Ocean Surface Wind and Wave Retrieval Using C-and X-Band SAR

Thomas König, Xiao-Ming Li, Stephan Brusch and Susanne Lehner

Remote Sensing Technology Institute
German Aerospace Center (DLR), Oberpfaffenhofen
Outline

- XMOD parameters tuning
- NRCS simulation with XMOD
- Wind field retrieval with VV polarization TerraSAR-X data
- Wind field retrieval with HH polarization TerraSAR-X data
- Conclusion
TerraSAR-X

TerraSAR-X is a sun synchron satellite with a right side looking X-band synthetic aperture radar (SAR)

<table>
<thead>
<tr>
<th>Wavelength</th>
<th>Scene extension</th>
<th>Incidence angle</th>
<th>Polarization</th>
<th>Resolution</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.031m</td>
<td>10, 30, 100 km</td>
<td>20°-60°</td>
<td>Single/Multi</td>
<td>2m-16m</td>
</tr>
</tbody>
</table>

**Imaging geometry**
Coastal wind field retrieval using SAR data  X-Band

- CMOD -> XMOD

- Tuning data set:

SIR-C/X campaigns in April/October, 1994:

Spaceborne Imaging Radar-C/X-Band Synthetic Aperture Radar (SIR-C/X-SAR) flew on space shuttle Endeavour on mission STS-59 April 9-20, 1994. The instrument was scheduled for a second flight on shuttle mission STS-68 in October 1994.

SIR-C/X-SAR is a joint project of the National Aeronautics and Space Administration (NASA), the German Space Agency (DLR) and the Italian Space Agency (ASI).
Geophysical model function: XMOD

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

- \( U_{10} \) — wind speed
- \( \theta \) — incidence angle
- \( \varphi \) — angle between wind direction and SAR look direction

Scheme of parameters tuning

- ECMWF Wind
- XMOD
- Inc angle
- \( x_0 \sim x_4 \)
- NRCS
- Heading
### X-SAR Characteristics:

<table>
<thead>
<tr>
<th>Wavelength</th>
<th>Scene extension</th>
<th>Incidence angle</th>
<th>Polarization</th>
<th>Resolution</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.031m</td>
<td>15-40 km</td>
<td>25°-60°</td>
<td>VV</td>
<td>30m</td>
</tr>
</tbody>
</table>

Printout of X-SAR Digital Quick Look from the Pacific Ocean

---

**Printout of X-SAR Digital Quick Look from the Pacific Ocean**

*D-FAF Job Number: 349057*  
*X-SAR/MGD*  
© DLR/DFD 1996

---

**Pacific Ocean**  
GMT: 05–CCT–1994/06:32:51  
Data Take ID: D78.60  
Latitude / Longitude of Image Center: S 27.18° / W 74.84°  
D–FAF Product ID: X2SAR941005063251MGD–DP19970330164242  
Illumination  
Flight Direction  
North

---

**Deutsches Zentrum für Luft- und Raumfahrt e.V.  
in der Helmholtz-Gemeinschaft**  
Remote Sensing Technology Institute
Locations of X-SAR Data Used:

Green: 114 data for parameters tuning

Red: 52 data for testing

Around 90% of TSX incidence angle range covered

Histogram of different wind speeds for model tuning
XMOD NRCS depending on incidence angle, wind direction and wind speed
XMOD NRCS depending on incidence angle, wind direction and wind speed
Comparison of XMOD1.2 wind speed to QSCAT and In Situ ones
Coastal wind field retrieval using SAR data  X-Band

TerraSAR-X Stripmap mode scene acquired on July 9, 2007 at 06:29 UTC
XMOD Implementation on TerraSAR-X

Wind speed from VV Stripmap TerraSAR-X image

July 23, 2007 at 05:33 UTC over the Baltic sea

HIRLAM Model Forecast, July 23, 2007 at 6:00 UTC
Wind speed retrieved by VV polarization stripmap TerraSAR-X data

Jul. 2, 2007 at 17:35 UTC over English Channel

QSCAT, Jul. 2, 2007 at 19:30 UTC
Wind speed retrieved by VV polarization stripmap TerraSAR-X data

Aug. 14, 2008 at 17:45 UTC, Cook strait

QSCAT, Aug. 14, 2008 at 18:30 UTC
Wind speed retrieved by VV polarization stripmap TerraSAR-X data

Aug. 3, 2008 at 17:45 UTC over Cook Strait

Satellite cloud imagery from MODIS over Cook Strait acquired on Aug. 3, 2008

QSCAT, Aug. 3, 2008 at 18:12
Wind speed retrieved by VV polarization stripmap TerraSAR-X data

on May 23, 2008 at 23:21 UTC over Miami

DWD Model, May 24, 2008 at 00:00 UTC

QSCAT, May 24, 2008 at 23:42 UTC
9 March 2010, TSX-1 ScanSAR

Wind Speed [m/s]
Coastal wind field retrieval using SAR data  X-Band HH Polarisation

Model: Polarization ratio from Thompson

\[ P(\theta) = \frac{\sigma_{0}^{VV}}{\sigma_{0}^{HH}} = \frac{(1 + \alpha \tan^2 \theta)^2}{(1 + 2\tan^2 \theta)^2} \]

\[ \alpha = 1.73 \]

Polarisation ratio from Mouche:

\[ P(\theta) = \frac{\sigma_{0}^{VV}}{\sigma_{0}^{HH}} = A \exp(B\theta) + C \]

\[ A = 0.0248 \]
\[ B = 0.1057 \]
\[ C = 1.43878 \]
Model 1: Polarization ratio model from Thompson

\[ P(\theta) = \frac{(1 + \alpha \tan^2 \theta)^2}{(1 + 2 \tan^2 \theta)^2} \]

Model 1-1 turned by Dual-Polarization mode

Model 1-2 turned by HH single Polarization mode
Model 2: Polarization ratio from Mouche

\[ P(\theta) = A \exp(B \theta) + C \]
Wind fields retrieved with polarization ratio models

1) VV  
2) HH, Model 1-1  
3) HH, Model 2-1  
4) HH, Model 1-2  
5) HH, Model 2-2

Wind speed from VV and HH polarization TerraSAR-X data acquired on Aug 3, 2008 at 17:45 UTC over Cook Strait
Wind fields retrieved with polarization ratio models

1) VV
2) HH, Model 1-1
3) HH, Model 2-1
4) HH, Model 1-2
5) HH, Model 2-2

Wind speed from VV and HH polarization TerraSAR-X data acquired on Aug14, 2008 at 17:45 UTC over Cook Strait
Wind speed retrieved by HH polarization spotlight TerraSAR-X data

Mar. 25, 2008 at 05:59 UTC over German North Sea

DWD Model, Mar. 25, 2008 at 06:00 UTC

QSCAT, Mar. 25, 2008 at 05:12 UTC
Wind speed retrieved by HH polarization stripmap TerraSAR-X data

Mar. 26, 2008 at 05:41 UTC over Sylt Island

DWD Model, Mar. 26, 2008 at 06:00 UTC

QSCAT, Mar. 26, 2008 at 04:48 UTC
Polarization Ratio (VV/HH) Dependency on Incidence Angle and Wind Speed

- TSX Product Types:
  - SL - Dual Pol.
  - SM - Dual Pol.

Graphs showing the relationship between TSX incidence angle and sigma naught ratio, and wind speed and polarization ratio (VV/HH).
Coastal wind field retrieval using SAR data  X-Band HH Polarisation

30 km x 100 km
TSX HH Stripmap
2. Juli, 2007,
7:35 UTC

Offshore Windfarm
Conclusion

- An X-Band GMF (XMOD) was established for VV polarized data which for incidence angle of 20°~60° and wind speed in the range 2m/s~20 m/s can describe the relationship between X-band radar cross section, wind speed, wind direction and incidence angle accurately. The model is developed for X-SAR data and is valid for TerraSAR-X also.

- Retrieved wind fields from TerraSAR-X show meaningful results up to the coast reflecting local variations.

- For TerraSAR-X, XMOD was extended to HH polarized data by fitting the polarization ratio $\sigma_{VV} / \sigma_{HH}$

- The wind comparison of HH TerraSAR-X data with QSCAT shows encouraging results. For high incidence angles, the polarization ratio is wind speed dependant.

- Further cases have to be investigated in order to establish a trustable error estimate.
Wind field retrieval using SAR data

Three consecutive ASAR Wide Swath Images (right) acquired in the Gulf of Mexico on Aug. 28, 2005 at 15:50 UTC
Left: center scene (400x400km), „wind field“-resolution appr. 150m, pixelsize 75m
Wind field retrieval using SAR data

Red: radius of maximum wind speed (according to HRD)
Blue: radius of hurricane force winds (according to HRD)

**SAR shows an underestimation of wind speed**
- mainly due to strong rain contamination and effects
due to severe sea state

Reppucci et al., TGARS. April 2010

Reanalyzed wind speed of hurricane Katrina, processed by NOAA HRD
Wind field retrieval using SAR data

strong attenuation due to rain

rainbands

damping: arises from attenuation of the microwaves by raindrops in the atmosphere, from a modification of the sea surface roughness induced by the impact of raindrops and by wind field variations associated with the rain band.

The area of enhanced backscattering “C” is due to a thunderstorm cell.
## Wind field retrieval using SAR data

<table>
<thead>
<tr>
<th></th>
<th>Acquisition Time</th>
<th>Image center Coordinates</th>
<th>Measured Max Wind Speed</th>
<th>SAR Retrieved Max Wind Speed</th>
<th>Measured Central Pressure</th>
<th>SAR Retrieved Central Pressure</th>
</tr>
</thead>
<tbody>
<tr>
<td>Hurricane Katrina</td>
<td>28-08-05 15:50</td>
<td>26.1° N, 87.7°W</td>
<td>70 m/s</td>
<td>68 m/s</td>
<td>905 mb</td>
<td>901 mb</td>
</tr>
<tr>
<td>Hurricane Rita</td>
<td>22-09-05 03:45</td>
<td>23.5° N, 85.5°W</td>
<td>75 m/s</td>
<td>70 m/s</td>
<td>897 mb</td>
<td>890 mb</td>
</tr>
<tr>
<td>Typhoon Kiko</td>
<td>09-09-05 01:11</td>
<td>18.3° N, 131° E</td>
<td>45 m/s</td>
<td>48 m/s</td>
<td>955 mb</td>
<td>950 mb</td>
</tr>
<tr>
<td>Typhoon Kiko</td>
<td>11-09-05 01:46</td>
<td>29.4°N, 124.2°E</td>
<td>55 m/s</td>
<td>60 m/s</td>
<td>945 mb</td>
<td>930 mb</td>
</tr>
<tr>
<td>Typhoon Songda</td>
<td>06-09-04 13:23</td>
<td>28.8° N, 128.4°E</td>
<td>44 m/s</td>
<td>40 m/s</td>
<td>945 mb</td>
<td>946 mb</td>
</tr>
</tbody>
</table>

![Graph 1](image1.png)

![Graph 2](image2.png)
Thanks!