Validation of New Lidar Turbulence Algorithm at North American Sites

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AMERICAN CLEAN POWER PEAK

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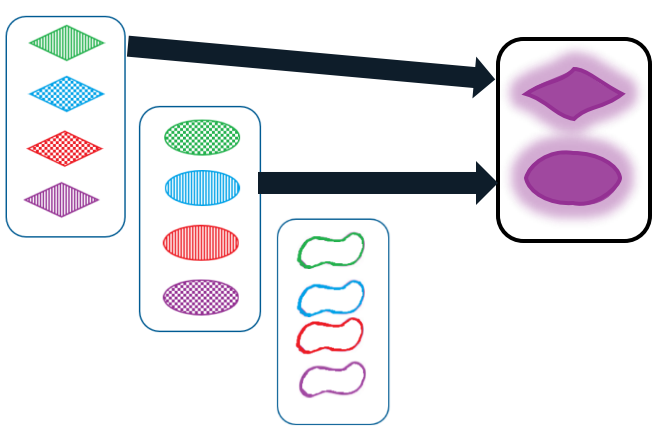
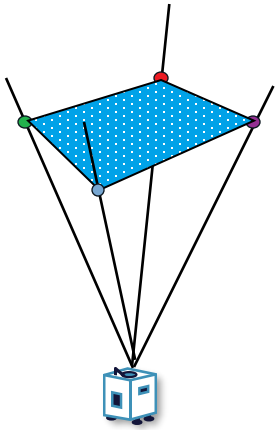
Introduction

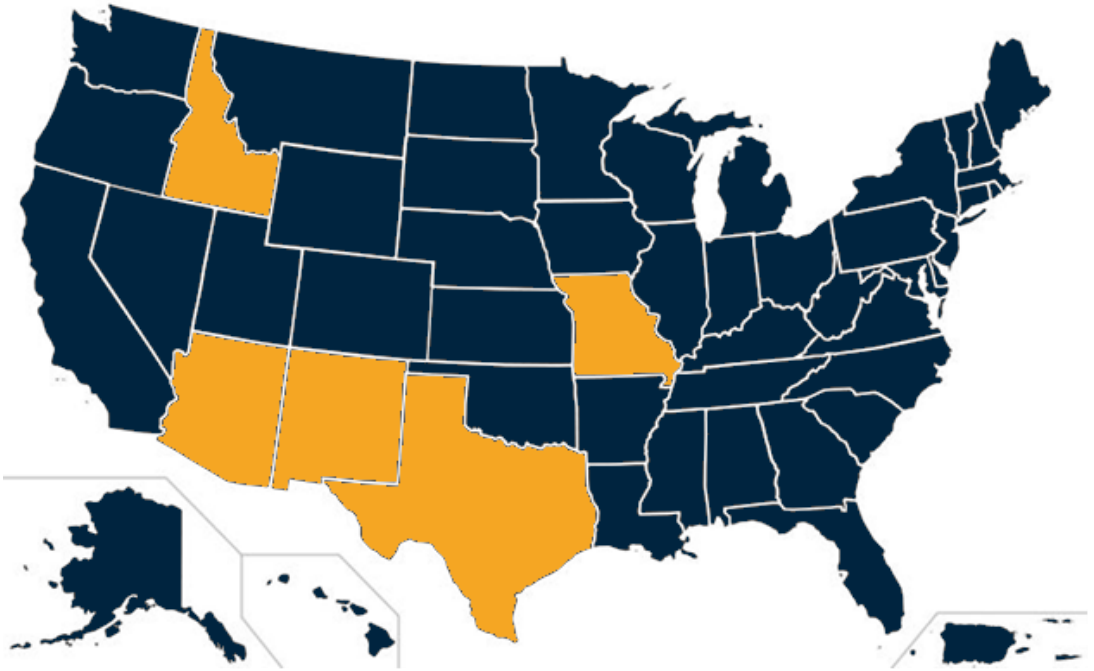
- Today, turbine suitability and loads validation are mostly carried out using cup anemometers
- Lidar systems are already widely accepted for measuring wind speed and wind shear measurements.
- If their ability to measure turbulence can be validated, lidar could carry out all aspects of wind resource assessment.
- Here we examine a new pulsed lidar turbulence algorithm (Pure-TI) against DNV-RP 0661 and IEA Task 52 KPIs

Pure-TI: Physically-Unified Reconstruction of Turbulence Intensity

- Algorithm presented at Peak 2025
- Physics-based reconstruction method for WindCube lidar
- Results shown here are from blind tests at 14 sites in the United States
- 500k datapoints ~9.5 years of data







Key Performance Indicators – Overview

Standard	TI Metric	Error Metric	Application	Passband (cup as reference)
DNV-RP 0661	$TI(V_{hub})$	RMBE	Energy Yield Assessment	±10%
			Site Suitability	−6%→+10% (WS<7 m/s) −3%→+10% (WS>7 m/s)
			Loads Validation	±5%
		RRMSE	Site Suitability	≤30% (WS<7 m/s) / ≤15% (WS>7 m/s)
			Loads Validation	≤15%
CFARS	$TI(V_{hub})$	MBE	Energy Yield Assessment	±1% Best/ ±2% Min
	$\sigma_{90,V_{hub}}$	MBE	Site Suitability / Loads Validation	±1.5% Best/ ±3% Min
IEA Task 52 (in development)	$I_{eff}(V_{hub})$	IQR	Site Suitability / Loads Validation	±5%
	DI		Loads Validation	±3%
	$\sigma_{90,V_{hub}}$		Site Suitability / Loads Validation	±3%

TI equations

$$TI(V_{hub}) = \frac{\sigma_{Vhub}}{V_{hub}}$$

$$\sigma_{90,V_{hub}} = \overline{\sigma_{V_{hub}}} + 1.28 \cdot std(\sigma_{V_{hub}})$$

$$\sigma_{eff}(V_{hub}) = \left[\frac{1}{N}\sum_{i=1}^{N}\sigma_i^m\right]^{\left(\frac{1}{m}\right)}$$

$$I_{eff}(V_{hub}) = \frac{\sigma_{eff}(V_{hub})}{V_{hub}}$$

$$DI = \left[\frac{1}{N}\sum_{i=1}^{N}\sigma_i^m\right]^{\left(\frac{1}{m}\right)}$$

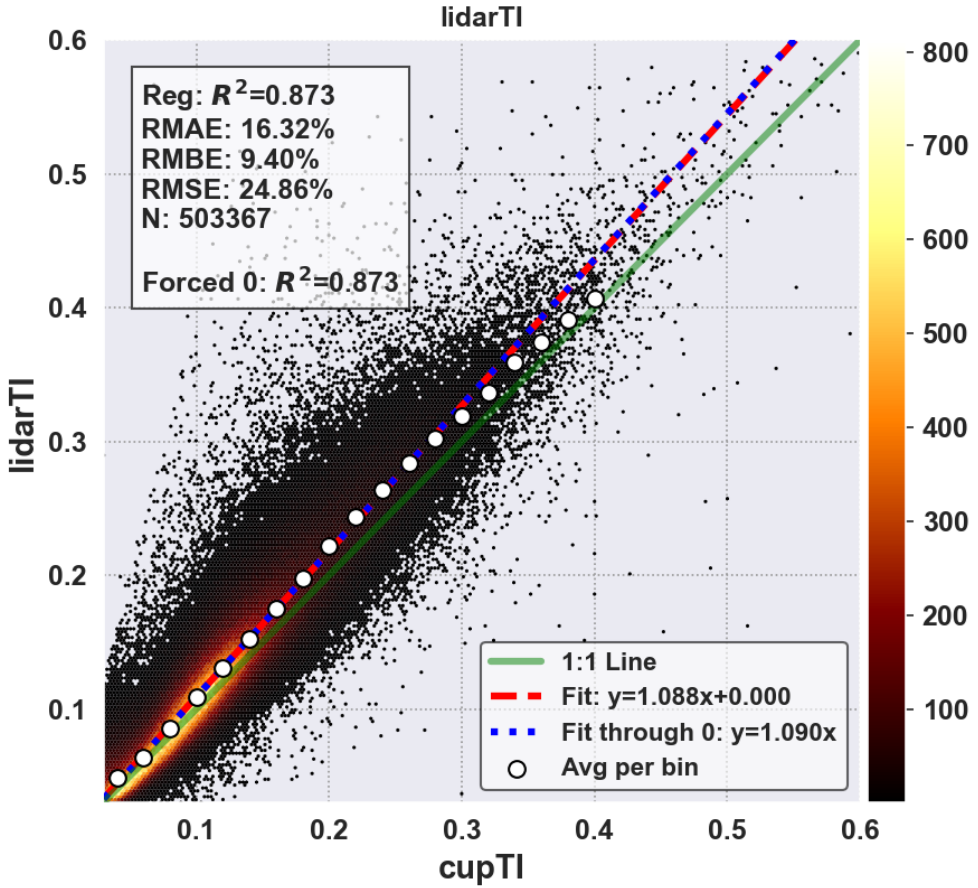
$m \in [4, 9, 14]$

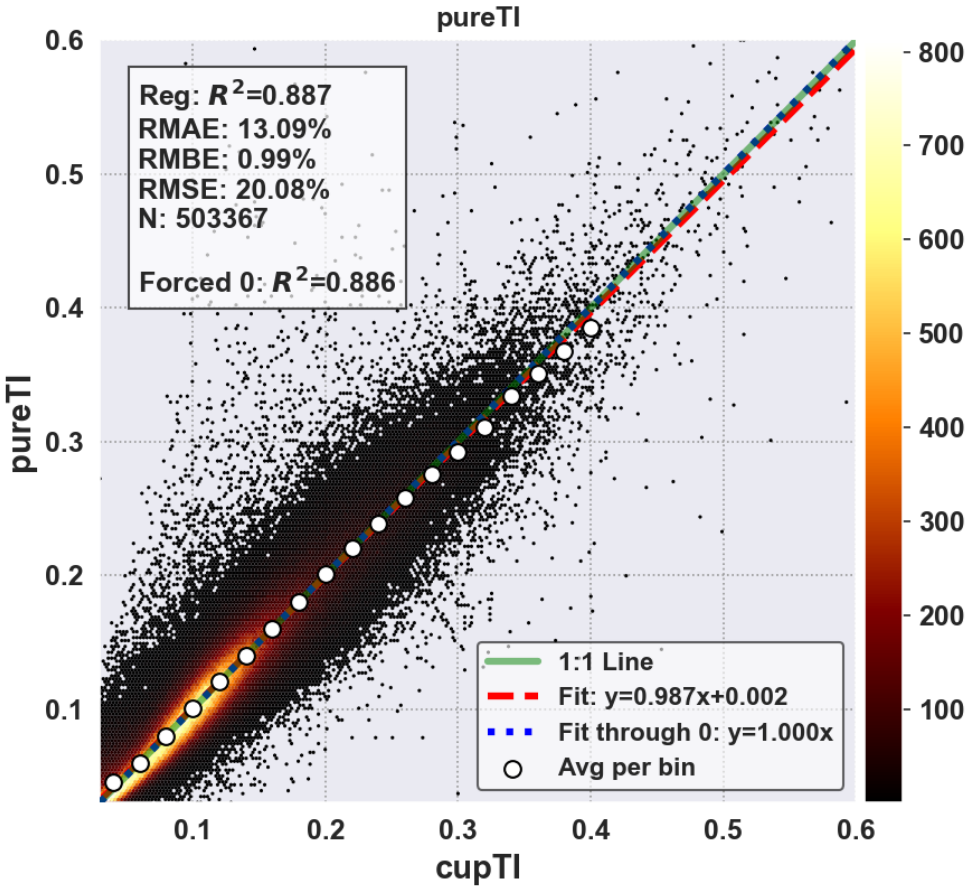
Wind speed binning



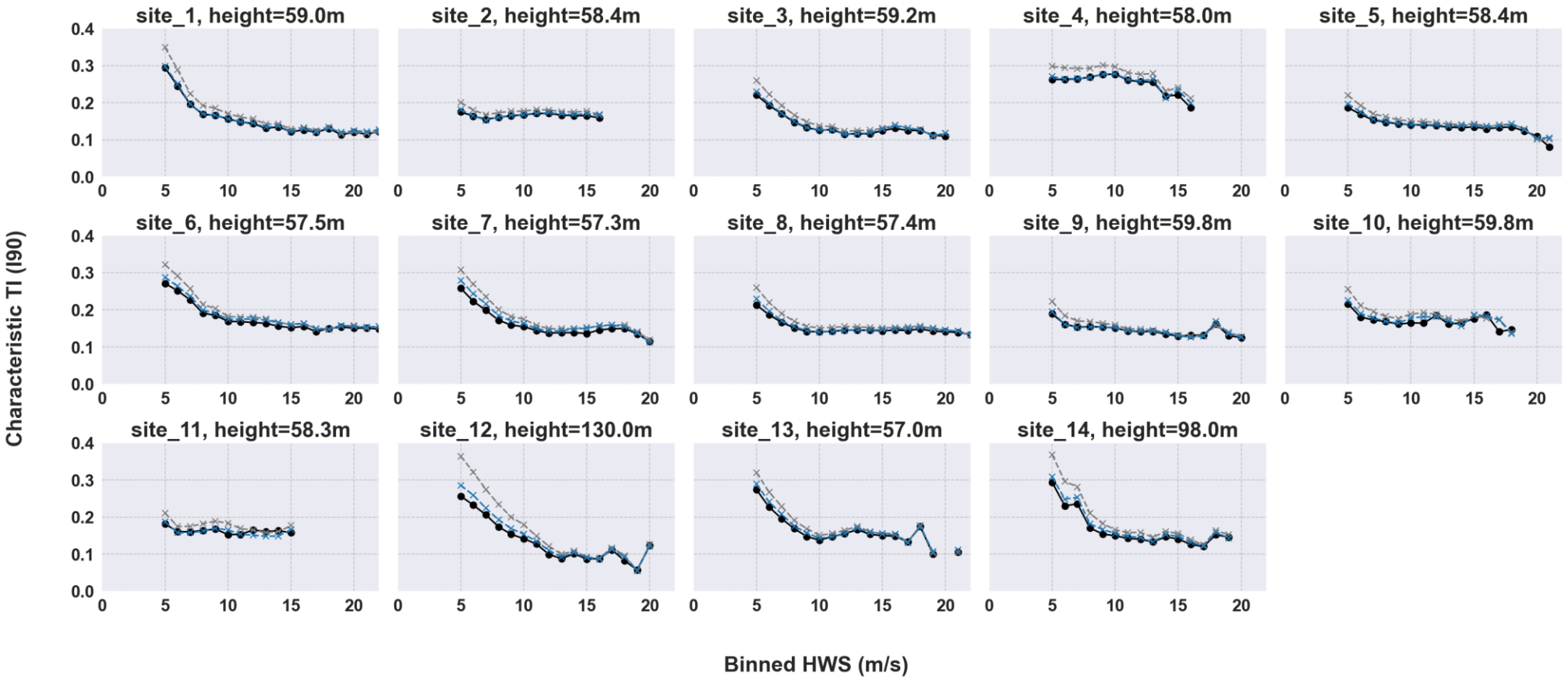


Overall Results – US Sites Only





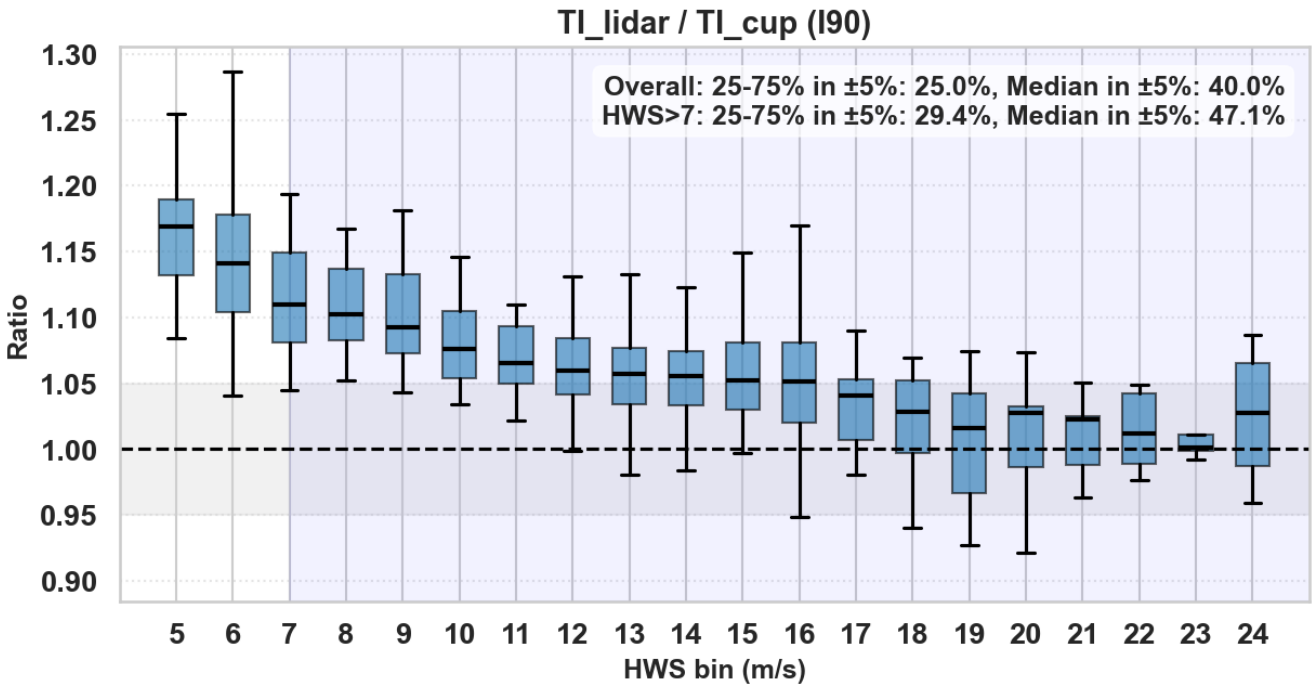
Representative TI Curves

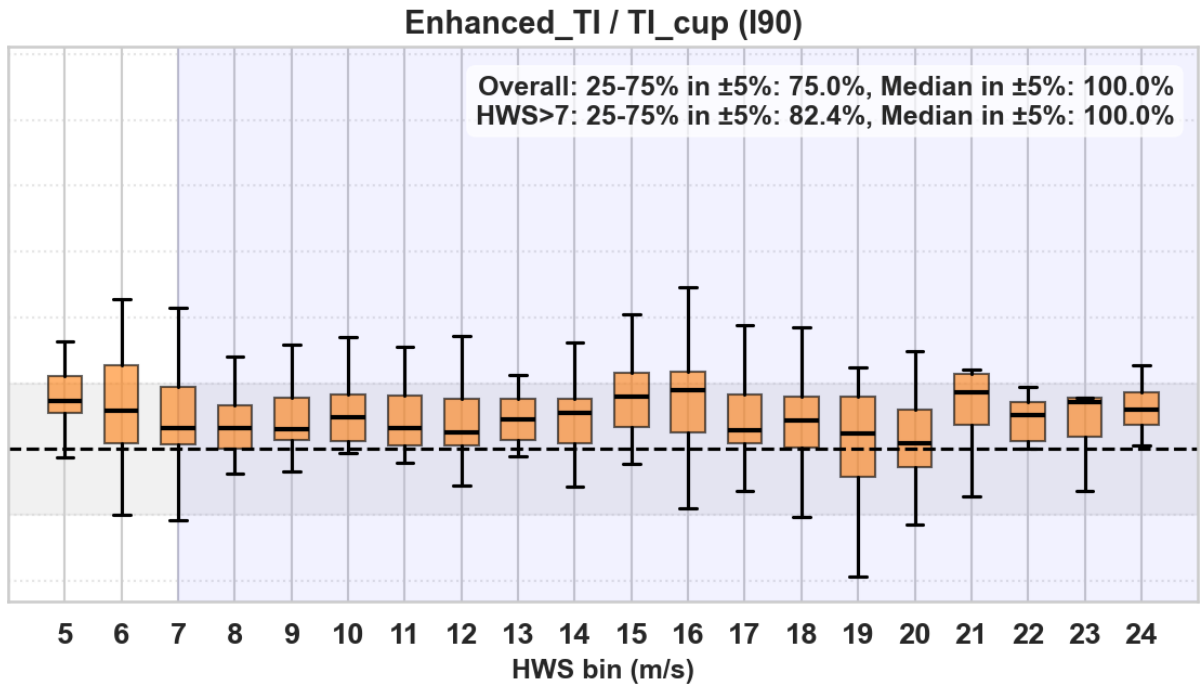


USA: many towers are only 60m tall

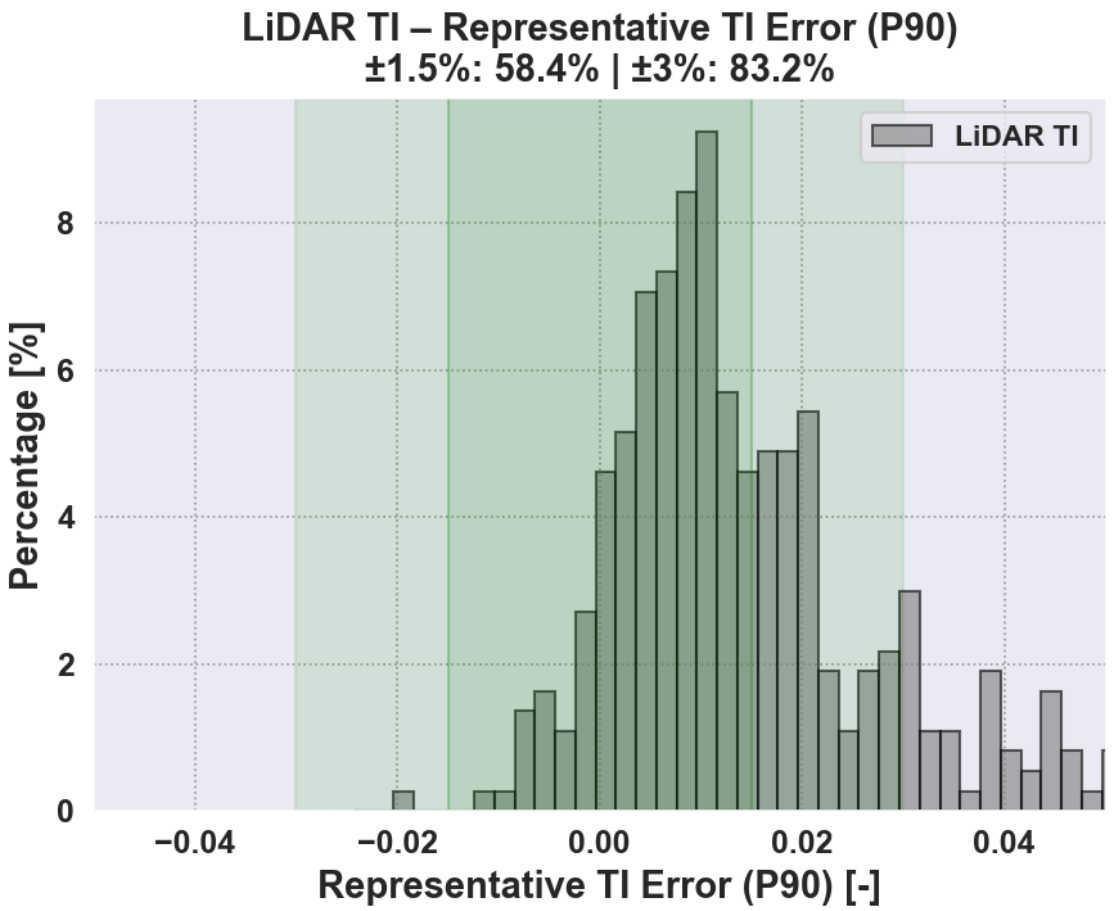
Common to use σ_{60m} to estimate σ_{hub}

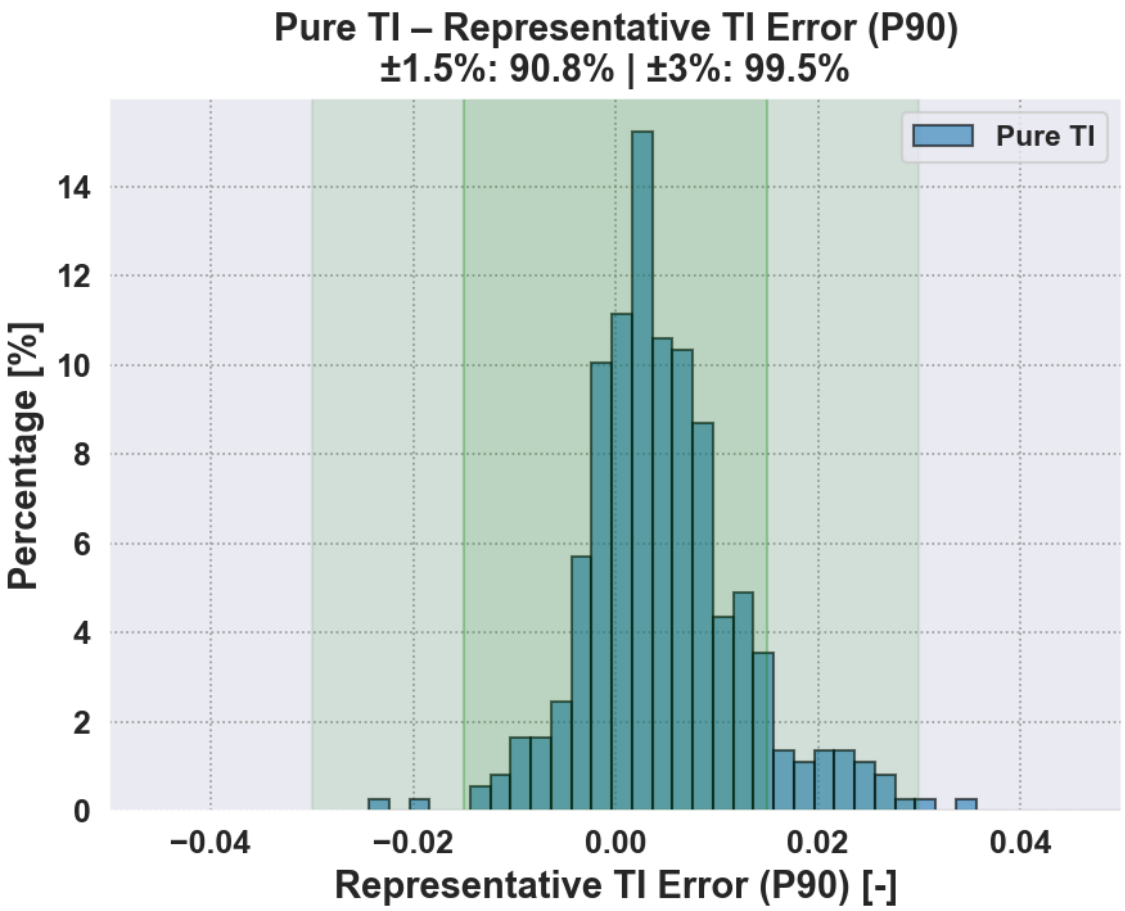
Representative TI RMBE (IEA Task 52)



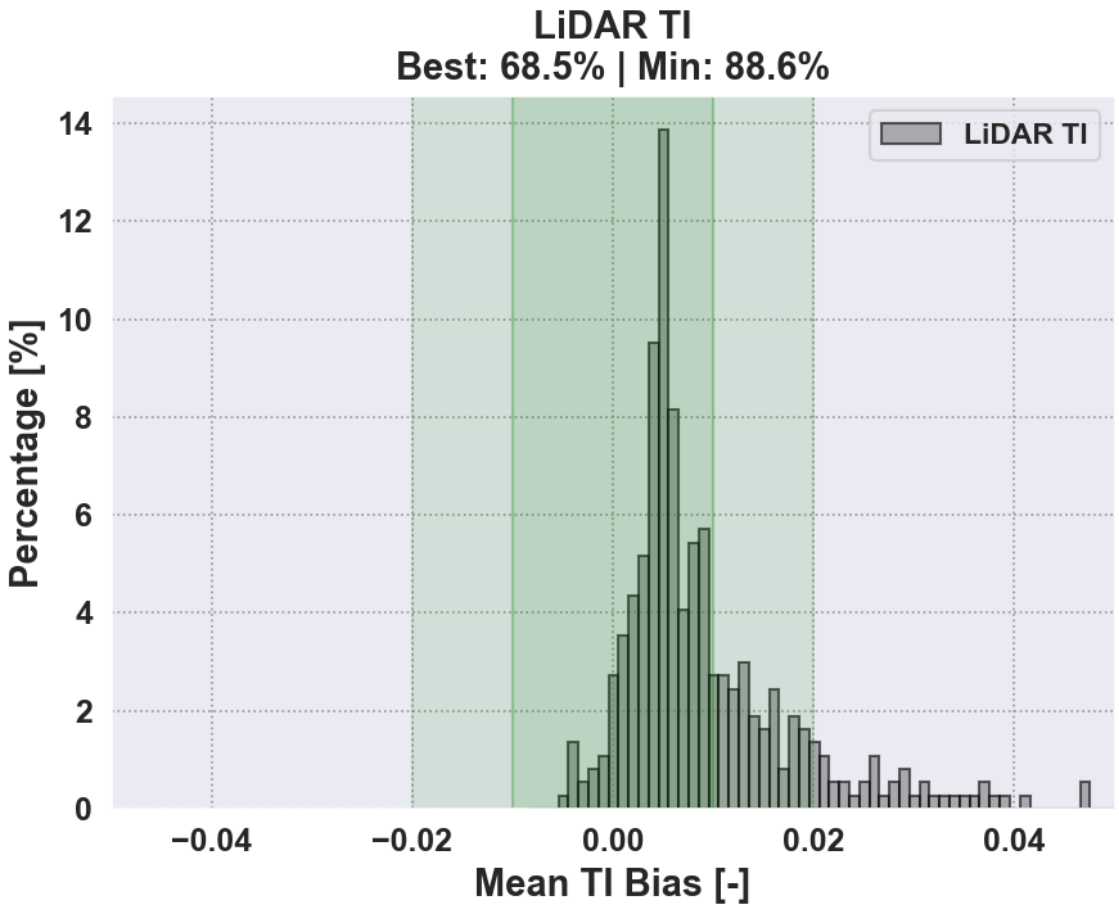


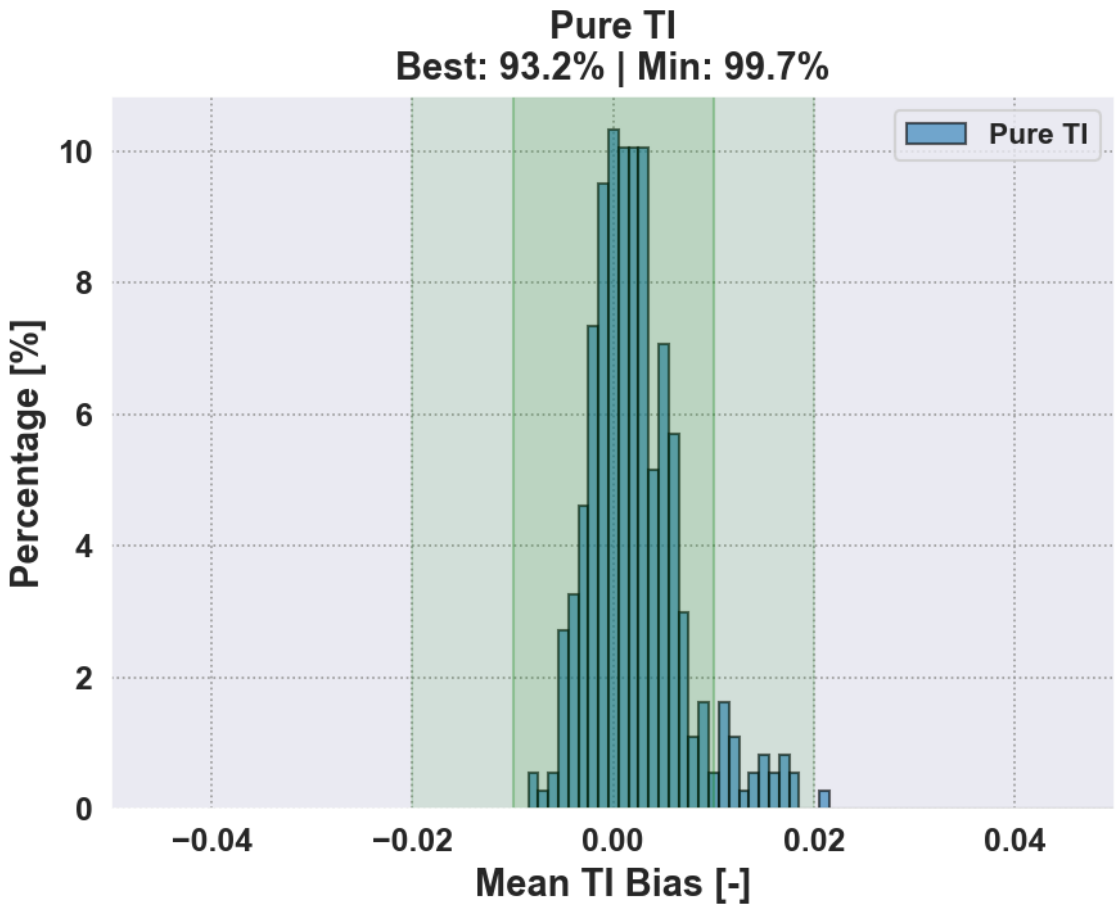
Representative TI MBE (CFARS)



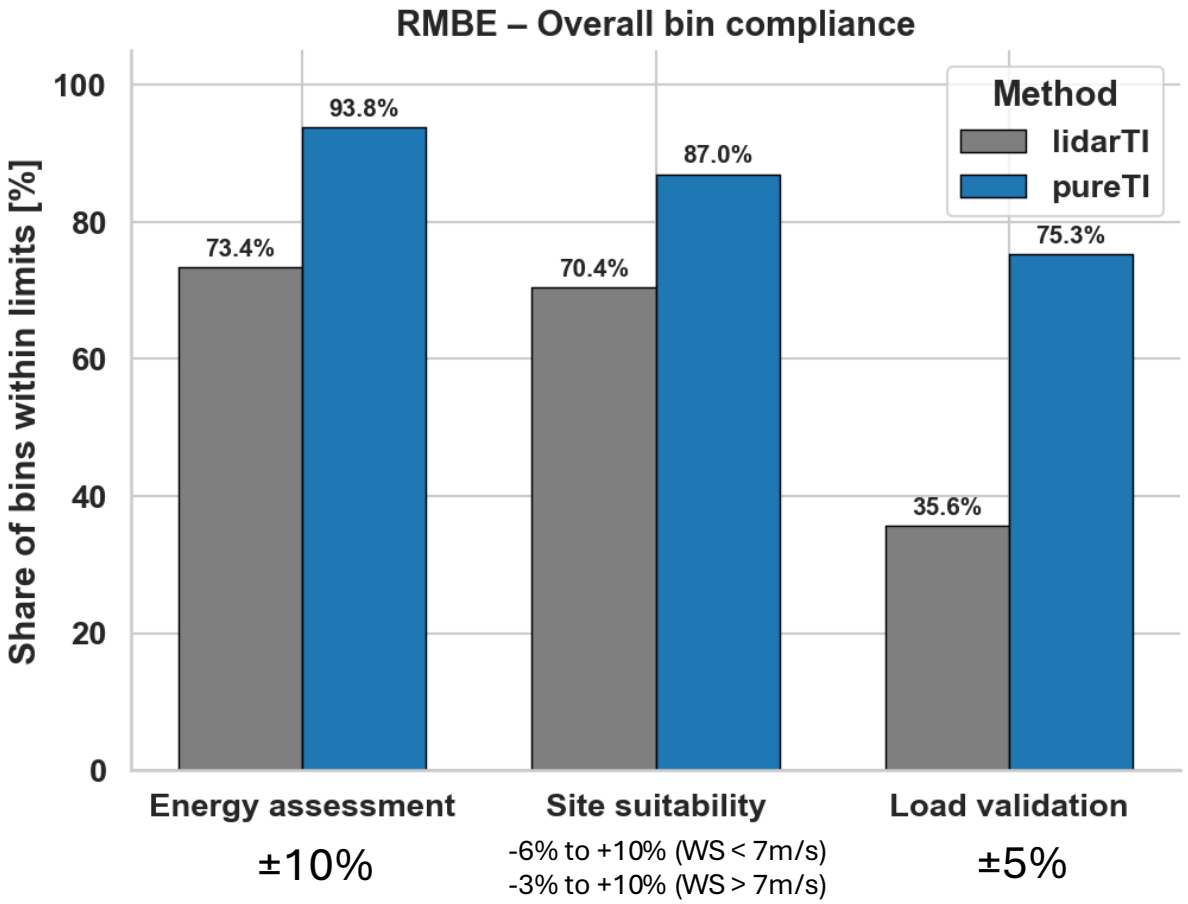


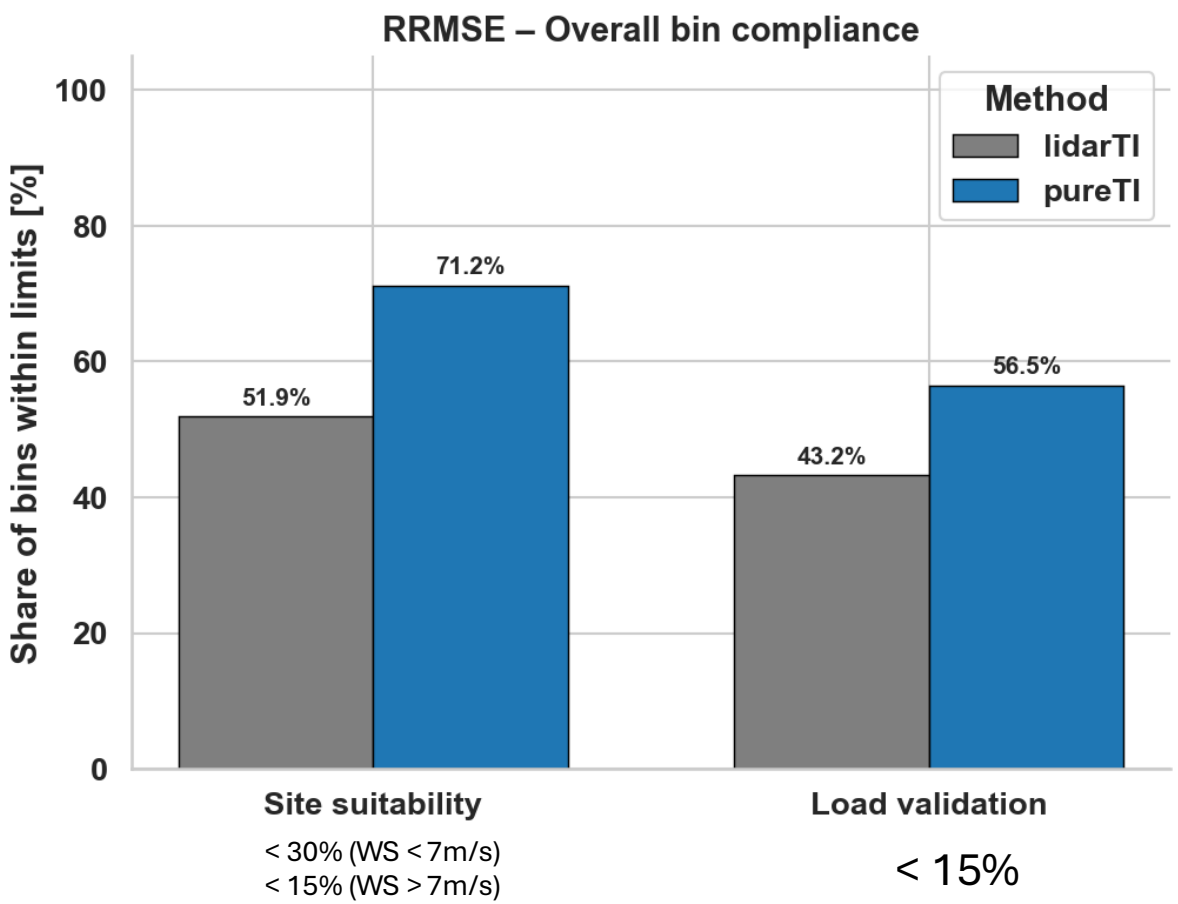
Mean TI MBE (CFARS)





TI RMBE and RRMSE (DNV-RP 0661)



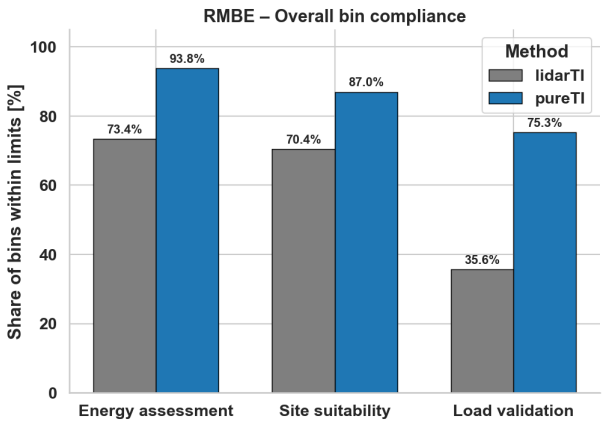


TI RMBE and RRMSE (DNV-RP 0661)

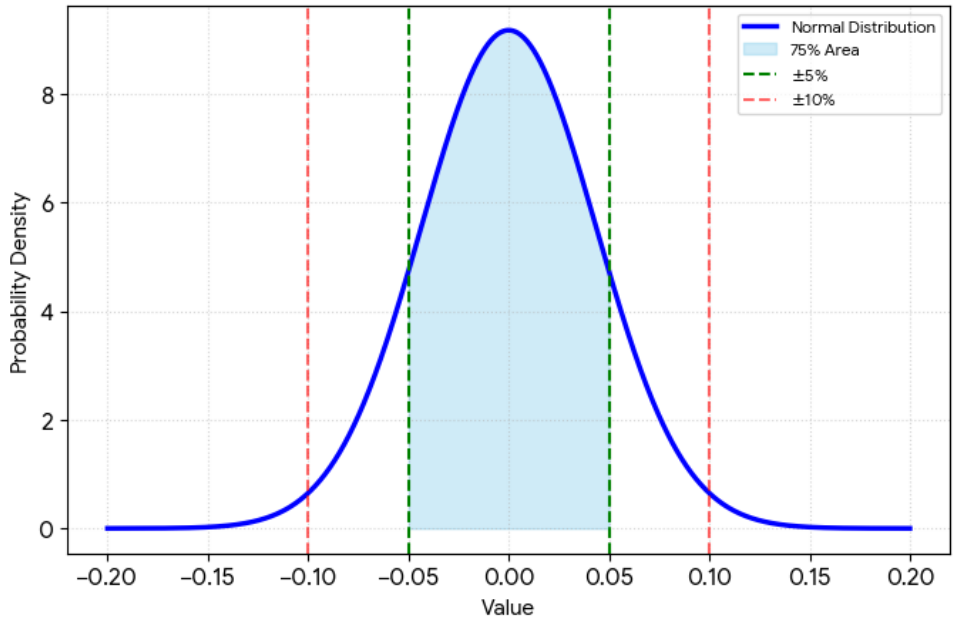
Residual errors form a distribution with:

75.3% of values within ±5%

93.8% of values within ±10%



±10% ±5%



Residual errors can be modeled by a Normal distribution with:

- $\sigma = 4.35\%$, $\mu = 0.99\%$

This can be interpreted that the Pure-TI algorithm has 4.35% *relative* uncertainty for wind speed-binned average TI

Ex: for TI = 15%, this would yield an *absolute* error of 0.6%

Conclusion & Next Steps

- Pure-TI is meeting industry KPIs at US sites:
  - CFARS: 93% Mean TI Best Practice, 90% representative TI Best practice
  - IEA Task 52: 82% Bin IQR within 5% for representative TI, 100% median values within 5%
  - DNV-RP: 87% Bin Mean TI RMBE within site suitability passbands, 75% for Loads
- Validating RRMSE KPI may not add value for the SS/LV/EYA applications
- Worldwide validation including 75 lidars worldwide, including 8 in complex terrain, to be presented at WindEurope

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