A Novel Optimization Approach for Ocean Vector Wind Retrievals Using SAR Measurements

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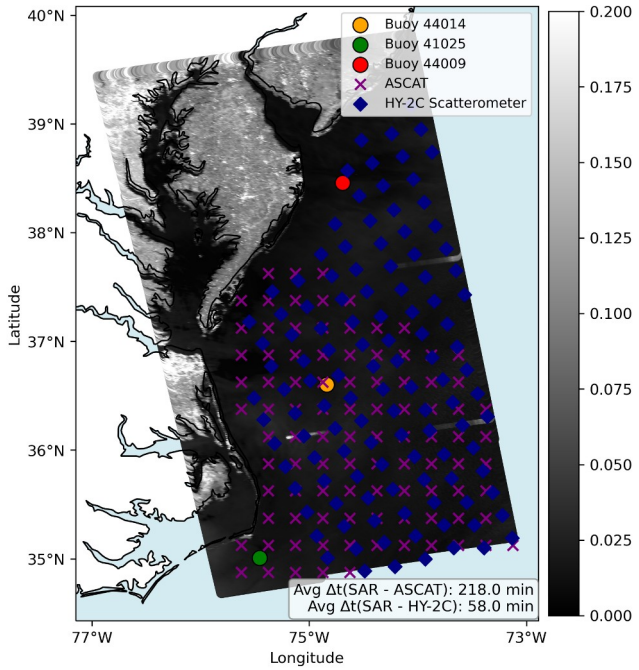
Presenter： Giuseppe Grieco

Limitations of A Priori Wind Inputs in SAR Retrieval



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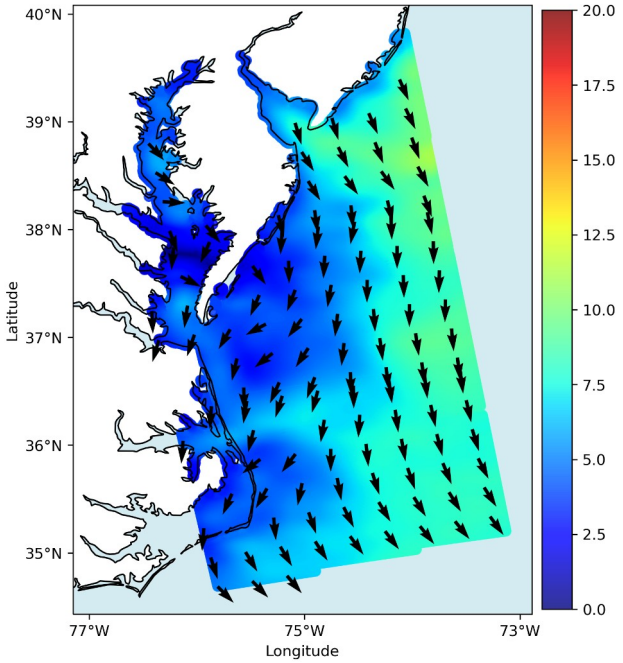
Sentinel-1 SAR imagery and colocated ASCAT, HY-2C scatterometer, and buoy observations



Priori wind field
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From ERA5

Motivation: Although SAR offers high-resolution wind field observations, its inversion results heavily depend on external wind field inputs, limiting retrieval autonomy and reliability—especially under complex sea states.

ERA5 wind fields (10 m, surface level) are widely used as prior information for SAR wind retrieval.

While generally accurate, they exhibit two major limitations:

- Coarse resolution (~25 km), which limits their ability to capture fine-scale wind structures observed by SAR.
- Low reliability near coastal regions due to land-sea contrast and model smoothing effects.

Scatterometer data such as ASCAT and HY-2B/2C face similar issues:

- Stable but coarse resolution
- Reduced data quality near coasts

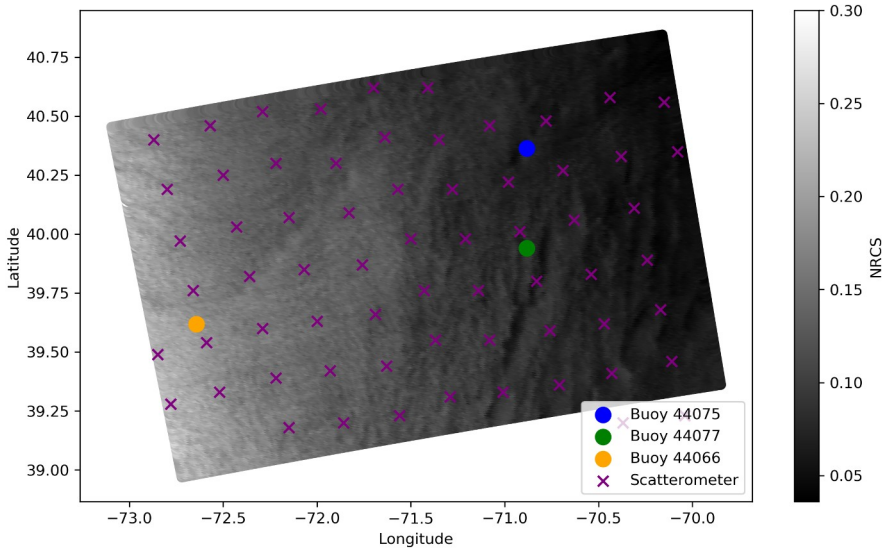
Methodological Framework

Cost Function:

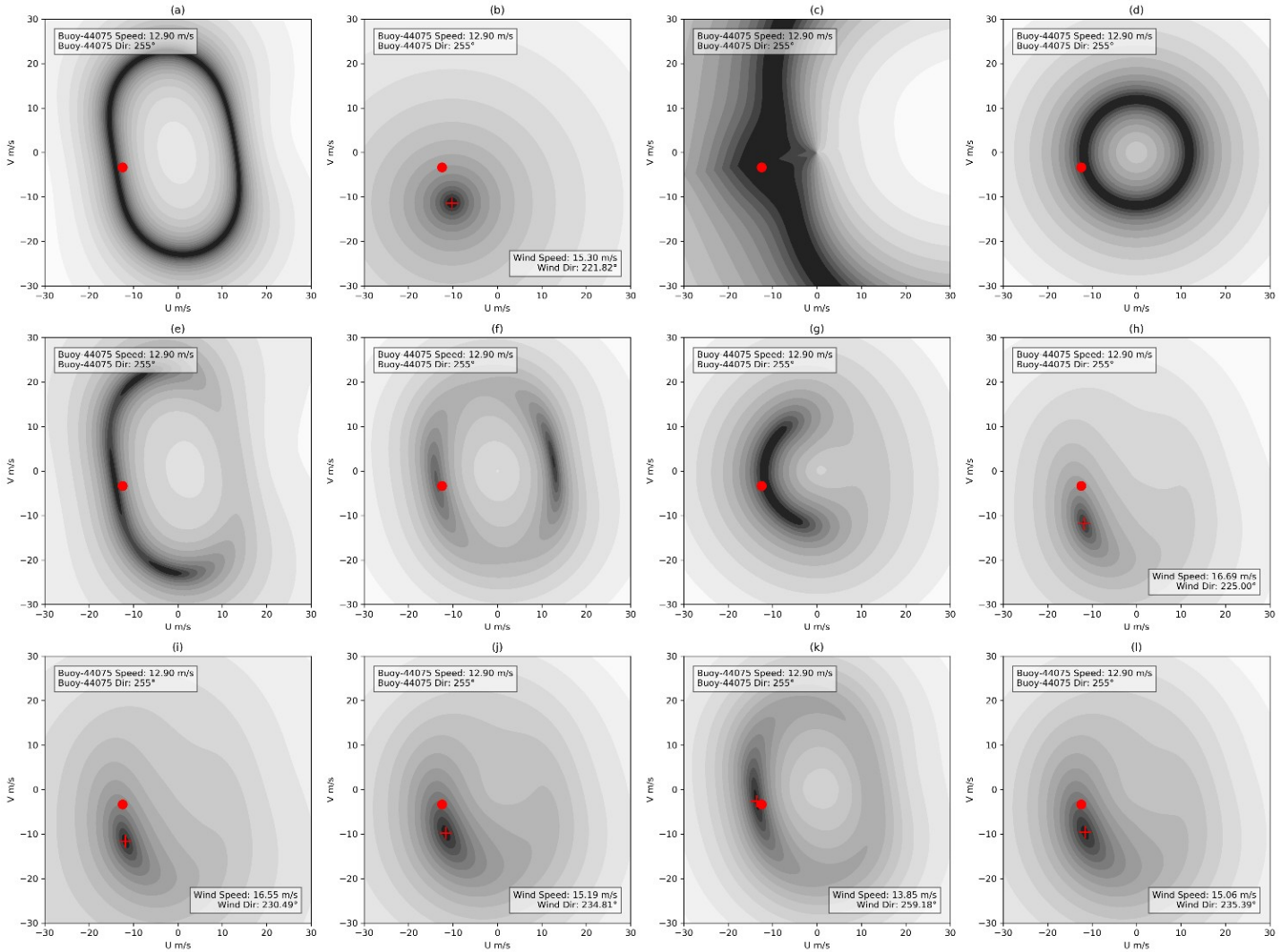
$$p\left(\mathbf{v}_t \mid \sigma_m^o, f_{\mathrm{CDOP}}^{\mathrm{DA}}, \lambda_c^{20^\circ}\right) \propto p\left(\sigma_m^o \mid \sigma_t^o\right) \cdot p\left(f_{\mathrm{CDOP}}^{\mathrm{DA}} \mid f^{\mathrm{DA}}\right) \cdot p\left(\lambda_c^{20^\circ} \mid \lambda_c\right)$$

$$J(\mathbf{u}) = \underbrace{\left(\frac{\sigma^0 - \mathrm{CMOD}(\mathbf{u})}{\Delta\sigma^0}\right)^2}_{\text{NRCS term}} + \underbrace{\left(\frac{f^{DA} - \mathrm{CDOP}(\mathbf{u})}{\Delta f^{DA}}\right)^2}_{\text{Doppler term}} + \underbrace{\left(\frac{\lambda_c - \lambda_C^{20^\circ}}{\Delta\lambda_c}\right)^2}_{\text{Azimuth cutoff term}}$$

Study Area:



Methodological Framework



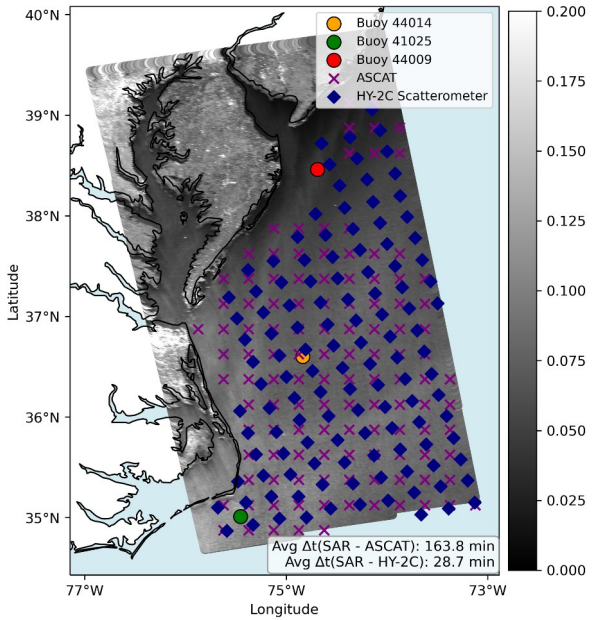
Contributions of Individual Cost Function Terms and Visualization of Inversion Results

Shading: Darker areas represent lower cost values, indicating more likely wind vectors.
Markers:
🔴 Red circle: Ground-truth wind vector from buoy
❌ Red cross: Retrieved wind vector minimizing the cost function

Subplots :
(a) NRCS
(b) Prior wind model
(c) Doppler shift
(d) Azimuth cutoffSubplots
(e) NRCS + Doppler
(f) NRCS + Azimuth cutoff
(g) Doppler + Azimuth cutoff
(h) Method from [1]
(i) Method from [2]
(j) Method from [3]
(k) Ours (no prior wind)
(l) Ours (with prior wind)

[1] Portabella, M., Stoffelen, A., and Johannessen, J.A., “Toward an optimal inversion method for SAR wind retrieval,” J. Geophys. Res. Oceans, 107 (C8), https://doi.org/10.1029/2001JC000925, 2002.
[2] A. A. Mouche, F. Collard, B. Chapron, K. F. Dagestad, G. Guitton, J. A. Johannessen, V. Kerbaol, and M. W. Hansen, “On the use of doppler shift for sea surface wind retrieval from sar,” IEEE Trans. Geosci. Remote Sens., vol. 50, no. 7, pp. 2901–2909, 2012.
[3] Y. Zhu, G. Grieco, J. Lin, M. Portabella, and X. Wang, “On the use of azimuth cutoff for sea surface wind speed retrieval from sar,” IEEE J. Sel. Topics Appl. Earth Observ. Remote Sens., 2024.

Case2 : Coastal area



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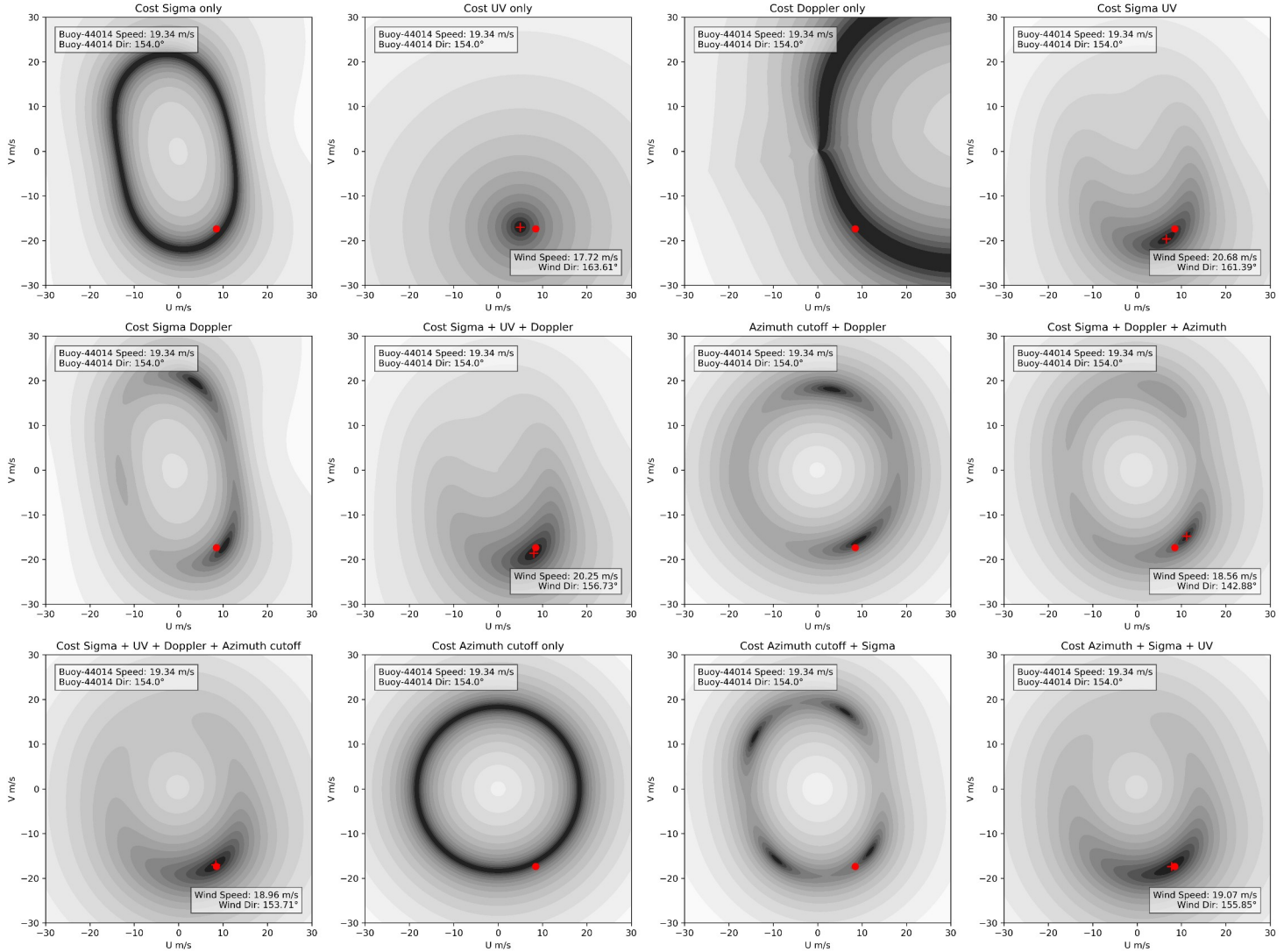
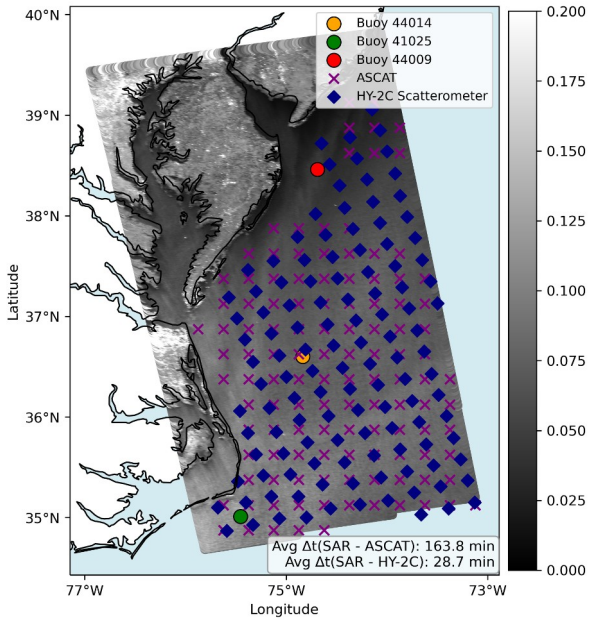
Three Sentinel-1 Images

Different combinations of cost function terms. The red dot indicates the ground truth from buoy 44014, and the red cross marks the optimal wind vector.



Case2 : Coastal area



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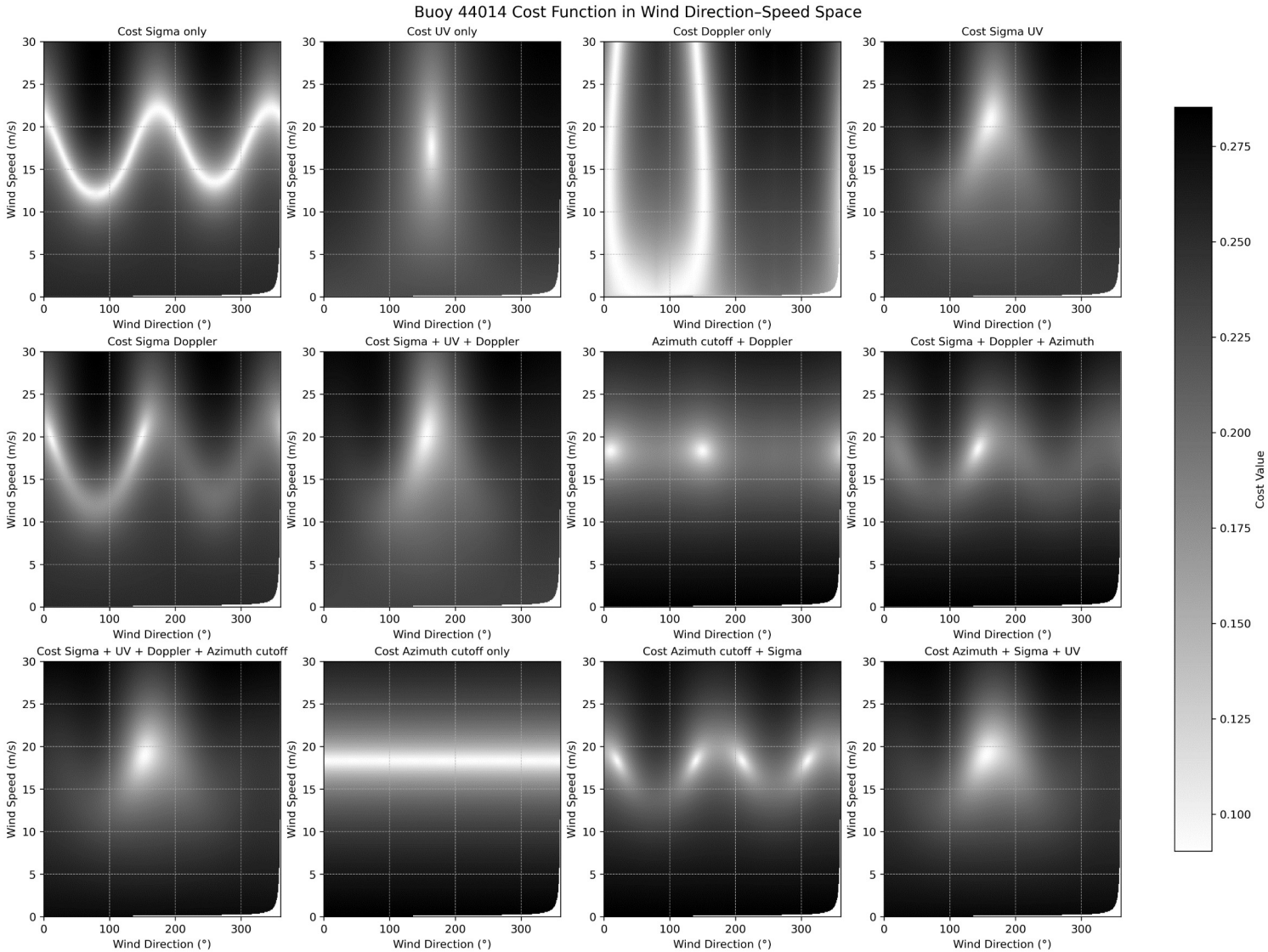
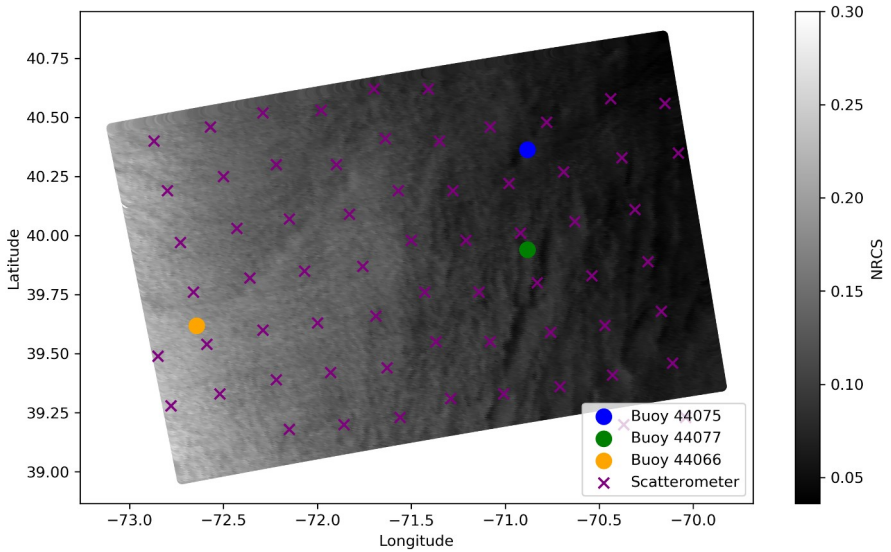
Three Sentinel-1 Images

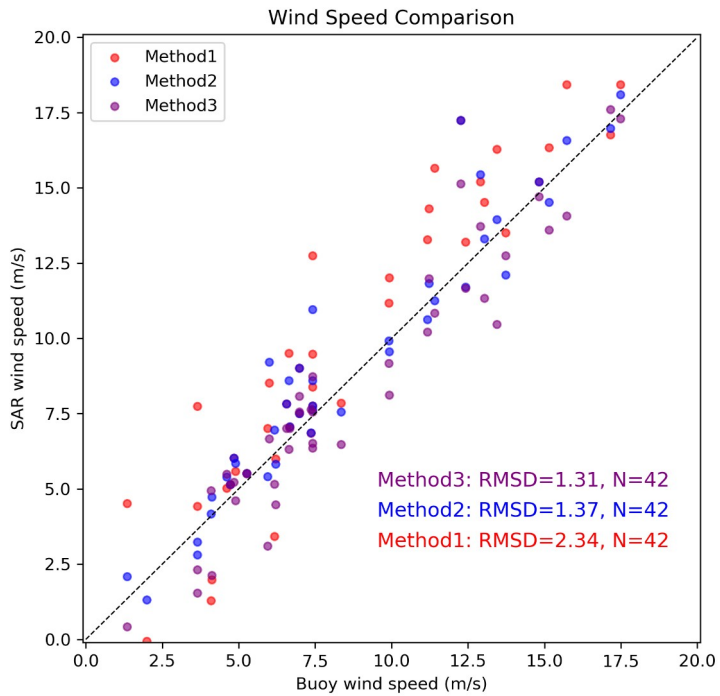
Converted to wind speed–wind direction representation, with wind direction ranging from 0° to 360° and wind speed ranging from 0 to 30 m/s.

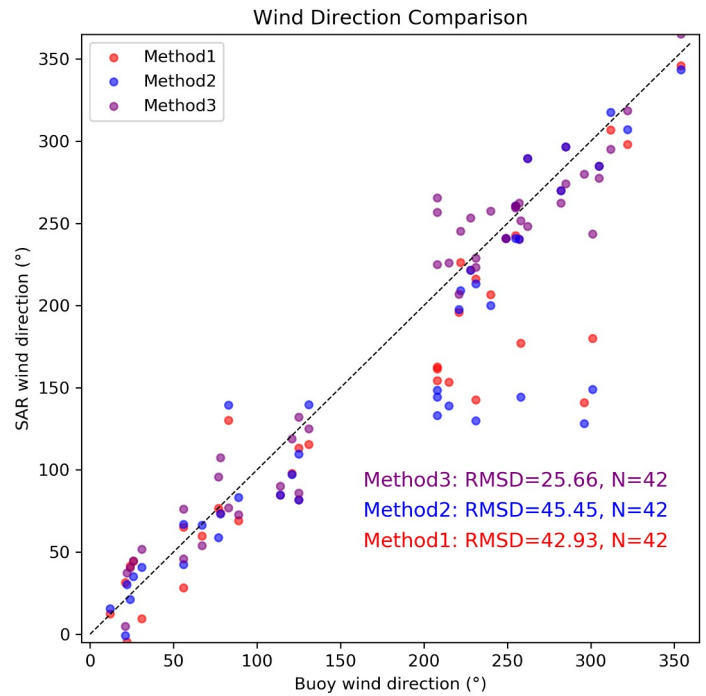


Validation using 2022 open-ocean SAR retrievals and NDBC buoy data



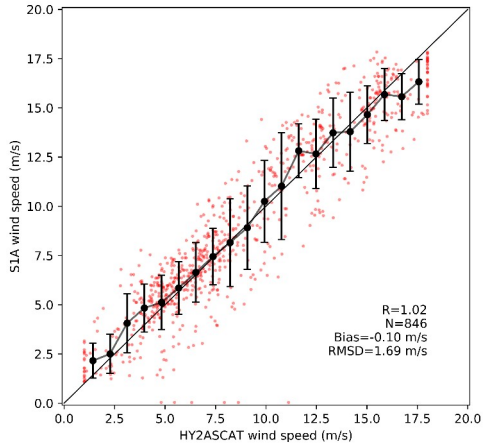
Location

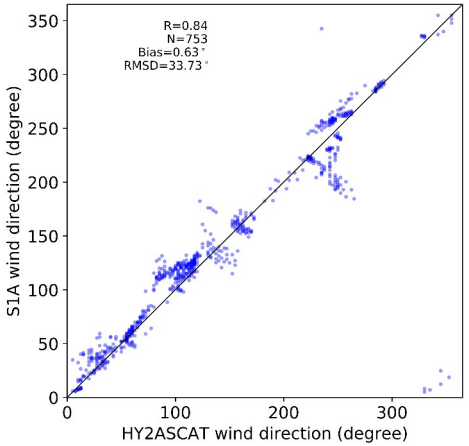




- ✓ Method 1: Wind speed retrieved using CMOD5.N, with a priori wind direction from ERA5
- ✓ Method 2: Bayesian approach proposed by Portabella et al. (2002)
- ✓ Method 3: Proposed method developed in this study

Validation using 2022 open-ocean SAR retrievals and HY-SCAT data





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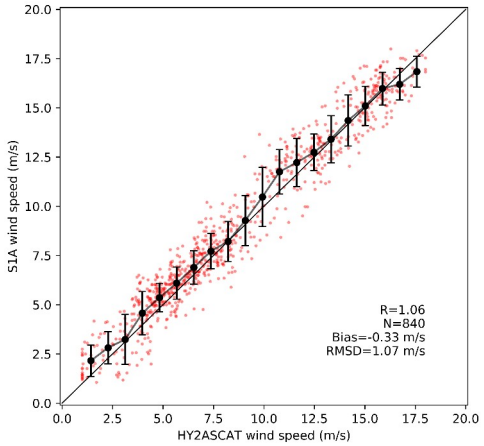
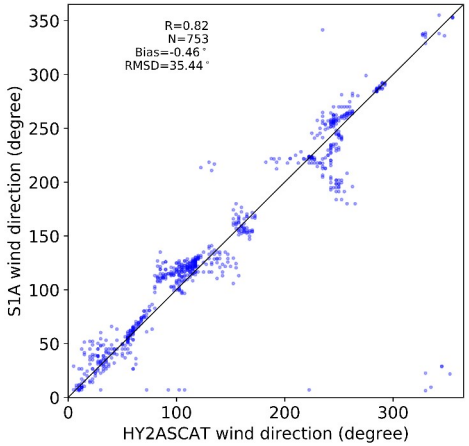
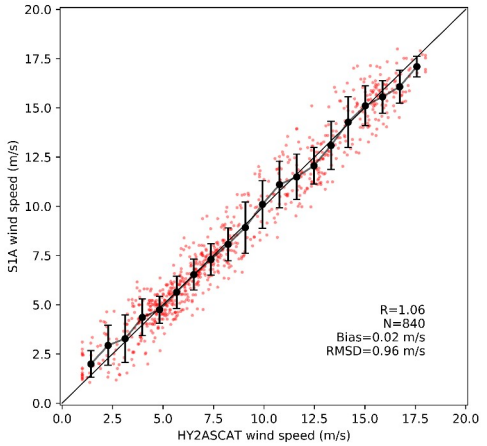
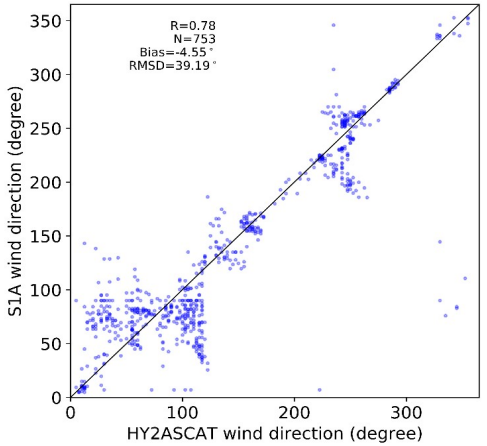




Method 2: Bayesian approach proposed by Portabella et al. (2002)





Method 3: Proposed method developed in this study

Summary and Outlook

Key Contributions

- ✓ Proposed a model-independent SAR wind retrieval method that relies solely on SAR-derived features (e.g., NRCS, Doppler, azimuth cutoff), avoiding dependence on external model inputs.
- ✓ Demonstrated that the method performs comparably or better than traditional approaches (e.g., CMOD+ERA5, Bayesian inversion) in terms of wind speed, and offers improved wind direction retrieval, especially in near-coastal areas.
- ✓ Showed better agreement with buoy data than with scatterometer or model-based results, indicating stronger consistency with real ocean surface conditions.

Limitations

- ◆ Limited validation in nearshore regions (within 10 km of the coast) and in diverse geographic areas.
- ◆ Wind and current Doppler contributions are not decoupled in the current framework.
- ◆ Performance under extreme conditions (e.g., strong winds, fronts) remains to be assessed.

Future Work

- ➢ Expand the dataset to include more diverse SAR scenes, especially near-coastal and high-dynamic environments.
- ➢ Develop a joint inversion framework for wind and surface currents to better isolate Doppler contributions.
- ➢ Refine optimization strategies and improve robustness under complex sea states.

Thank you!

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