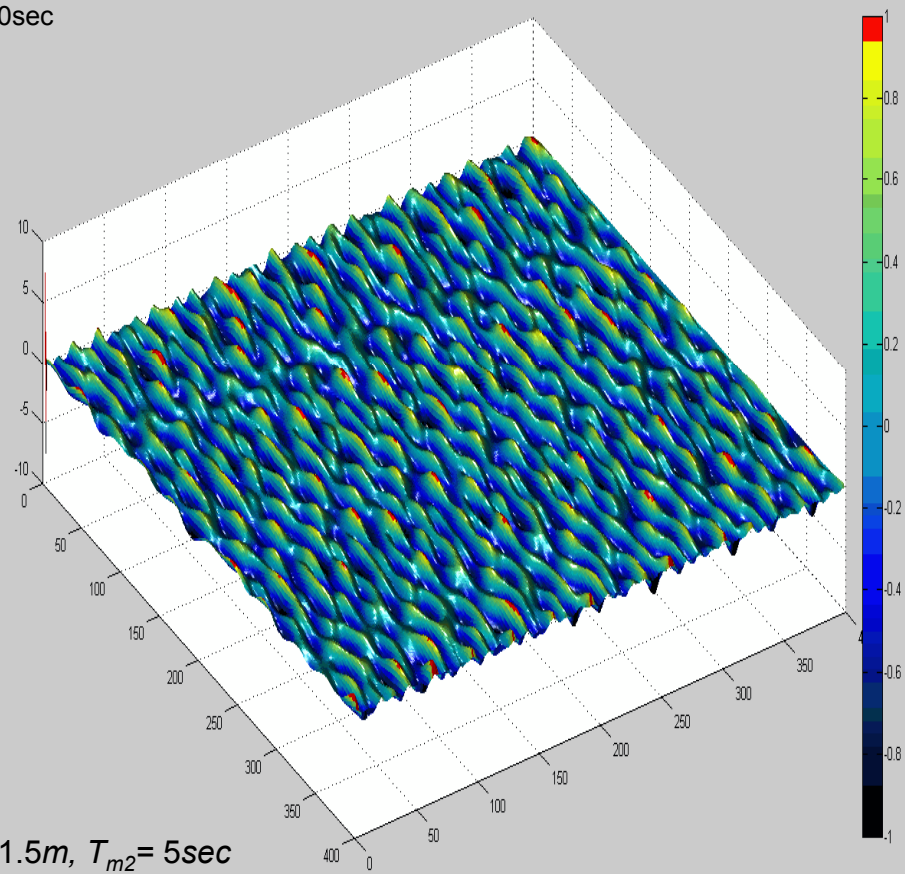
simulated wave height separated for swell and wind sea

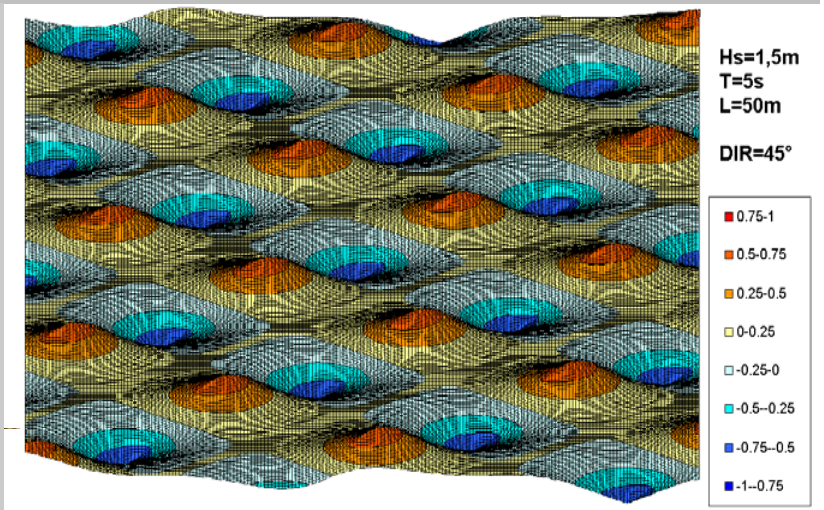
K-wave model on mesh 100x100m horizontal resolution

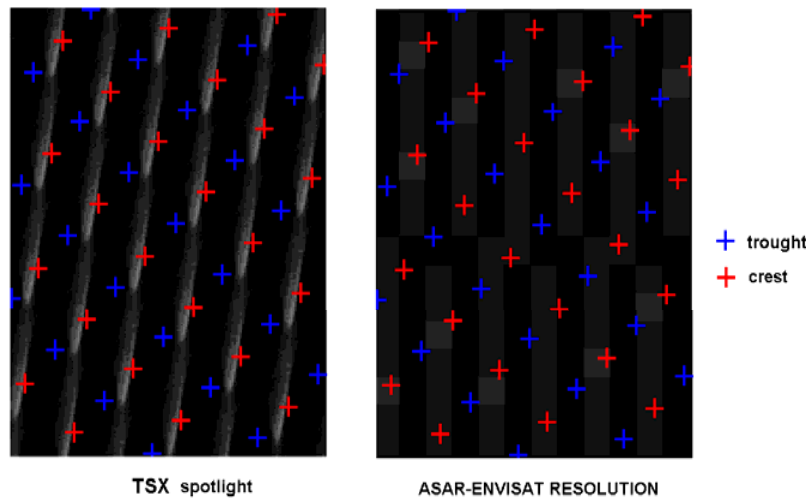
3.5 TerraSAR-X applications: *SAR data into wave modelling (3)*

surface simulation by using wave spectra from numerical wave model

Run: 10sec





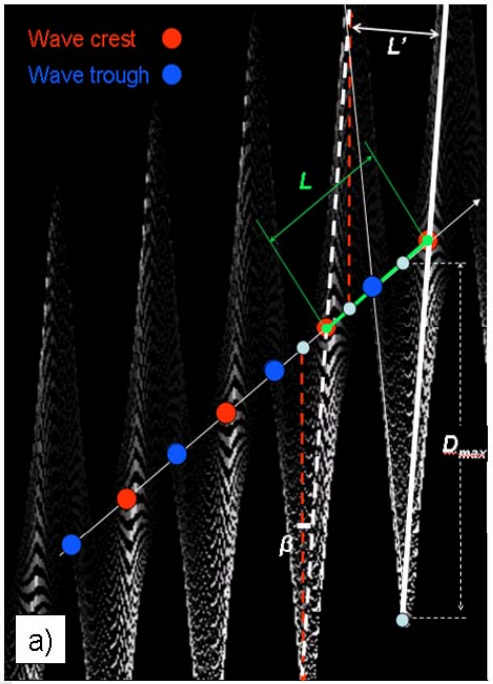


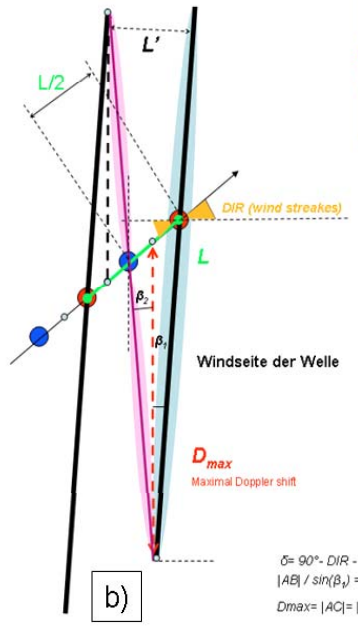
-20 -10 - 4 dB

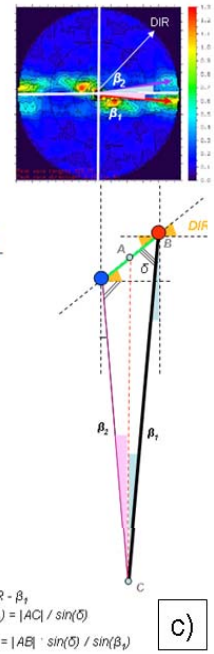
Modeled NRCS for a wave train traveling in direction 5° (up) and 45° (down) to range, incidence angle 52° (left) and 22° (right).

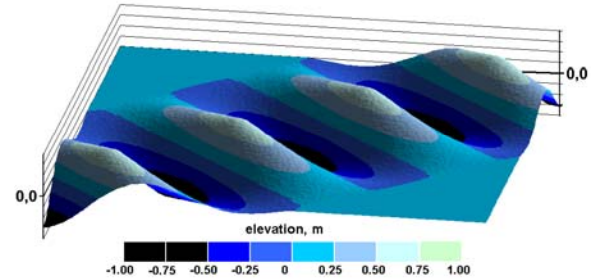
3.5 TerraSAR-X applications: *SAR data into wave modelling (4)*

Slope and length of the structures in spectra → height of the short-crest wind waves

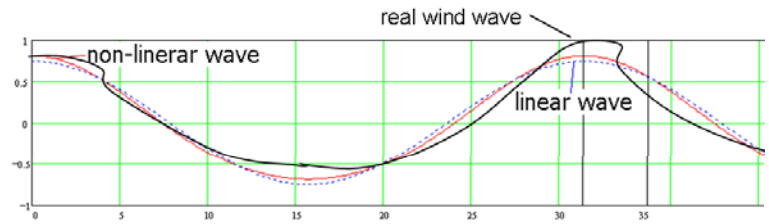




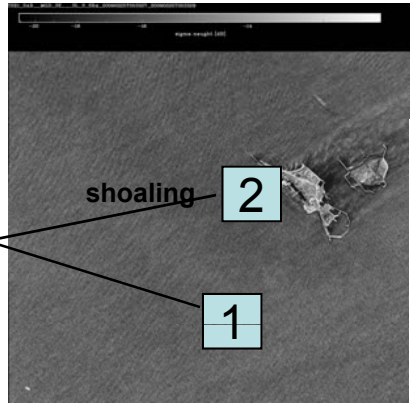




surface for short-crest wave as propagation of "single mountain" train

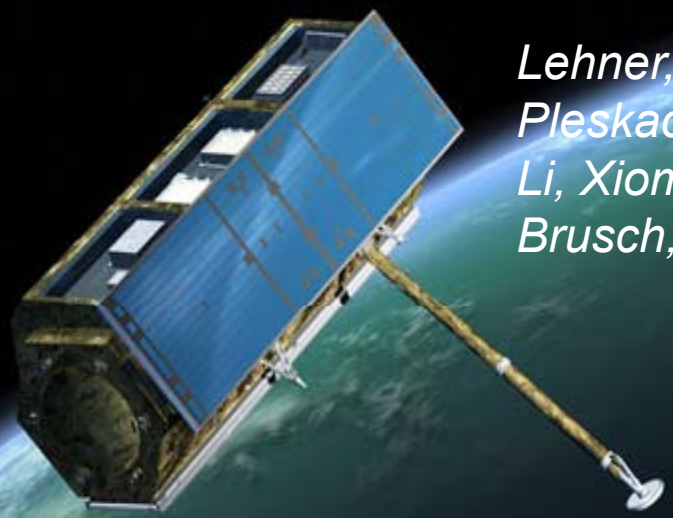


	Streaks properties	obtained parameters	resultant wave height
case 1	$L' = 25$m $\beta_1 = 3.5°$ $DIR = 28°$	$L = 35{,}9$m $T = 4{,}8$sec $D_{max} = 122$m $U_{orb}^{MAX} = 1.07$m/s	$Hs = 1.52$m
case 2 shoaling area	$L' = 28$m $\beta_1 = 1.5°$ $DIR = 32°$	$L = 32$m $T = 4{,}6$sec $D_{max} = 267{,}3$m $U_{orb}^{MAX} = 2.53$m/s	$Hs = 2.31$m

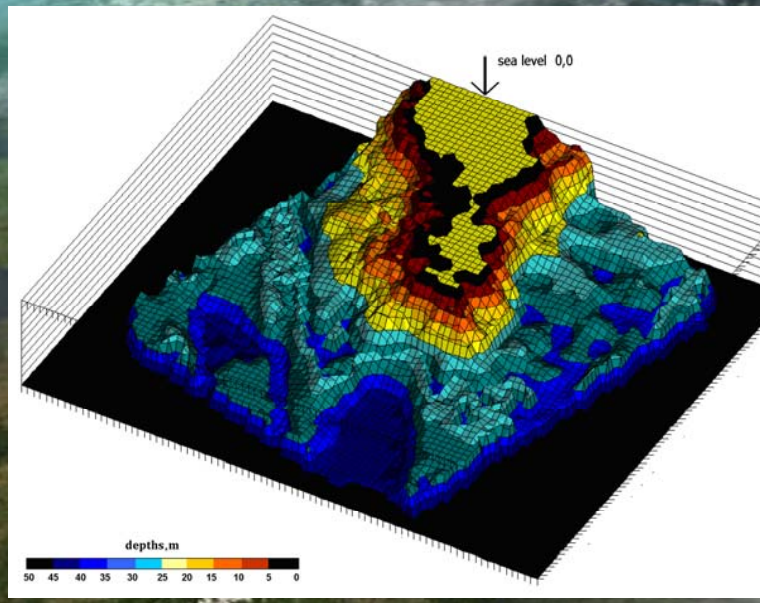


Wind ~13m/s

Sea State Measurement using Synthetic Aperture Radar Data



Lehner, Susanne
Pleskachevsky, Andrey
Li, Xioming
Brusch, Stephan



1. CWAVE_ENV – sea state from ASAR ENVISAT

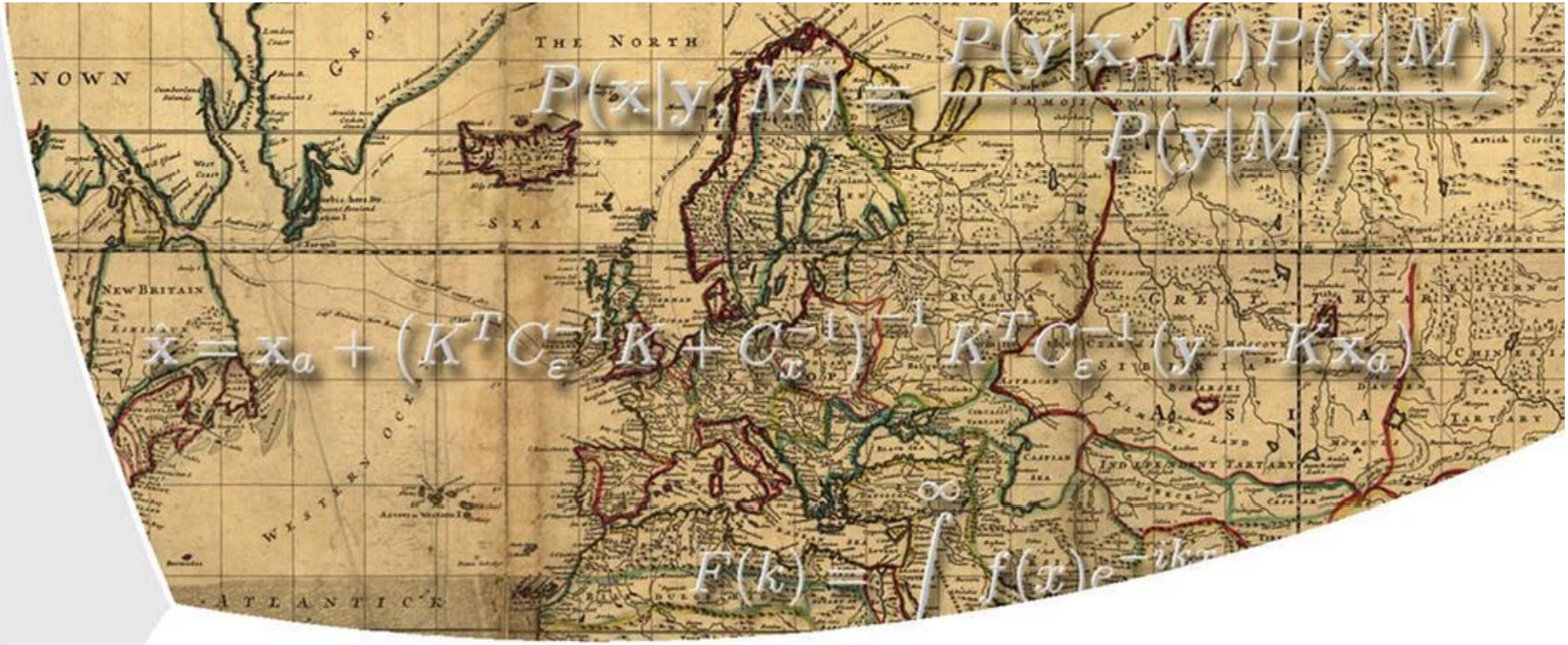
underestimation of wave height in wave-model forecasting especially during storms

2. XWAVE – sea state from TerraSAR-X high resolution data

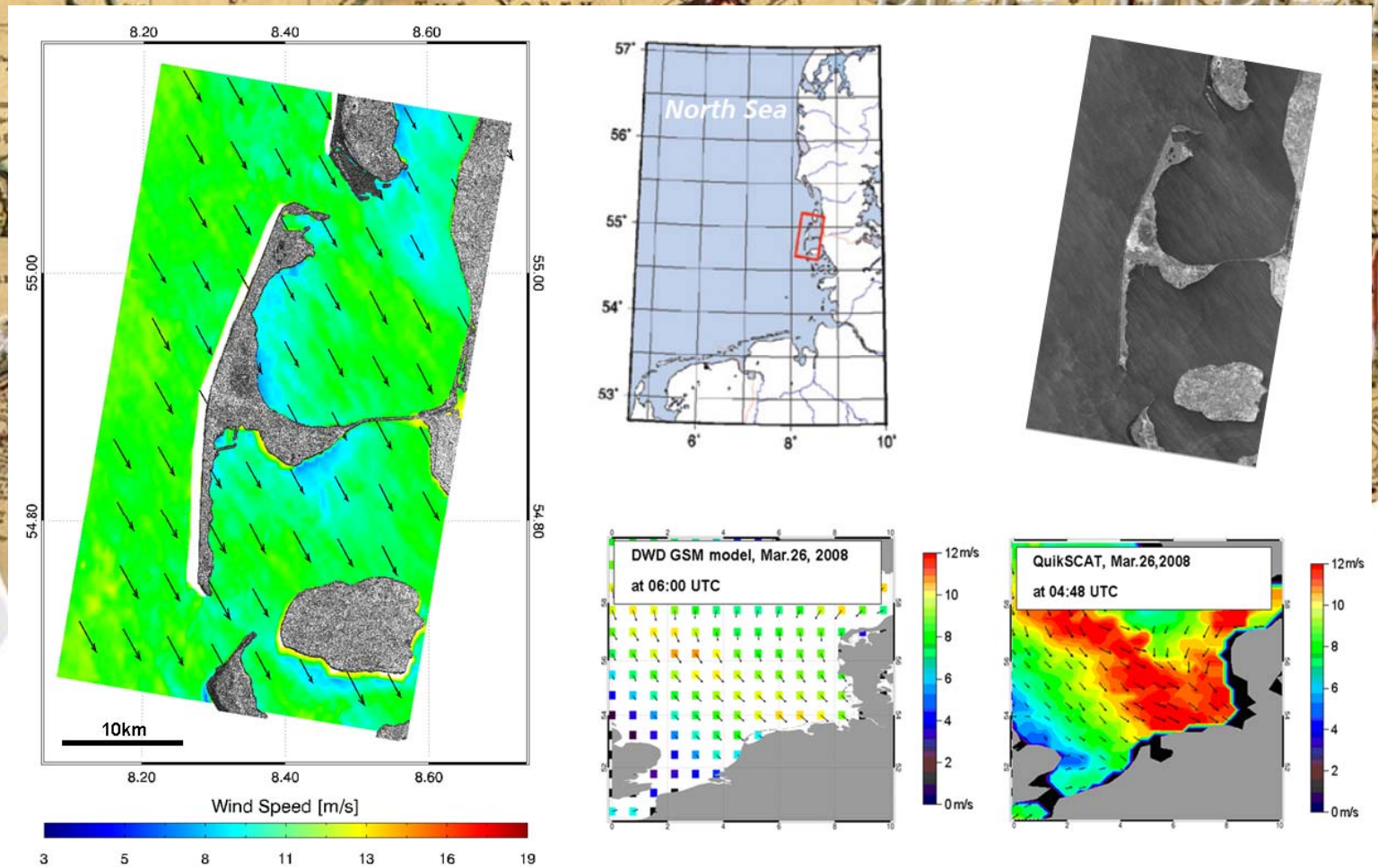
3. Underwater topography – banks, reefs detection and providing bathymetry maps

4. SAR data incorporation into wave modelling

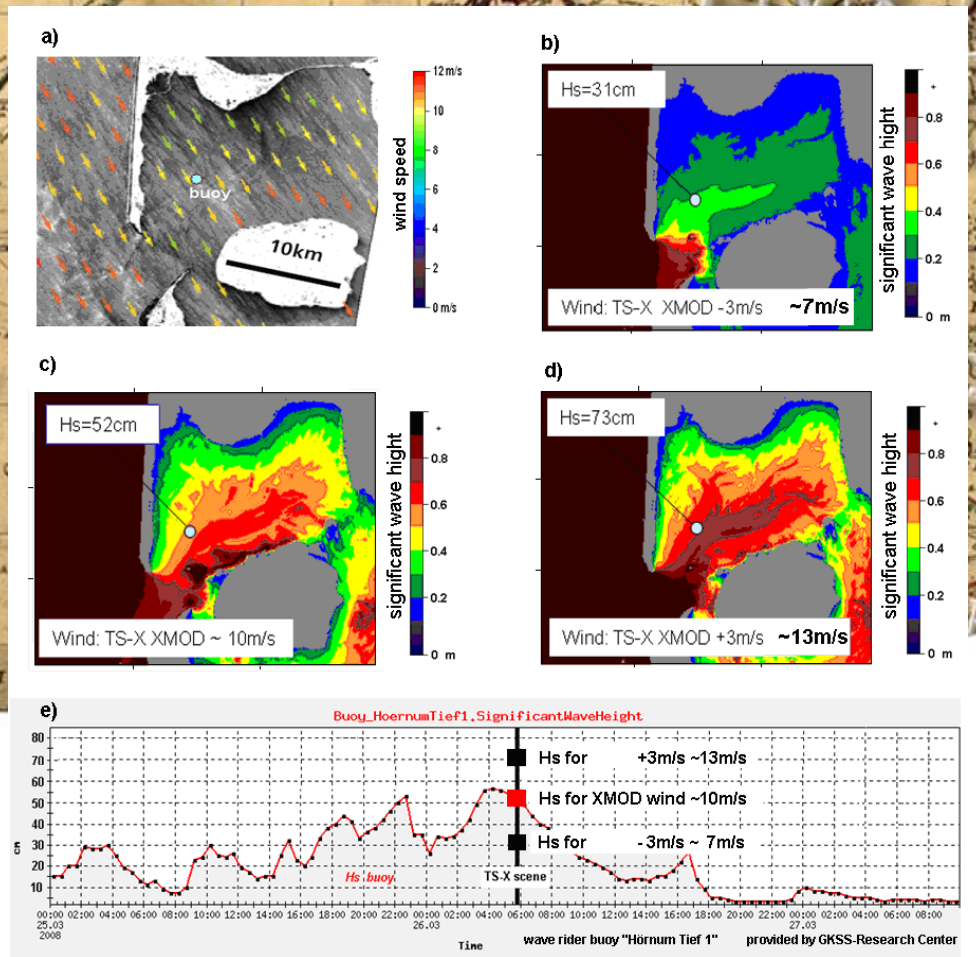
Thank you for your attention



Additional

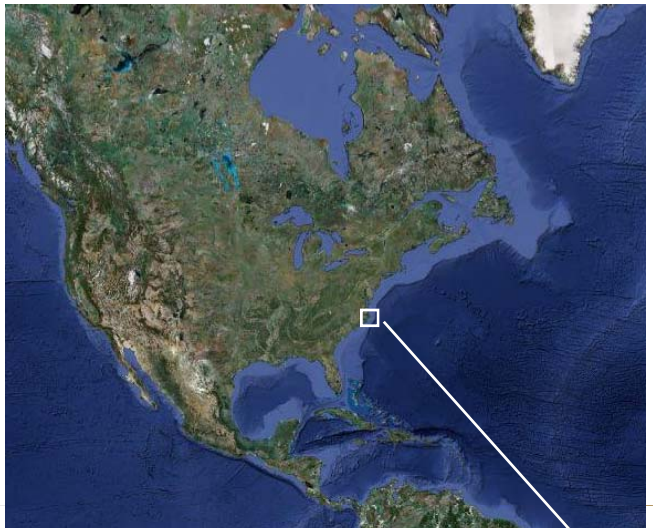


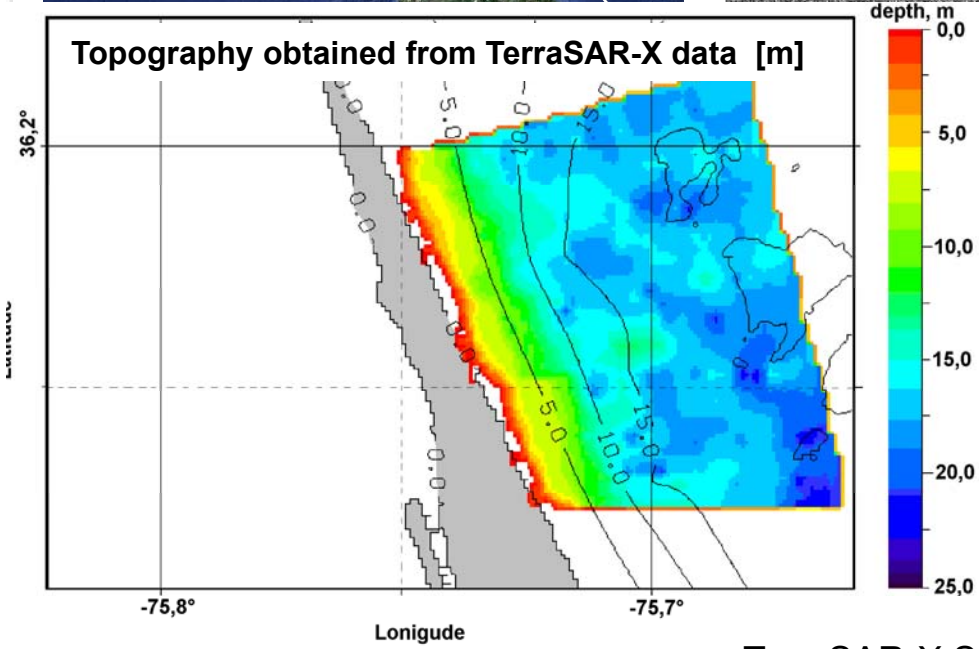
Wind speed retrieved from HH polarizated Stripmap data of TerraSAR-X acquired over Sylt Island, North Sea on Mar. 26, 2008 (left, wind speed errors due to insufficient information are white masked, top right the location and quicklook are show). Wind from QuikSCAT scattorometer data (25km resolution) and DWD forecast model GSM (0.75° resolution) for the North Sea (bottom right). The retrieved wind fields show fine-scale turbulence effects which are not visible by coarser data.

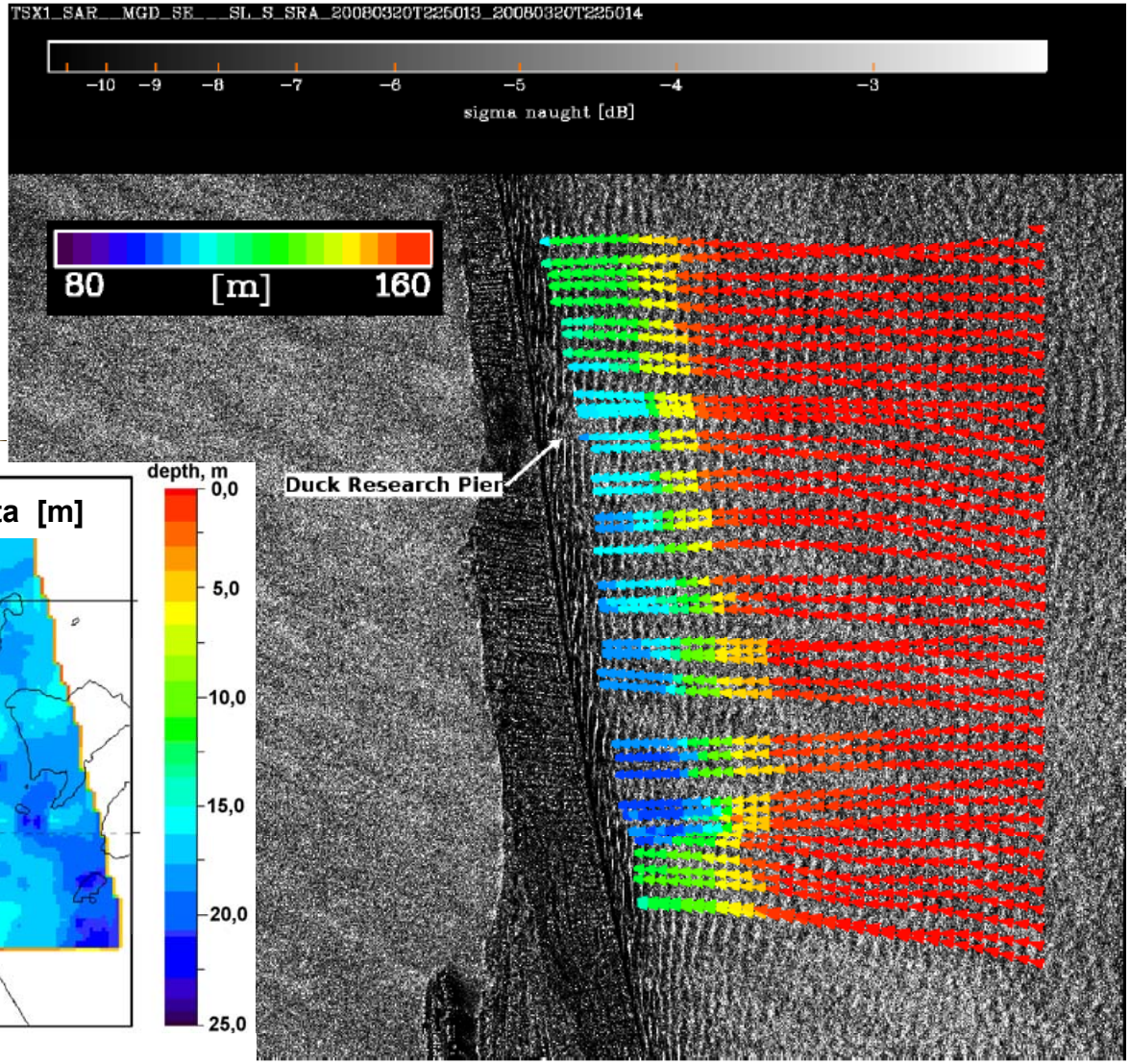


Retrieved wind field (section 2.1 and fig.3) shows local variations (a), wave height simulated using TS-X derived wind ~10m·s^{-1} at buoy position 54°46'2"N 8°22'8"E (c) corresponds with buoy measurement well (e). Varying the TS-X retrieved wind speed (increased and decreased at 3m·s^{-1}) results strong deviation about ~ 25% of modeled wave height (b, d).

Duck Research Pier







TerraSAR-X Spotlight acquired on March 20, 2008 and wave rays