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Results from a Joint Industry Project on Quantifying Measurement Uncertainty of Floating LiDAR without Reference Met Masts

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A Multi-Device Statistical Framework Applied to Floating LiDARs in Offshore Korea

BACKGROUND AND MOTIVATION

Floating LiDAR Systems (FLS) are routinely assigned wind speed measurement uncertainties of 3-4% in offshore wind resource assessments; range derived from Dutch North Sea measurement uncertainty values. Empirical evidence from multi-device field deployments is limited, with most uncertainty estimates derived from manufacturer specifications and controlled verification studies rather than operational inter-device comparison. This risks inflation of uncertainty values, P90 energy estimates and increases the perceived project risk.

RESEARCH QUESTION

Can the measurement uncertainty of FLS be robustly quantified using only field data from multiple (similarly) located devices, without recourse to a reference met mast?

STUDY AND DATASET

- **Location:** Offshore Republic of Korea (multiple lease areas)
- **Devices:** Nine floating LiDAR buoys (Stage 2 and Stage 3 technologies, all ZX Lidars)
- **Period:** >1 year of 10-minute wind speed records at 140 m AMSL
- **Analysis groups:** Data stratified into three overlapping subsets with 4, 6, and 8 devices (Groups 1, 2, 3) to test robustness across device combinations and temporal periods

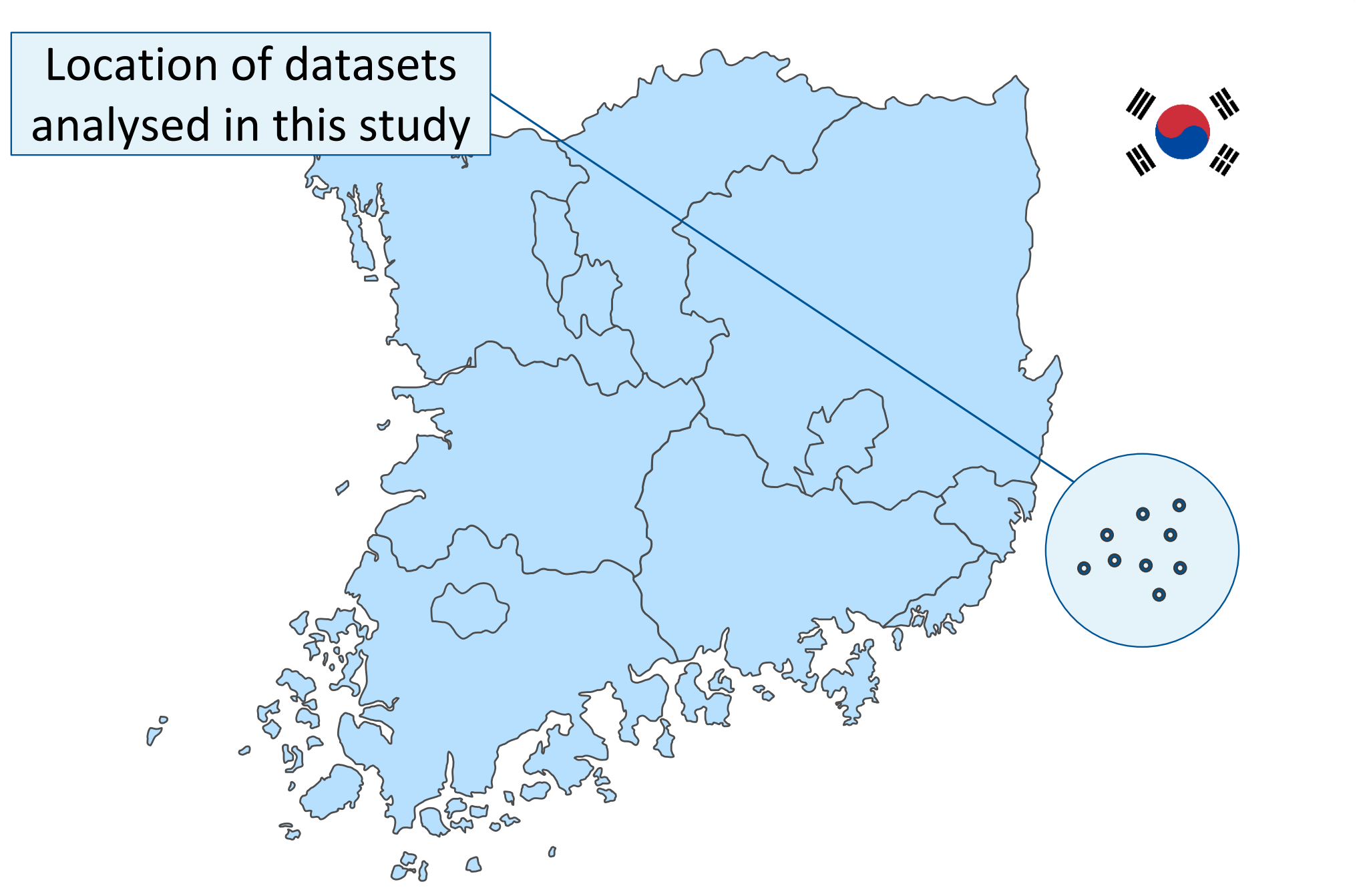

Figure 1: Map of Korean FLS measurements (not true to scale).

THEORETICAL FRAMEWORK

Total measurement uncertainty decomposed into three orthogonal components:

$$\sigma^2_{total} = \sigma^2_{instrument} + \sigma^2_{temporal} + \sigma^2_{spatial}$$

Instrumental Uncertainty ($\sigma_{instrument}$): Persistent device-specific biases quantified using linear mixed-effects model with Restricted Maximum Likelihood estimation:

$$v_{i,t} = \mu_t + b_i + \epsilon_{i,t}$$

where $b_i \sim \mathcal{N}\left(0, \sigma^2_{instrument}\right)$ is device-specific random intercept.

Centering transformation removes systematic bias:

$$\tilde{v}_{i,t} = v_{i,t} - \frac{1}{N}\sum_j v_{j,t}$$

***Spatial correction*:** Initial results showed device bias b_i correlated with distance-to-shore ($r = 0.81, p = 0.016$). Spatial detrending applied:

$$\overline{v_i} = \beta_0 + \beta_1 d_i + \eta_i$$

Only residual η_i enters instrumental uncertainty; spatial trend handled separately.

Temporal Uncertainty ($\sigma_{temporal}$): Captures finite-sample variability and atmospheric fluctuations via **block bootstrap** (10,000 resamples, block lengths 24–144 records from autocorrelation analysis).

Spatial Uncertainty ($\sigma_{spatial}$): Wind field heterogeneity across locations after removing coastal gradient (standard deviation of η_i).

Monte Carlo synthesis: 10,000 samples drawn from each component; 95% confidence intervals (CI) computed.

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RESULTS AND DISCUSSION

Uncertainty Components – *Preliminary Results*

Component	Group 1	Group 2	Group 3
Instrumental (%)	0.87	0.85	0.33
Temporal (%)	1.40	1.15	1.32
Spatial (%)	0.77	0.78	0.34
Total (95% CI, %)	**1.83**	**1.65**	**1.40**

KEY FINDINGS

- **Instrumental uncertainty <1%** across all groups; variance decomposition shows >99% of variability from atmospheric fluctuations, not device differences.
- **Temporal uncertainty dominant** (1.15–1.40%), reflecting finite campaign duration.
- **Leave-one-out sensitivity:** Group 2 shows one outlier device inflating uncertainty by 27%; Group 3 stable (all devices <10% impact). Larger networks more robust.
- **Mesoscale consistency check:** All nine FLS within ±1% of reanalysis products (RMS 0.3–0.7%).

CONCLUSIONS

Total FLS measurement uncertainty **1.4-1.83%** for this Korean dataset is materially lower than the 3-4% commonly employed in the industry. Instrumental uncertainty <1% supports device interchangeability.

Measurement uncertainty reduction of 3.5% to 1.8%, results in an overall uncertainty reduction of **≈1.1%±0.4%** depending on the sensitivity.

LIMITATIONS AND FUTURE WORK

Geographic specificity: Results from single offshore region; replication needed in other wind climates to test transferability.

Methodology refinements: moving from ad-hoc to spatial-first correction, adding flexible spatial models with cross-validation and quantifying correlations between components. Changes aim for cleaner component separation and more rigorous, GUM-consistent, uncertainty propagation.

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