Intercomparison of Satellite Wind Products for Tropical Cyclones

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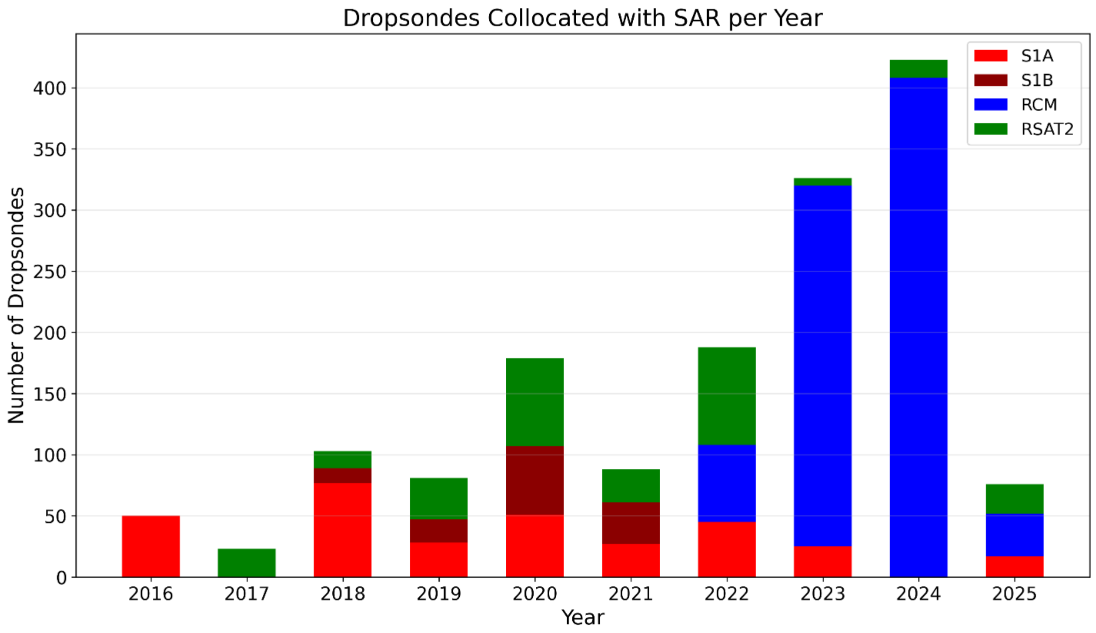
Synthetic Aperture Radar Wind Inspection with NOAA-P3 Data

- SAR wind data over TCs has tripled in yearly quantity
- NOAA P-3 aircraft missions are coordinated with SAR overpasses to validate TC surface wind retrievals using reconnaissance
  - Prior SAR validation studies relied heavily on SFMR with limited sample sizes (Shao et al. 2017, Mouche et al. 2019, Knaff et al. 2021)



SFMR Reliability:
Implications for SAR Wind Validation

SFMR hardware and algorithm issues are systematic

(Holbach 2022, 2026; Jelenak 2025)

NOAA terminated SFMR dissemination from the P-3s in September 2024 and removed the database from operational use due to quality integrity concerns (NHC 2024)

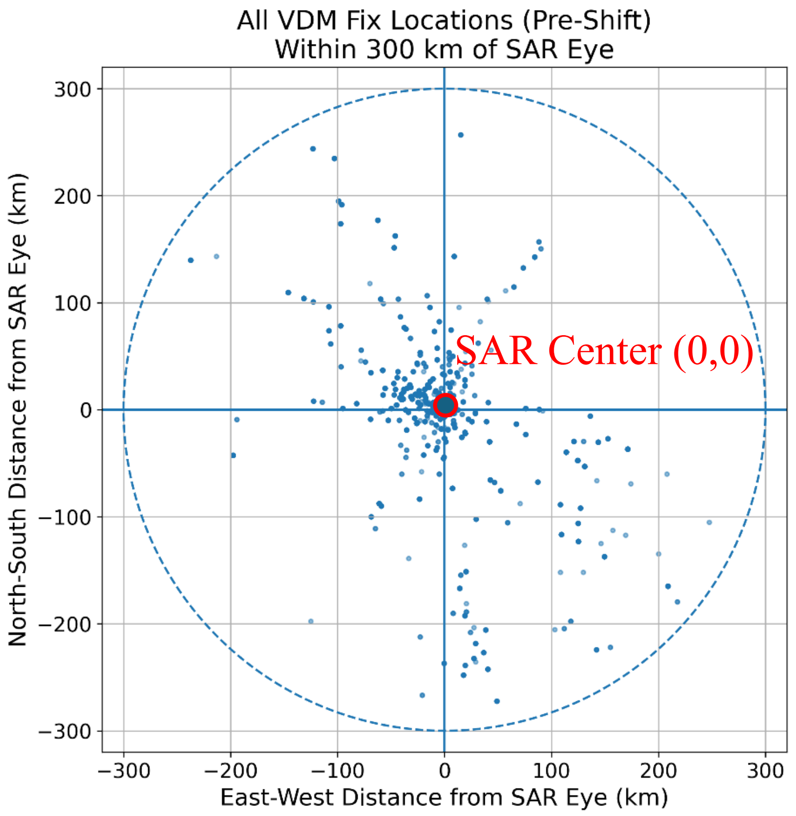
Because SFMR has been a major high-wind reference for SAR GMF training and validation, its uncertainty strengthens the need for independent dropsonde-based SAR validation

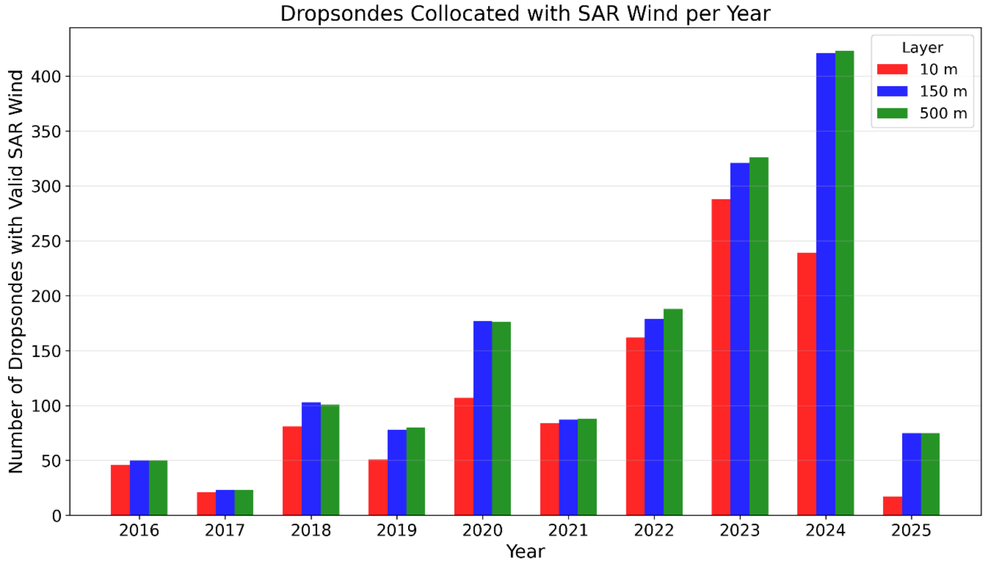
Collocation Framework

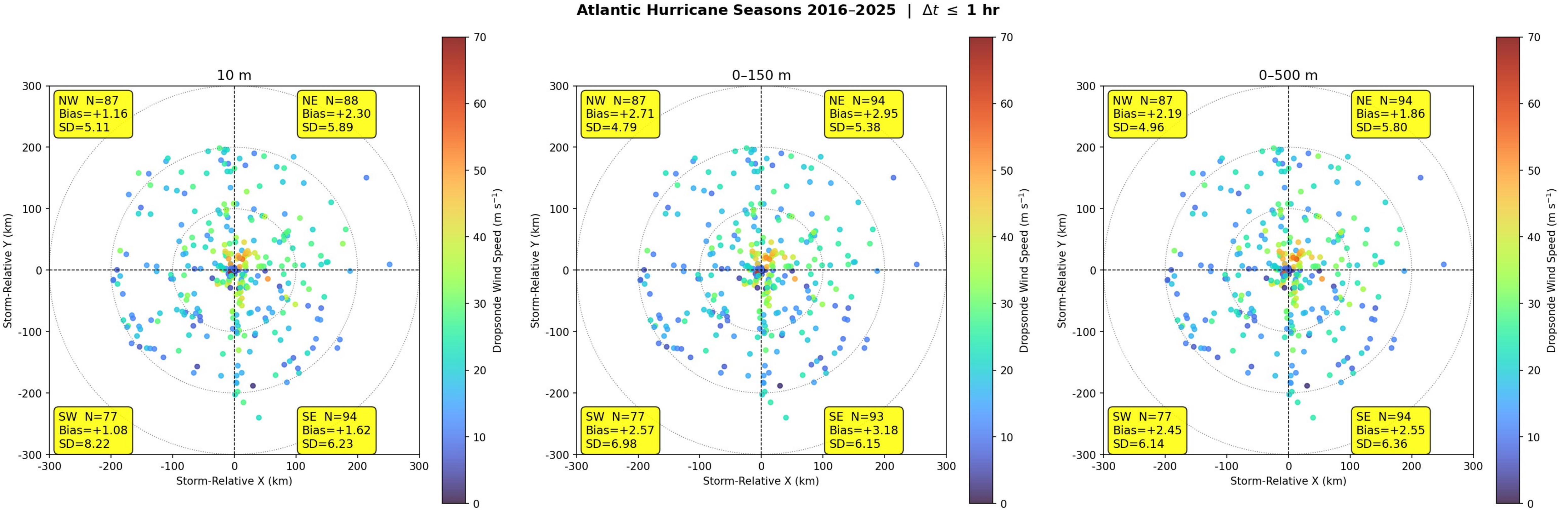
- SAR-Relative Coordinate System
  - Vortex data Message (VDM) = The anchor
  - NOAA STAR Center Fixes

- Dropsondes = Primary wind validation reference
  - Collocated to SAR using a 1-km averaging method

- Tail Doppler Radar (TDR) = Precipitation environment
  - Distinguishing stratiform from deep convective conditions (Wadler et al. 2023)







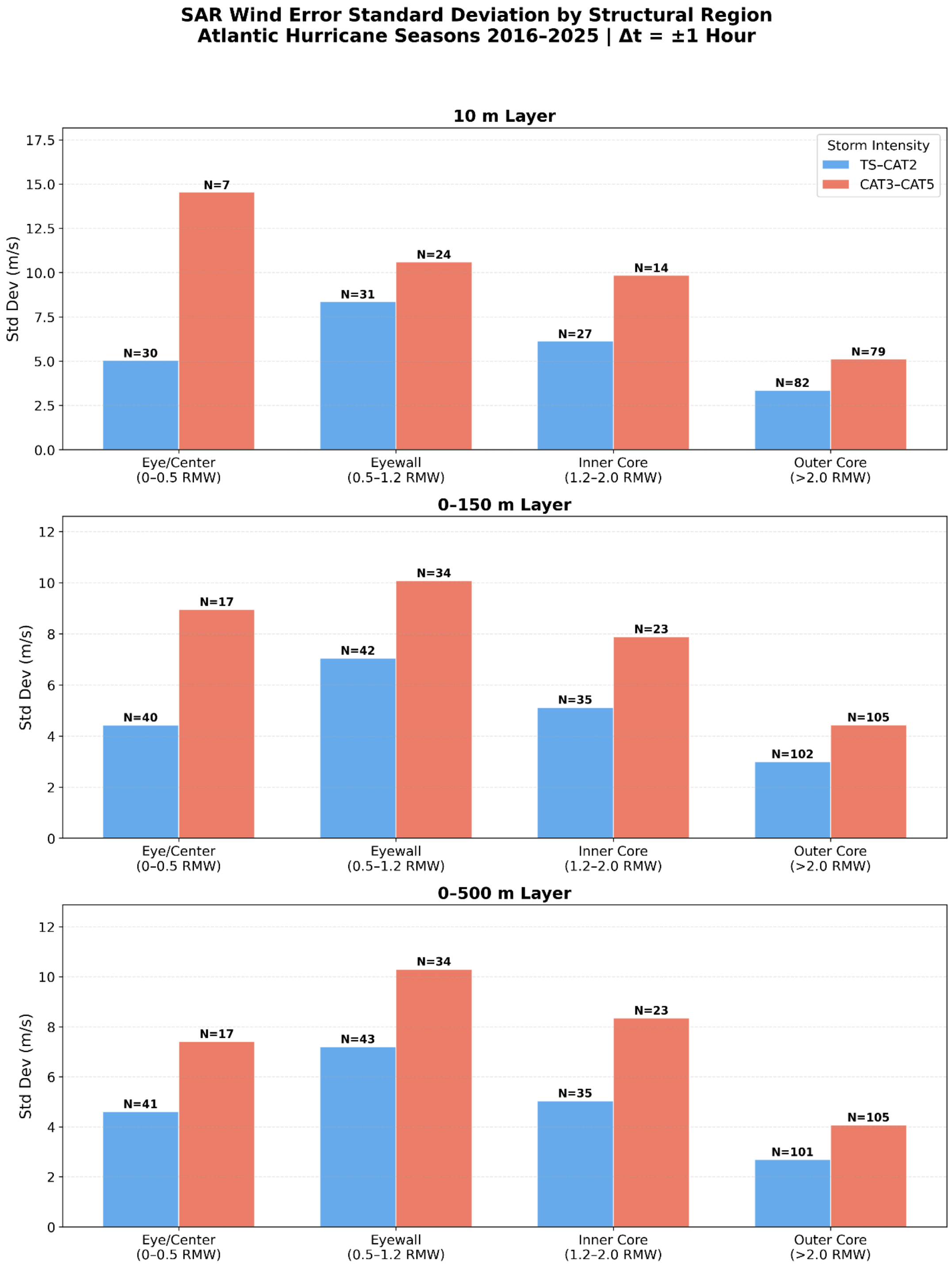
Dropsonde Categorization

- 10-m wind speed → Direct comparison to SAR's 10-m retrieval
- WL150 → mean wind over the lowest 150 m (Uhlhorn & Black, 2003)
- MBL → mean wind over the lowest 500 m (Franklin et al., 2003)
- Collocation windows: ±15 min to ±1 hour

Comparison by Storm Intensity

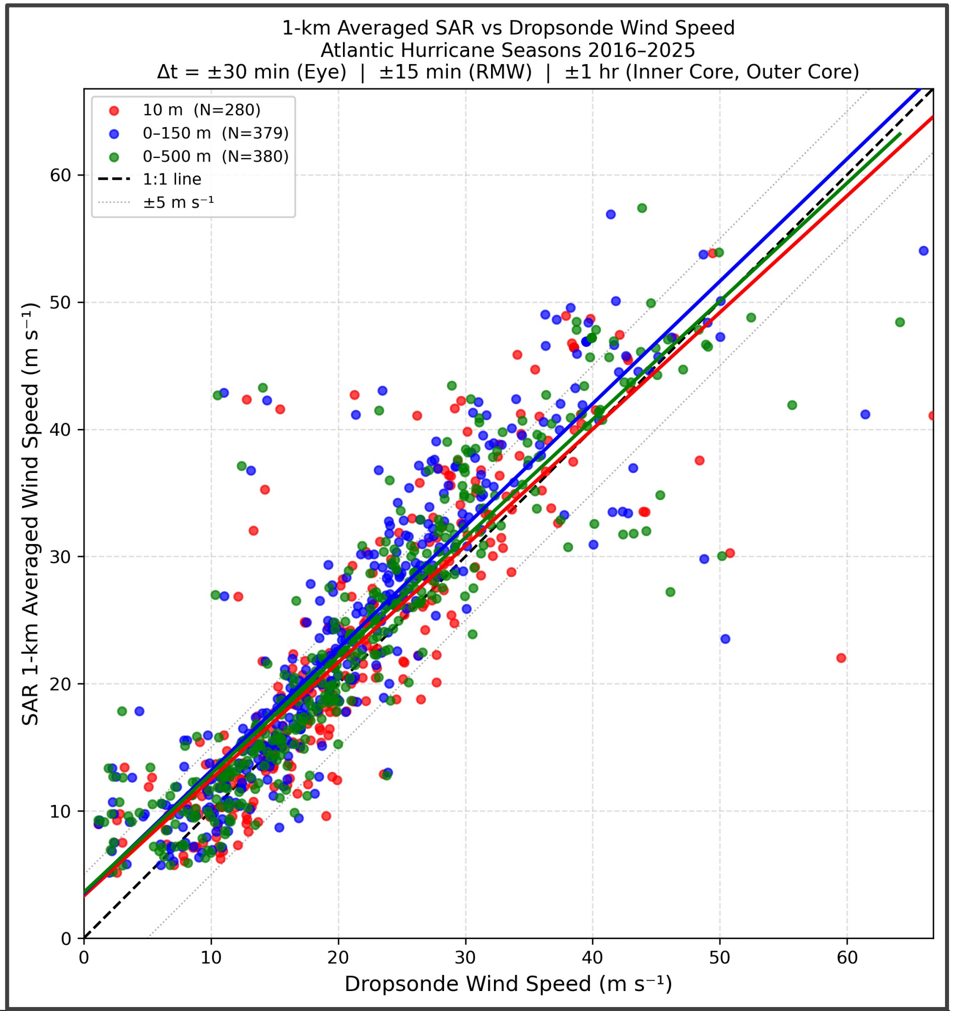
- Greatest Uncertainty:
  - Major storms
  - Eye – 10m layer
  - RMW – 150 m & 500 m layer

- Best Performance:
  - Weaker storms
  - Outer core – across all layers



Comparison at Varying Time Thresholds

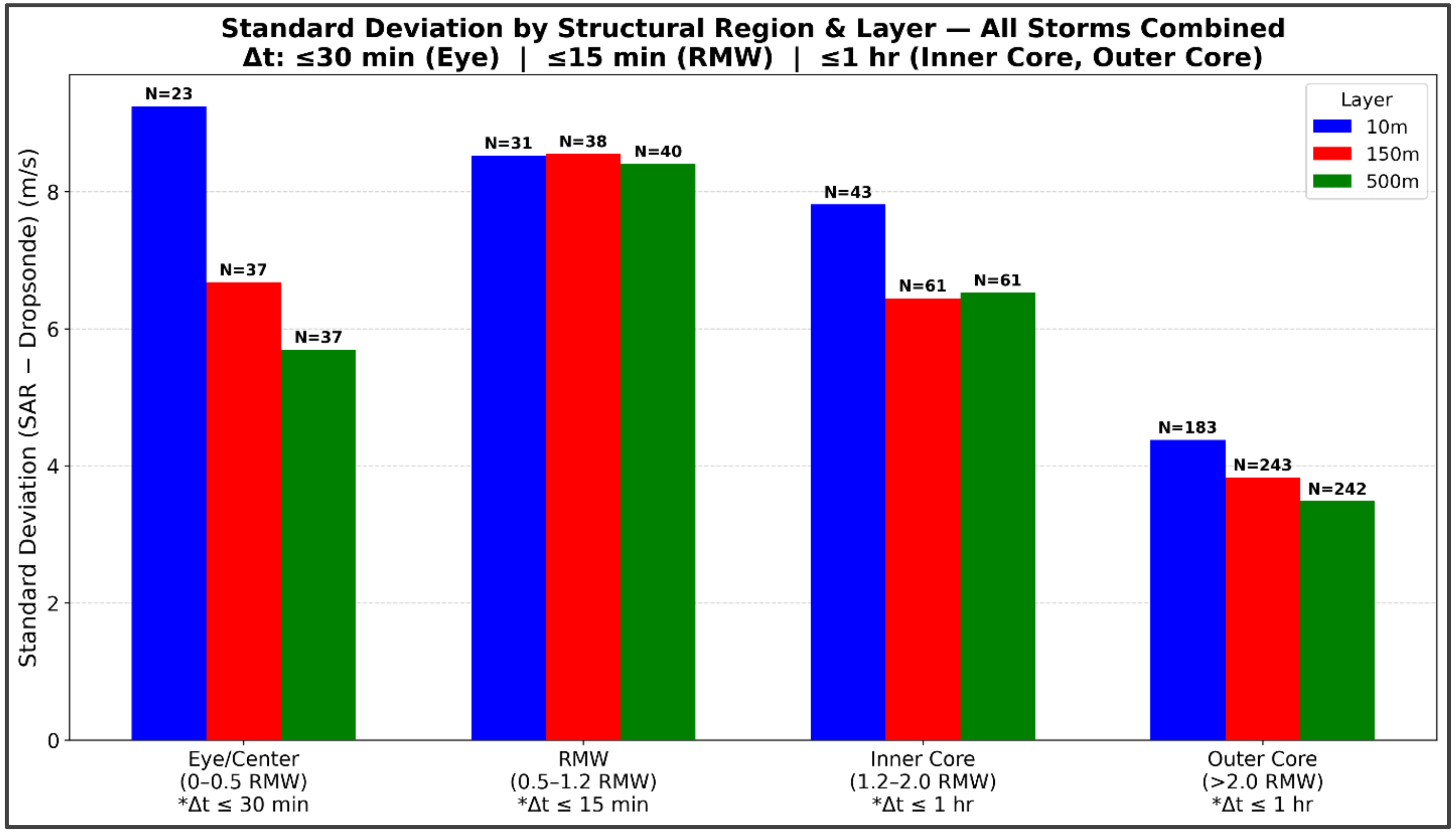
- SAR is positively biased across all layers
- Deeper boundary layer averaging improves agreement
  - MBL achieves the best statistics (r = 0.903, RMSE = 5.45 m/s)



Layer	N	Bias ($m\ s^{-1}$)	RMSE ($m\ s^{-1}$)	MAE ($m\ s^{-1}$)	r	Slope	Intercept
10 m	280	+1.48	6.33	4.20	0.847	0.917	3.32
0–150 m	379	+2.73	5.94	4.14	0.892	0.962	3.53
0–500 m	380	+2.05	5.45	3.67	0.903	0.929	3.61

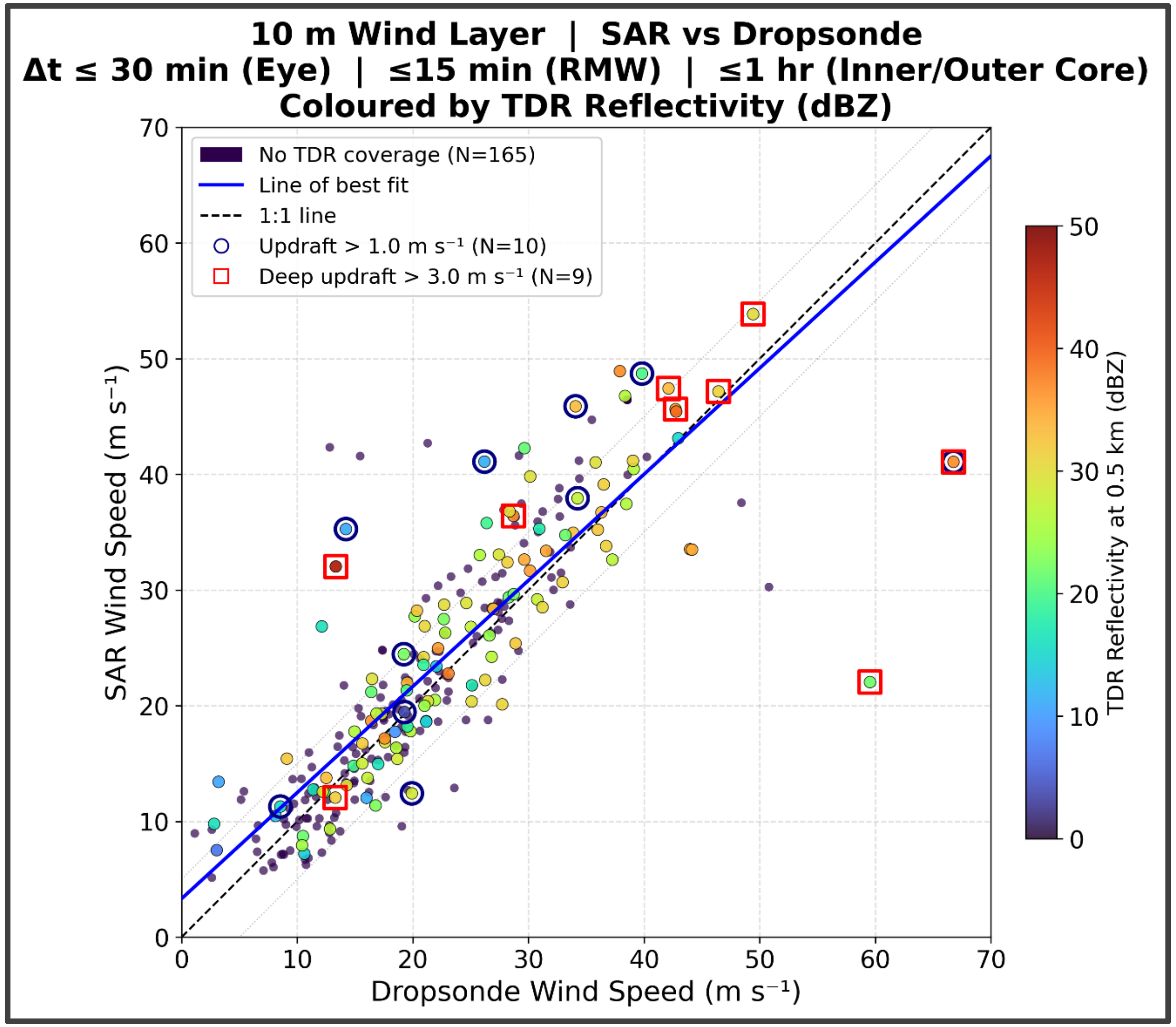
SAR Retrieval Comparison by Structural Region

- Highest uncertainty → Eye + RMW
- Best Performance → Outer core
  - Deeper boundary layer averaging consistently reduces scatter across all structural regions



TDR Reflectivity Analysis

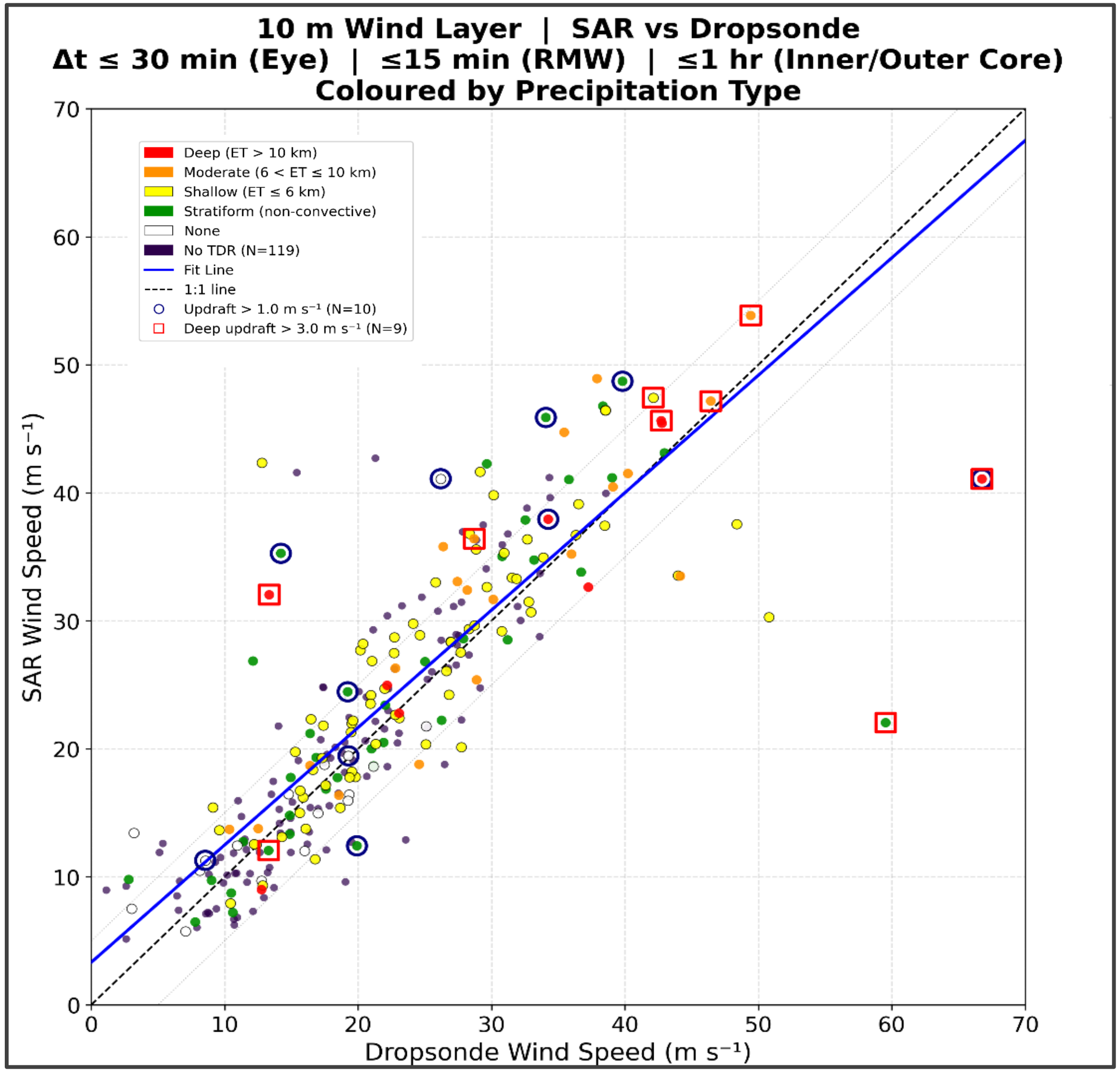
- SAR scatter increases in high-reflectivity environments
- High-reflectivity points carry a higher RMSE
  - Greater point-to-point variability
- Deep updraft points show the most erratic behavior
- No-TDR coverage population limits the ability to attribute SAR error to convective contamination cleanly



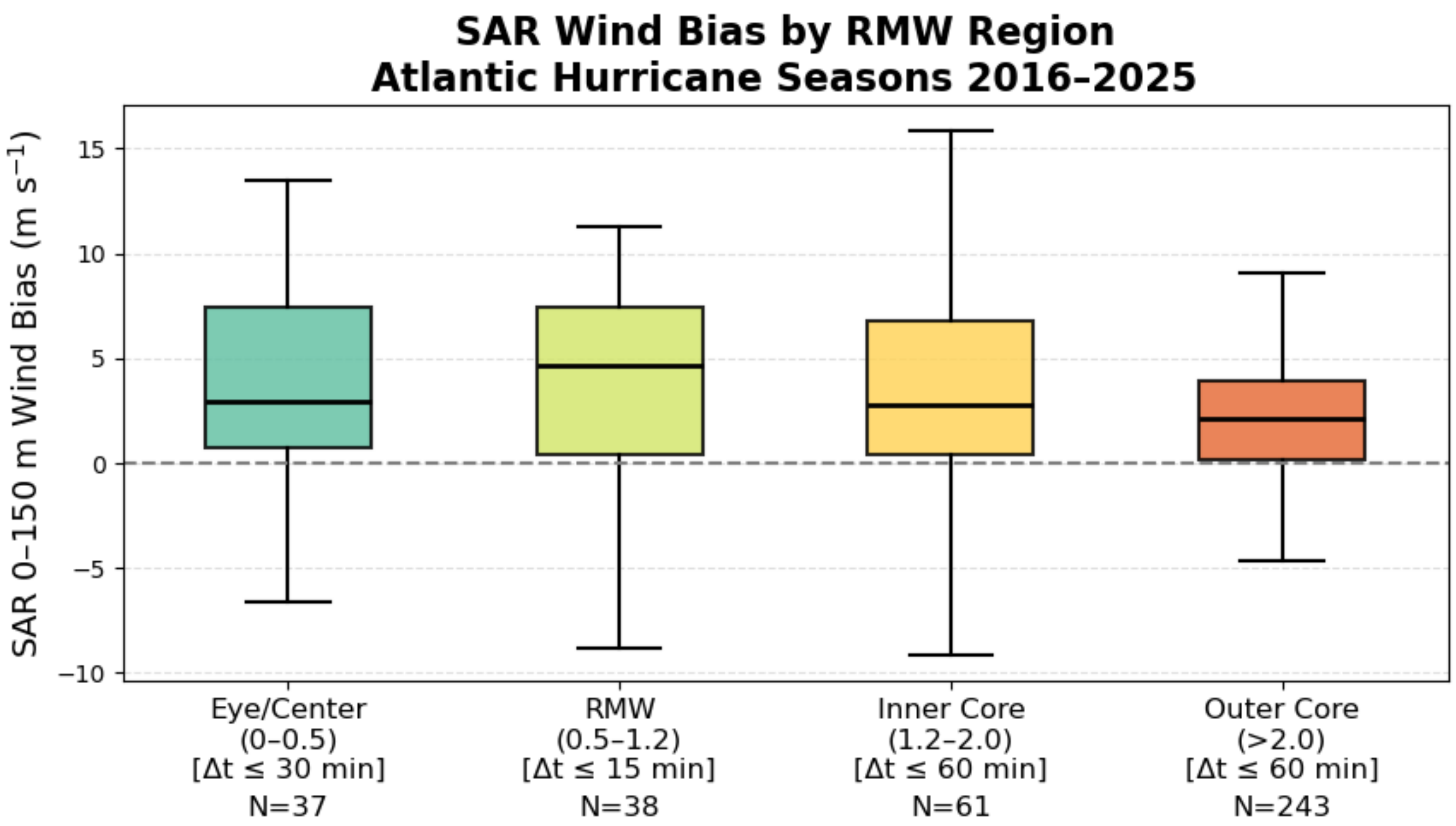
Category	N	Bias (m s⁻¹)	RMSE (m s⁻¹)
All points	280	+1.48	6.33
Refl ≥ 30 dBZ	48	+0.62	7.21
Refl < 30 dBZ	95	+1.88	6.68

Comparison by Precipitation Regime

- Convective points show higher bias
- Near-surface updrafts:
  - Updraft-enhanced sea-surface roughness leading to SAR overestimation.
- Deep updrafts:
  - Competing attenuation and roughening effects at higher winds



Category	N	Bias (m s⁻¹)	RMSE (m s⁻¹)
Convective	106	+1.94	6.77
Non-Convective	55	+1.29	7.71



Implementing SAR

- SAR winds run ~3–5 m/s high across the entire TC
- The RMW bias is the most consistent (~4.5 m/s)
- Inner core winds carry the largest uncertainty
- Greater confidence in the outer core

Further Analysis

- Sensor Integration
  - ASCAT
  - CYGNSS
- Case studies of near-simultaneous acquisitions
  - Helene 2024, Erin 2025
- Additional Datasets:
  - IWRAP
  - Compact Raman Lidar (2021–2022)
  - TC-PRIMED (2016–2023)