SAR Wind Field Retrieval with Respect to Tropical Cyclones funded by ONR Code 32

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Why SAR for Tropical Cyclones

QuikSCAT
Hurricane eye of Katrina
Hurricane eye of Katrina
Hurricane eye of Katrina
Hurricane eye of Katrina
SAR Typhoon Processing System within the ITOP Project of ONR
General Approach for Ocean SAR Wind Field Retrieval (WiSAR)

Local Gradient Method

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

Binomial filter
2 dim. B2 Filter
2 dim. B4 Filter

Optimized Sobel Filter

3 0 -3
10 0 -10
3 0 -3

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

\[\Phi \quad \theta \quad u_{10}\]

\[\sigma_{0}\]
Wind Direction Ambiguity Removal
Wind Direction Ambiguity Removal

1. Select grids with only one wind direction (400m)
2. Select nearest neighbor for the other wind directions
Wind Direction Ambiguity Removal

3. Polar wind directions around hypothetic eye with 180 deg ambiguity
4. Limit radius around the eye

polar winddir in hypothetic eye plus simulated 180 ambiguity, radius < 10km
Wind Direction Ambiguity Removal

5. Retrieve 60% quantile of simulated polar wind at 400 m grid wind
6. Use eye location and polar wind to remove 180 deg ambiguity and wind directions with difference above 60 deg.
Wind Direction Ambiguity Removal

7. Select nearest neighbor of all scales to previously selected wind directions
8. Smooth wind directions
Comparison of SAR to QuikScat winds

QuikSCAT wind direction [°]

- WiSAR direction
- GD direction
- QuikSCAT direction

QuikSCAT wind speed [m/s]
- cor 0.69
- rms 4.55 m/s
- bias -1.34 m/s

QuikSCAT wind direction [°]
- cor 0.97
- rms 16.6°
- bias 5.7°
SAR Wind Speed Error Masks

Non wind phenomenon mask
SAR Wind Speed Error Masks

Out of Definition Mask

Out of definition mask 2-4-6 correspond to \((\text{rcs}+0.5)-(\text{rcs})-(\text{rcs}-0.5)\)

\[ \theta = 20^\circ, \text{ downwind} \]

\[ \text{wind speed [m/s]} \]

\[ \text{NRCS [dB]} \]
SAR Wind Speed Error Masks

Uncertainty Mask
Comparison of SAR and SFMR Wind Speeds

SAR wind speeds with superimposed adjusted SFMR flight track
Assimilation SAR Winds into HWIND

Radarsat-2 SAR image

NURC Wind Field

Typhoon Malakas
Wind Speed Error and Certainty Masks

SAR modb polic

out of definition mask 2/4/6 if cos+0.5<cos otherwise is out of range

ncos uncertainty mask 0.5db

points given to Helind
Assimilation into HWIND

HWIND with in situ and SFMR

HWIND with SAR wind field solely
Comparison of SAR to Quikscat winds

SAR wind directions
NURC-GD merged

cor = 0.96
rms = 17.6°
bias = 6.4°

HWIND wind directions
assimilation of SAR wind field (solely)

cor = 0.97
rms = 16.6°
bias = 5.7°
Comparison of SAR to Quikscat winds

SAR wind speeds
NURC-GD merged

HWIND wind speeds
assimilation of SAR wind field (solely)

\[ \text{corr} = 0.69, \quad \text{rms} = 4.55\text{m/s}, \quad \text{bias} = -1.34\text{m/s} \]

\[ \text{corr} = 0.85, \quad \text{rms} = 3.20\text{m/s}, \quad \text{bias} = -0.64\text{m/s} \]
TerraSAR-X Winds Compared to ASCAT Results (Preliminary)
Inclusion of Doppler Shift Information for SAR Wind Retrieval
SAR wind directions are retrieved from wind streaks (rms of 20°) lack of inflow.

SAR wind speeds are retrieved from C-band models (rms of ~2 m/s).

For extreme winds the wind speed the rms is significantly larger (~5 m/s).

SAR wind retrieval scheme is fully automated.

Validation of X-band model for high winds.

Inclusion of Doppler shifts for wind direction retrieval.
Application of APLs Boundary Layer Model

PBL model

U10

k \cdot \nabla P

swath of pressure gradient vectors

fit a surface pressure field

swath of pressure gradient vectors
Assimilation into HWIND
Comparison of SAR to Quikscat winds

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NURC-GD merged

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HWIND wind directions
assimilation of SAR wind field (solely)

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Application of APLs Boundary Layer Model

SAR wind field

SAR out of definition mask

SAR input to SLP model

Hurricane Ike
Application of APLs Boundary Layer Model

SLP pressure field  SLP retrieved wind field  SAR retrieved wind field

Hurricane Ike
Application of APLs Boundary Layer Model
Typhoon Malakas, Radarsat-2 Retrieved Wind Fields
Typhoon Malakas, Wind Speed Error and Certainty Masks
Typhoon Malakas, Assimilation into HWIND

HWIND with in situ and SFMR 1 min

HWIND with in situ and SFMR 10 min.

HWIND with SAR wind field 10 min.
Typhoon Malakas, Comparison to Numerical Model Results

- HWIND with in situ and SFMR 10 min.
- HWIND with SAR wind field 10 min.
- ECMWF winds
Typhoon Megi, Comparison to ASCAT Results
Typhoon Megi, 200m Resolution Wind Field
Typhoon Malakas, Assimilation into APLs Boundary Layer Model

SAR input wind including masks

Boundary Layer Model retrieved wind field

Boundary Layer Model retrieved pressure field

SAR input U10N
Max: 34.1 m/s at (141.974, 19.816)

SLP-filtered U10N
Max: 29.3 m/s at (142.000, 19.843)

SAR-derived SLP
Obs Normalization; Min: 983.73 mb at (141.159, 19.697)
Publications:

1. Synthetic Aperture Radar Retrieved Winds Assimilated into HWIND (SLP-winds)
2. Estimation of Wind Speed Uncertainties in Synthetic Aperture Radar Wind retrieval
3. Automated SAR Eyefinding in SAR images
4. Synthetic Aperture Radar Wind Retrieval of Tropical Cyclones
5. Descalloping of Synthetic Aperture Radar Images
6. SAR Retrieved Pressure Fields
7. SLP iterated SAR winds
8. The Dave’s Paper’s
9. Empirical Wave Retrieval
10. Physical Wave Retrieval
11. Comparison or merged SAR wave retrieval
12. Duncan Ross Comparison (Waves)
13. SARTyps group paper?
NURC Summary

Run eye finder on entire CSA Hurricane data set promising results

Uncertainty estimator comparison to SFMR validation with *in situ* ongoing

Comparison of SAR retrieved winds in Hurricanes to QuikSCAT show to little inflow

Assimilation of SAR retrieved winds into HWIND shows improvement of wind field compared to QuikSCAT (e.g. no hourglass)

GMF for X-band shows promising results (to be investigated also for moderate winds)
Simulated Effect of Wind Speed Ambiguities

Hwind + SAR

Upper solution

Lower solution

Cluster-Mask

Rebuilt Wind
Comparison to Numerical Model Results

HWIND with in situ and SFMR 10 min.
HWIND with SAR wind field 10 min.
ECMWF winds
Comparison of SAR to QuikSCAT winds

QuikSCAT wind speed [m/s]

cor 0.68
rms 5.16 m/s
bias 1.76 m/s

Radar look direction with respect to wind direction [deg]

- pts radi<100km
- pts radi<200km
- pts radi<350km