Validation of Coastal Wind and Wave Fields by High Resolution Satellite Data

Susanne Lehner, Miguel Bruck, Andrey Pleskachevsky

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SWH by CWAVE from Global ENVISAT ASAR Data

Correlation : 0.90
Bias(ASAR–Model) : −0.02m
RMSE : 0.52m
Scatter Index : 0.18
Entries : 55814

Correlation : 0.91
Bias(ASAR–Model) : −0.07m
RMSE : 0.57m
Scatter Index : 0.20
Entries : 55824
Spatial variability of sea state (~300m) by TerraSAR-X images
Spatial variability of sea state (~300m) by TerraSAR-X images

XWAVE algorithm
Horizon mask Neustrelitz for TerraSAR-X and ENVISAT

Near Real Time Services for TS-X in < 20 min in European MarSur Projects MARISS with EMSA, JRC, ESA, several European satellite providers
Wind Field: XMOD Algorithm

Geophysical Model Function GMF (Wind → Roughness of Sea Surface)
Connection between Radar NRCS, Wind Speed, Wind Direction and Incidence Angle
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;
- \( \theta \) — incidence angle;
- \( \varphi \) — angle between wind direction and SAR look direction

XMOD1, Y. Ren et al, IJRS, tuning dataset from X-SAR (shuttle mission)
XMOD2, X. Li et al, Spie 2011 (tuning onTS-X data)
Comparison of Wind Speed Algorithms

\[ \text{Cor} = 0.99 \]
\[ \text{RMSE} = 12.46 \]
Case study over Alpha Ventus

Alpha Ventus is the first offshore wind farm of Germany, located at the North Sea
Case study over Alpha Ventus, Wind Farm North Sea

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

VV polarization,
spatial res. 3 m
Sea surface wind field derived from the TS-X data over Alpha Ventus
Comparison of TS-X wind measurements to DWD (global) model

Higher variability in TS-X data
Wind Input K-Model

- wind + 3m/s
- wind - 3m/s

GKSS (HZG) buoy

Lehner, IJRS, 2011

Hs modelled by K-model

buoy measurement

Earth Observation Center
XWAVE: Sea State Parameters from TerraSAR-X Images

signal intensity $I$

signal modulation $m$

image spectra $S$

filtering, $L_{\min}$, $L_{\max}$

XWAVE function

Parameters: $H_s$, $L_p$, $T_p$...

2-D Image spectrum

buoy spectrum

1D integrated image spectrum

2-D Imagespektrum im Wellenzahlraum

1D Spektrum im Frequenzraum

signal intensity $I$
Collecting data set over NOAA buoys, Image data have to be ordered for acquisition about 2 days in advance
XWAVE Algorithm: estimation of Significant wave height from TS-X data

based on analysis of image spectra and uses fitted parameters

\[ H_s = a_1 \cdot 4 \sqrt{E \sin \theta \left(1.0 + a_2 \cos(\alpha)\right)} + a_3 \]

- \( E \): total energy calculated from the image spectrum in domain \( \lambda_{min} \) and \( \lambda_{max} \).
- \( \theta \): the incidence angle
- \( \alpha \): peak wave direction relative to azimuth (satellite flight) direction
- \( a_1 .. a_3 \): coefficients determined by TS-X, TD-X data fitting with wave height given by buoys and DWD (German weather center) wave model data.
Modelling of Sea State over Helgoland with K Model and boundary conditions from TS-X

North Sea, Helgoland

Lehner et al. IJRS, 2011
SWH from K-Model with boundary conditions from TS-X

- The wind field: XMOD
  - boundary spectra include two parts:
  - swell (obtained using XWAVE)
  - wind sea (JONSWAP spectra)

Boundaty spectra from TSX
XWIND , XWAVE
Application: Sea-State spatial Variability and Wind Field estimation using TerraSAR-X Synthetic Aperture Radar Data

- Spatial variability is observed by TS-X imagery

- Wind field estimated

sea state at wave power plant differs from the one at the buoy location

Comparison of spectral shape parameters for image and wave spectra

collocated measurements

Independent measurements
Example: Pico island, Sea State near Pico Wave Farm

Buoy spectrum
SAR spectrum

2d spectrum

1d frequency spectrum

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<th>2011-02-14</th>
<th>$H_s$ (m)</th>
<th>$T_p$ (s)</th>
<th>$T_{02}$ (s)</th>
<th>$T_{-10}$ (s)</th>
<th>$\theta_m$ (°)</th>
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<td>TS-X 19:41</td>
<td>4.3</td>
<td>18.1</td>
<td>11.8</td>
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SM, VV polarization, February 14, 2011

M. Bruck et al, EWTEC, 2011

ASCAT time: 22:00

Wind vectors derived by the ASCAT
Wind speed derived from TS-X data
Determination of Underwater Bathymetry

using Dispersion Relation

A. Pleskachevsky et al., Ocean Dynamics
Underwater topography from TerraSAR SAR and Optical

Grid size 150m
Determination of Underwater Bathymetry

Validation

A. Plekachevky et al
Oceandynamics, 2011
Summary

Obtained information on the highly variable wind field and sea state in coastal areas using high resolution TerraSAR data.

Use information from refraction to obtain underwater bathymetry.

Methods

- Estimation by XMOD and XWAVE algorithm.
- Comparison/Validation of wind field sea state parameters derived from TS-X SAR data with *in-situ* buoy measurements.
- Characterization of sea state using integrated sea state and spectral shape parameters.

Goal

Real Time Satellite Services for North Sea, Baltic Sea, Mediterranean in cooperation with DWD.

NRT Maritime Monitoring Services in European Framework, EMSA, JRC, FRONTEX.
Thank you for your attention!
TerraSAR-X Nominal Imaging Modes

**StripMap Mode**
- Resolution: 3 m \(\times\) 3 m
- Scene Size: 30 km \(\times\) 50 km
  [Range \(\times\) Azimuth]
- Coastal NRT < 20 min

**SpotLight Mode**
- Resolution: 1 m \(\times\) 1.5... 3.5 m
- Scene Size: 10 km \(\times\) 5...10 km
  [Range \(\times\) Azimuth]
- Harbour, breakwaters, platforms

**ScanSAR Mode**
- Resolution: 16 m \(\times\) 16 m
- Scene Size: 100 km \(\times\) 150 km
  [Range \(\times\) Azimuth]
- Ships, sea ice
Pico island: Spotlight VV polarization, 27 March 2010 19:41

Boxsize: 770 m
Wind Field Algorithm XMOD 1.0

NRCS by XMOD dependent on Incidence angle and wind direction (at angle of 35°).

Y. Ren et al IJRS, PORSEC 2010

Earth Observation Center
Implementierung aus SAR abgeleiteter Parameter in numerische Seegangsmodelle

TerraSAR-X Szene

Wind und Randwerte

Topographie und Seegangsmodell

Seegangsmodell Ergebnisse

Randspektrum aus zwei Teilen:
- Dünnung (XWAVE)
- Windsee (JONSWAP)

Windfeld: XMOD Algorithmus
Seegang: XWAVE Algorithmus
Graciosa island: Stripmap VV polarization February 13, 2011

Buoy spectrum
SAR spectrum

2 D spectrum
1 D spectrum

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<th>$T_{02}$ (s)</th>
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<th>$\theta_m$ (°)</th>
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