Wind Retrieval from Synthetic Aperture Radar Operating at Cross Polarization

ONR DRI 32 ITOP
Impacts of Typhoons on the Ocean in the Pacific

J. Horstmann\textsuperscript{1,2}, S. Falchetti\textsuperscript{2} C. Wackerman\textsuperscript{3}, R. Foster\textsuperscript{4}, M. Caruso\textsuperscript{5} and H. Graber\textsuperscript{5}

\textsuperscript{1}Helmholtz-Zentrum Geesthacht, Germany
\textsuperscript{2}Center for Maritime Research and Experimentation, Italy
\textsuperscript{3}General Dynamics, USA
\textsuperscript{4}APL, University of Washington, USA
\textsuperscript{5}Center for Southeastern Tropical Advanced Remote Sensing, USA
Why SAR for Wind Field Retrieval

Synthetic Aperture Radar

Scatterometer
SAR Wind Direction Retrieval via the Local Gradient Method (WiSAR)

Local Gradient Method

\[(B^2 B^4_{xy})^3 \xrightarrow{\text{Sobel}} (B^2 B^4_{xy}) \Phi\]

Binomial filter
2 dim. \(B^2\) Filter
2 dim. \(B^4\) Filter

Optimized Sobel-Filter

\[
\begin{pmatrix}
3 & 0 & -3 \\
10 & 0 & -10 \\
3 & 0 & -3 \\
\end{pmatrix}
\]
SAR Wind Speed Retrieval via a Geophysical Model Function (GMF)

Geophysical Model Function

\[ \sigma_0^{pol} = a(\theta)u^{\gamma(\theta)}[1 + b(\theta)\cos\phi + c(\theta)\cos(2\phi)] \]

GMF for C-, X- and L-band

Typhoon Megi
17 Oct. 2010 at 21:54 UTC.
SAR-Retrieved Winds (co-pol) in Comparison to QSCAT and SFMR

- **Correlation (cor)**: 0.96
- **RMS error (rms)**: 17.6°
- **Bias**: 6.4°

- **Correlation (cor)**: 0.70
- **RMS error (rms)**: 5.2 m/s
- **Bias**: 1.9 m/s
- **STDV**: 4.8 m/s

Typhoon Malaksa on 20 Sep. 2010 at 20:29 UTC
Estimation of Wind Field Uncertainties and GMF Limitations

SAR wind field

Limitation of GMF definition

Wind speed uncertainty
Noise Correction of Radarsat-2 Cross Pol NRCS

Radarsat-2 HV image of Typhoon Megi 17. Sep 2010

Corrected NRCS

Noise floor
Dependence of NRCS on Wind Speed (Including Noise Floor)
Dependence of NRCS on Wind Speed (Noise Floor removed)
Additional Dependencies of Cross-pol NRCS
Modelling of the NRCS Excluding Cross Talk

Cross-Pol RCS: 10 m/s Wind

Cross-Pol RCS: 15 m/s Wind

Cross-Pol RCS: 20 m/s Wind

Cross-Pol RCS: 10 m/s Wind

Cross-Pol RCS: 15 m/s Wind

Cross-Pol RCS: 20 m/s Wind
Modelling of the NRCS Including Cross Talk (-32 dB Isolation)
Radarsat-2 Crosspol (HV) Retrieved Wind Speeds

HH retrieved wind speed

HV retrieved wind speed new function

Radarsat-2 HV image of Typhoon Megi 17. Sep 2010
Comparison of Co- and Cross-pol Retrieved Wind Speeds to SFMR

Typhoon Malaksa 20 Sep. 2010 at 20:29 UTC
Validation of Co-pol and Cross-pol GMF with SFMR and Dropsondes

Horstmann et al., TOS 2013
SAR wind directions from orientation of linear features (rms of 18°, lack of inflow)

Filters have been developed to flag:

- non wind induced areas
- areas with uncertain wind speeds

C-band cross pol GMF developed (significant improvement in high wind speeds >25 m/s)

Further investigation of cross pol with respect to wind direction and incidence angle

Merging of co-pol and cross pol retrieved winds

What about rain under cross pol?
Comparison of Co- and Cross-pol Retrieved Wind Speeds to SFMR

Hurricane Earl 2 Sep. 2010 at 22:59 UTC
SAR Typhoon Processing System

- SAR processing
- Descalloping
- Recalibration
- Debanding

NRCS
- Incidence angle
- Satellite heading
- Longitude & Latitude
- Land mask
- Filter mask
- NRCS better

NURC eye
- GD eye
- Model eye

WiSAR
- GD wind

APL pressure
- GD waves
- CSTARS wave

Eye Location
- Wind speed
- Wind direction
- Pressure
- Wave direction
- Wave height
Automated Removal of Sensor Artifacts and Careful Calibration

Uncorrected

Debeamed

Scalloped

Uncorrected

Noise floor corrected

Horstmann et al., TGARS submitted

Romeiser et al., TGARS 2012
Merging Wind Directions from GD with WiSAR
General Approach for Ocean SAR Wind Field Retrieval (WiSAR)

Geophysical Model Function

\[ \sigma_0^{\text{pol}} = a(\theta)u^{\gamma(\theta)}[1 + b(\theta)\cos \phi + c(\theta)\cos(2\phi)] \]

GMF for C-, X- and L-band

Radarsat-2 image of Typhoon Megi 15 Oct. 2010 at 21:00 UTC
Comparison of Co- and Cross-pol Retrieved Wind Speeds to SFMR

<table>
<thead>
<tr>
<th>GMF</th>
<th>Bias [m]</th>
<th>Standard Deviation [m]</th>
<th>Correlation</th>
</tr>
</thead>
<tbody>
<tr>
<td>Co pol GMF</td>
<td>0.4</td>
<td>6.42</td>
<td>0.75</td>
</tr>
<tr>
<td>HV GMF</td>
<td>0.11</td>
<td>3.75</td>
<td>0.83</td>
</tr>
<tr>
<td>HV GMF wind direction dependent</td>
<td>-0.69</td>
<td>3.79</td>
<td>0.85</td>
</tr>
<tr>
<td>VH GMF</td>
<td>-1.48</td>
<td>3.22</td>
<td>0.8</td>
</tr>
</tbody>
</table>
Removal of SAR artifacts e.g. Scalloping

Romeiser et al., TGARS 2012
Development of X-band GMF for Wind Speed Retrieval

Validation for Moderate Winds

36 Cosmo-SkyMed imagery
25 km grid (782 co-locations)

TerraSAR-X image of Typhoon Megi

NOGAPS Wind Speed \[ m/s \]
SAR Wind Speed \[ m/s \]

\[ \text{bias} \ 0.1 \text{ m/s} \]
\[ \text{stddev} \ 2.4 \text{ m/s} \]

Thompson et al., JGR 2012
Development of Cross-pol GMF Fit to SAR Co-pol Winds

Wind Speed [m/s]

0 30

HH retrieved wind speed

HV retrieved wind speed

ITOP function

Radarsat-2 HV image of Typhoon Megi 17. Sep 2010
Ongoing and Outlook

Ingestion of SAR wind fields into HWIND

- Validation of the X-band GMF at high wind
- Investigation of X-band cross pol
- Merging of the co- and cross pol information for a even better wind product
- Including wave information in the wind retrieval

Typhoon Megi
17 Oct. 2010
Validation of SAR-Retrieved Wind Directions with QuikScat Winds

\[ \text{cor} = 0.96 \]
\[ \text{rms} = 17.6^\circ \]
\[ \text{bias} = 6.4^\circ \]

Horstmann et al., TOS 2013
Noise Correction of Radarsat-2 Cross Pol NRCS
Comparison of Co- and Cross-pol Retrieved Wind Speeds to SFMR
SAR-Retrieved Wind Field and Comparison to QuikScat data

Wind Speed [m/s]

$$cor = 0.96$$

$$rms = 17.6^\circ$$

$$bias = 6.4^\circ$$
Comparison of Radar Retrieved Wind speeds to \textit{in situ} Measured

\[ \sigma_0 \xrightarrow{\text{GMF}} u_{10} \] assuming 10 min mean neutral wind at 10 m

\[ u_{10} \xrightarrow{} u_0 \] assuming neutral stability

\[ u_0 \xrightarrow{\text{TC 3.x}} u_{\text{in situ}} \] taking available information on stability

Estimation of Friction Velocity from Radar Measurements via GMF

\[ \sigma_0 \xrightarrow{\text{GMF}} u_{10} \] assuming 10 min mean neutral wind at 10 m

\[ u_{10} \xrightarrow{\text{TC 3.x}} u^* \] assuming neutral stability
Noise Correction of Radarsat-2 Cross Pol NRCS

\[ \theta \text{ [°]} \]

\[ \sigma_{HV} \text{ [dB]} \]

\[ \sigma_{\text{orig}} \]
\[ \sigma_{\text{ne}} \]
\[ \text{debeam } \sigma_{\text{orig}} \]
\[ \sigma_{\text{orig}} - \sigma_{\text{ne}} \]
\[ \text{debeam } \sigma_{\text{orig}} - \sigma_{\text{ne}} \]

pixel [km]

519 448 373 291 202 101

-20 25 30 35 40 45