

Verification of dual-scanning lidar for wind resource assessment: **assessing turbulence, long-range and multiple height scanning**



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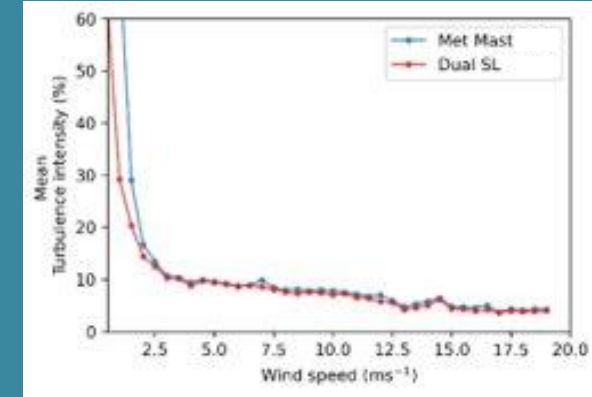
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Why dual scanning lidar?

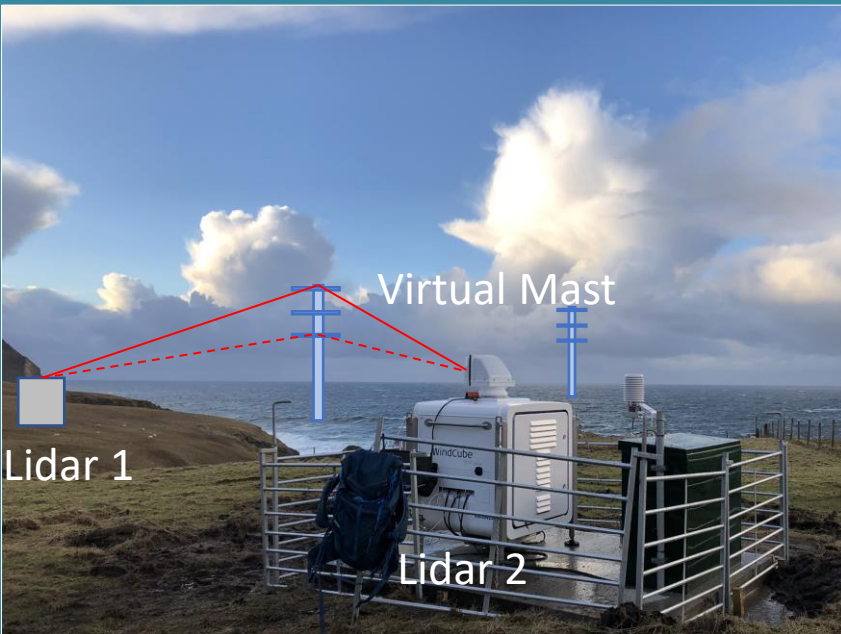
- Viable met mast replacement for WRA and site condition assessment onshore and offshore

- Versatile measurement configurations
 - Acquisition at range (<10km)
 - Multiple heights
 - Horizontal gradients



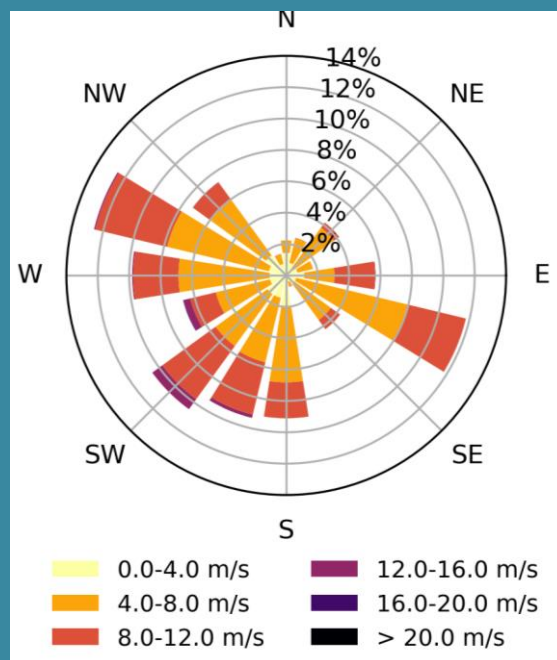
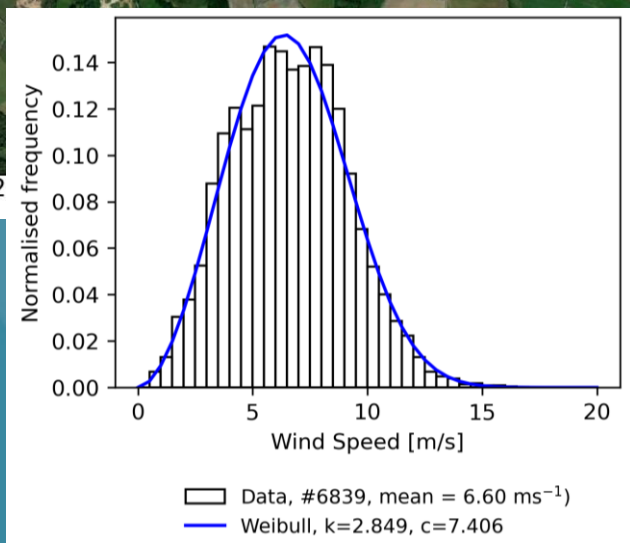
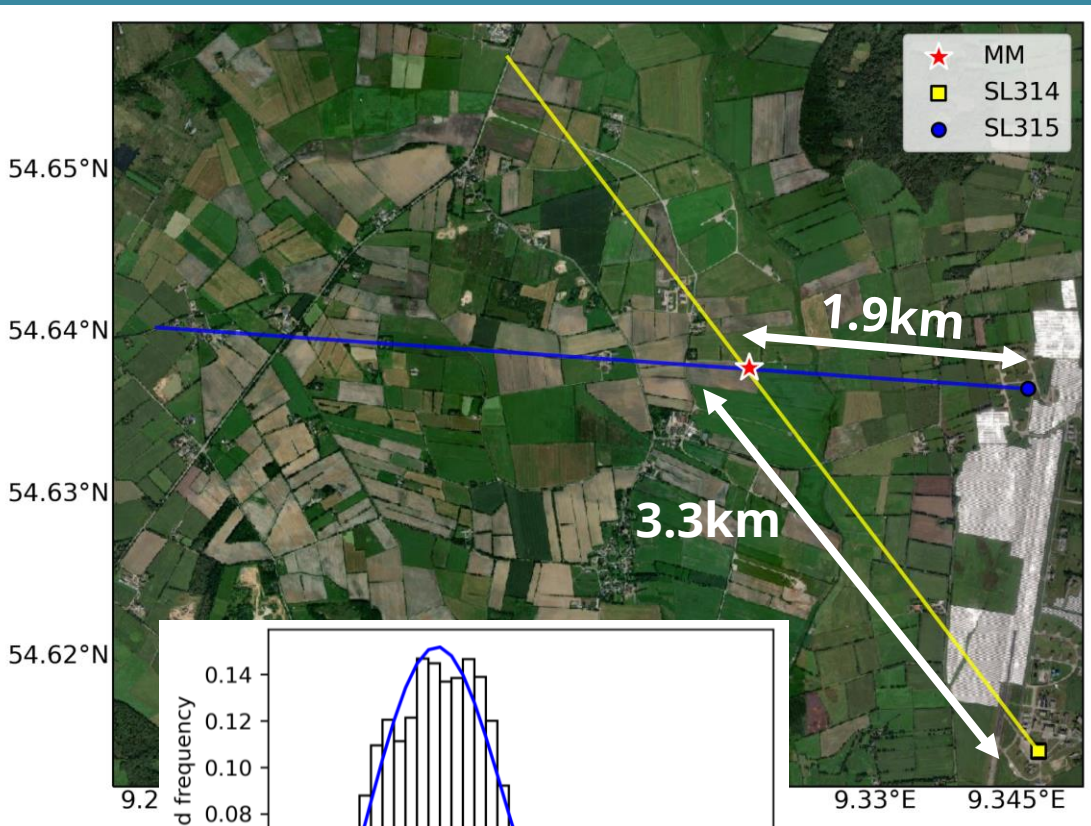
- **A key advantage:** potential to resolve (near) cup equivalent TI [e.g. Peña & Mann, 2019; Shimada et al., 2022,...]

- Some barriers to industry up-take...
 - System complexity
 - Cup equivalence
 - **No recommended practices (yet)...**



Dual-SL verification test at Janneby, Germany

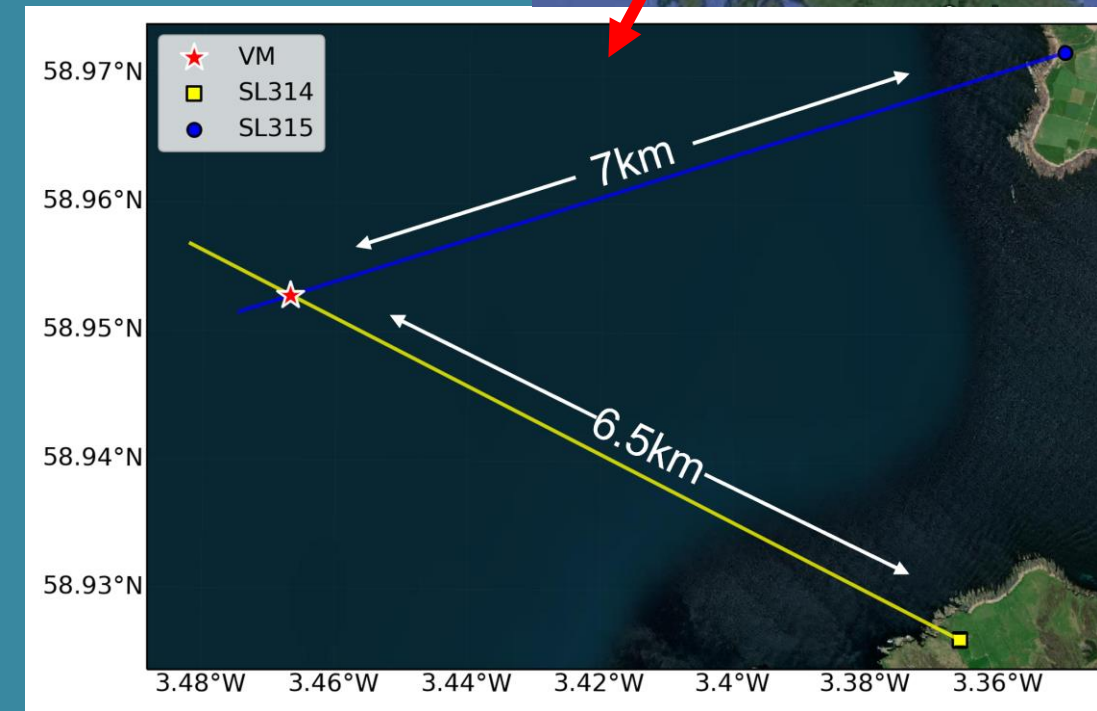
- 2x Vaisala WindCube 400s, units 314 and 315, pulsed lidars, range 6km
- Dual lidar configuration: fixed dwell, intersecting beam
- IEC-compliant Met mast, 100m (2 cups at 103m)
- Duration: ~68 days (08-2022 to 10-2022)



| SL | 314 | 315 |
|--------------------------|---------|---------|
| Azimuth | 322.85° | 274.29° |
| Elevation | 1.89° | 2.72° |
| Range min | 1000m | 1000m |
| Range max | 6000m | 6000m |
| Range res. | 100m | 100m |
| MM dist. | 3300m | 1900m |
| Accumulation time | 1s | 1s |

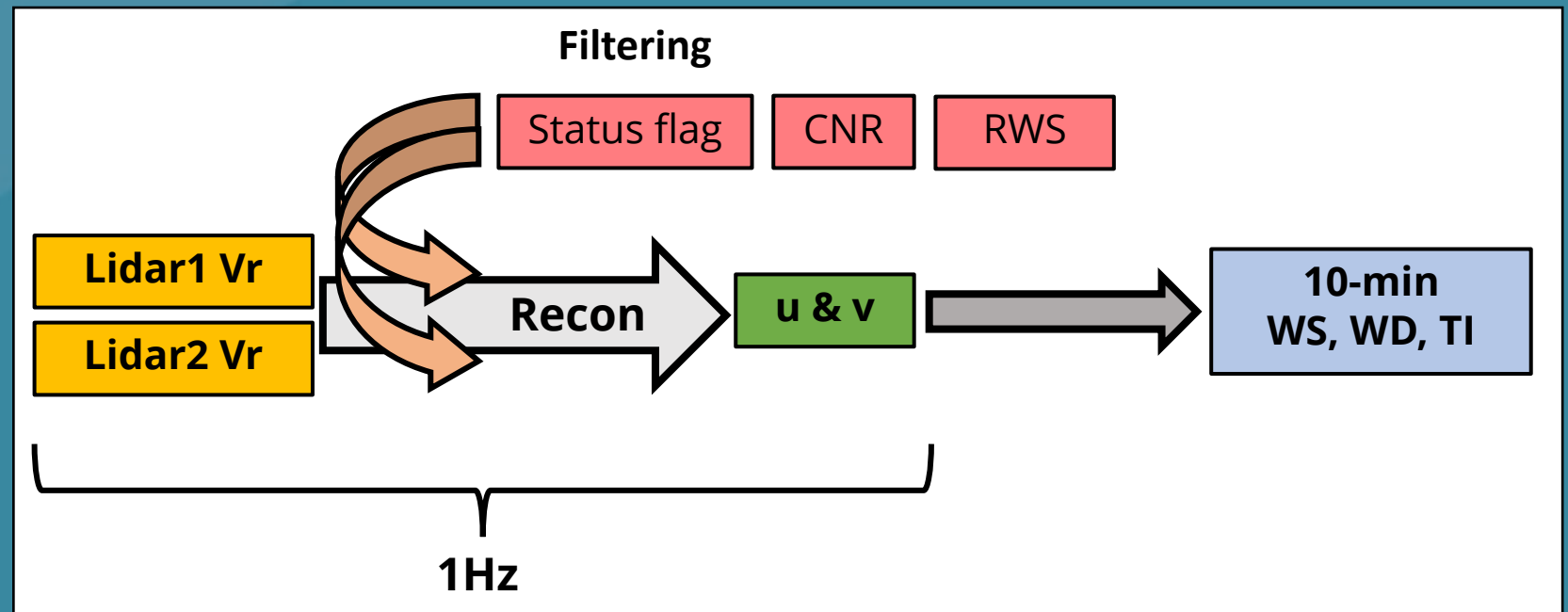
From Janneby to West of Orkney

- **Janneby** test conducted prior to lidar deployment in Orkney for site condition assessment for 2GW offshore wind farm development
- Use Janneby to examine 3-aspects of dual-mode capability:
 - 1) Measurement performance (of TI) and sensitivity
 - 2) Acquisition at long range
 - 3) Temporal equivalence for multi-height scans
- Use lessons-learned to feed into the development of recommended practices

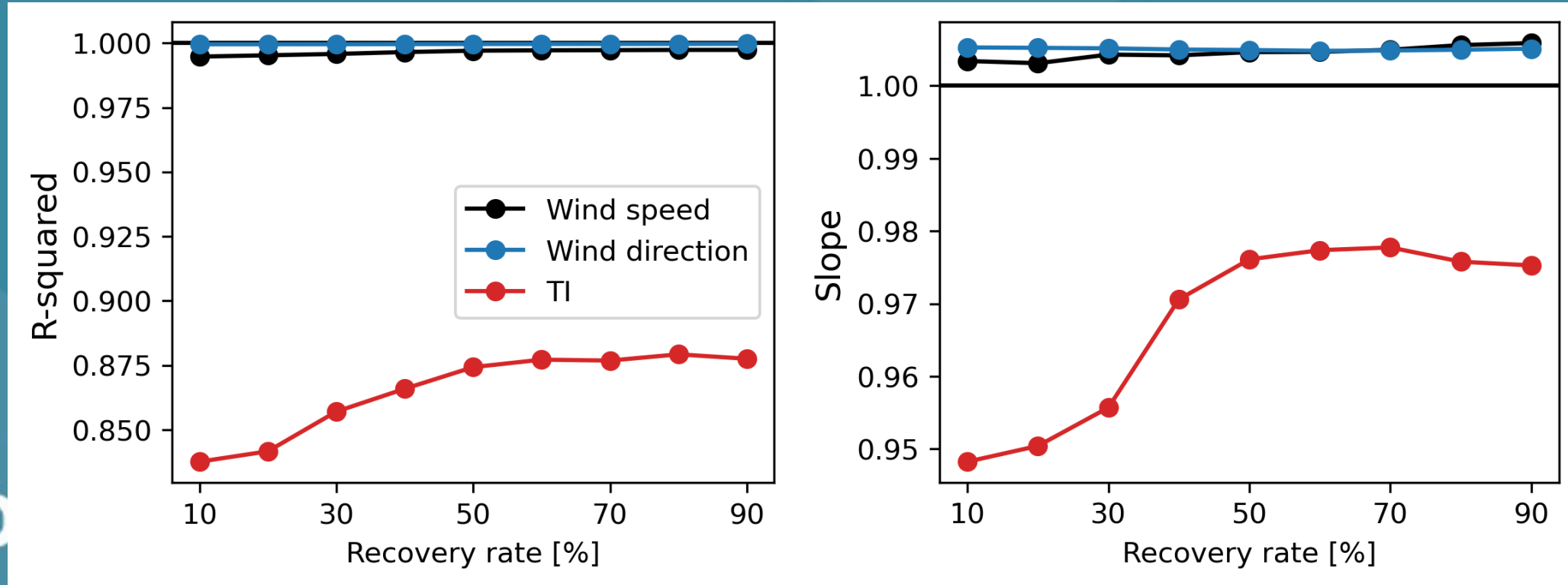


Wind reconstruction for dual mode

1. Line of site 1Hz radial velocities (V_r) filtered for
 - CNR (-29dB to -7dB)
 - Radial velocities within 10-min mean ± 3 s.dev
2. u and v wind components reconstructed to derive wind speed and direction
3. Data averaged to 10-min

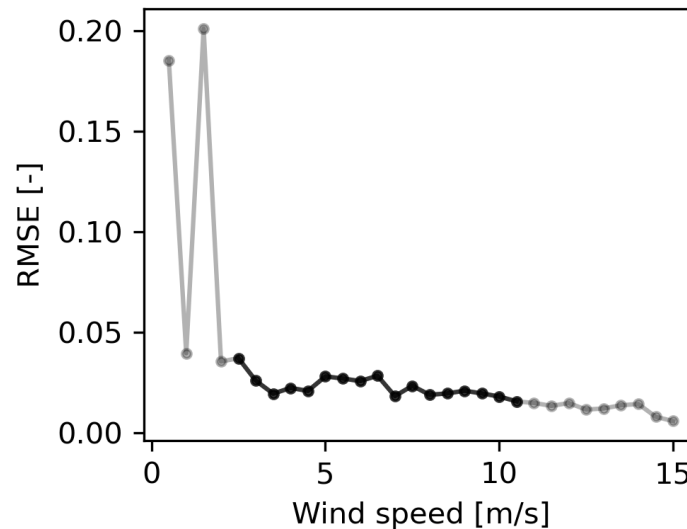
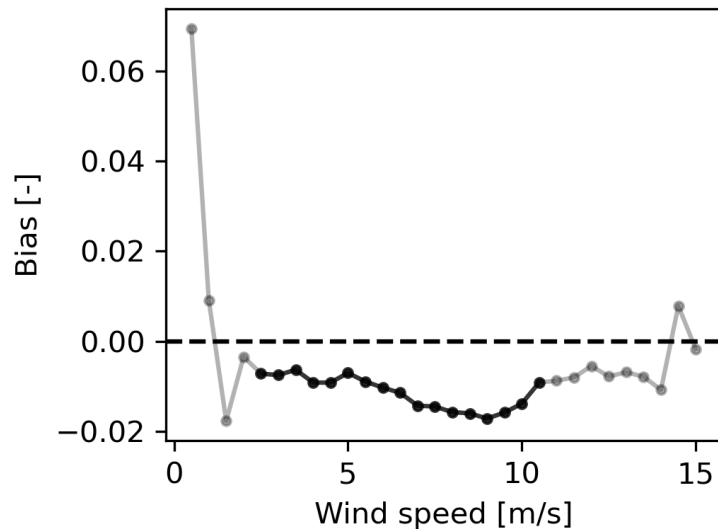
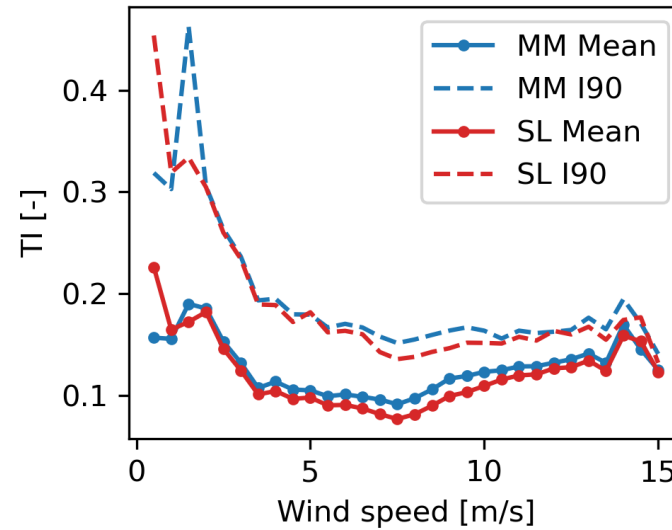
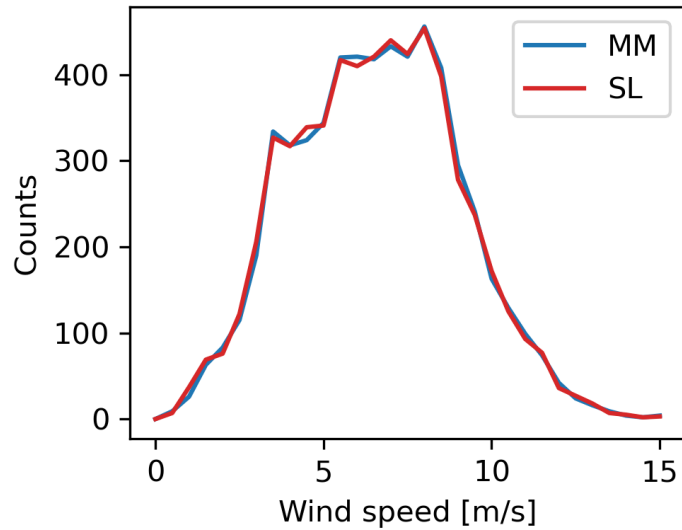


1. Baseline performance and sensitivity to availability



- Verification filtered by 1s reconstruction data availability exceedance (recovery rate)
- As low as 10% data recovery rate suitable for wind speed and direction
- TI more sensitive to recovery rate

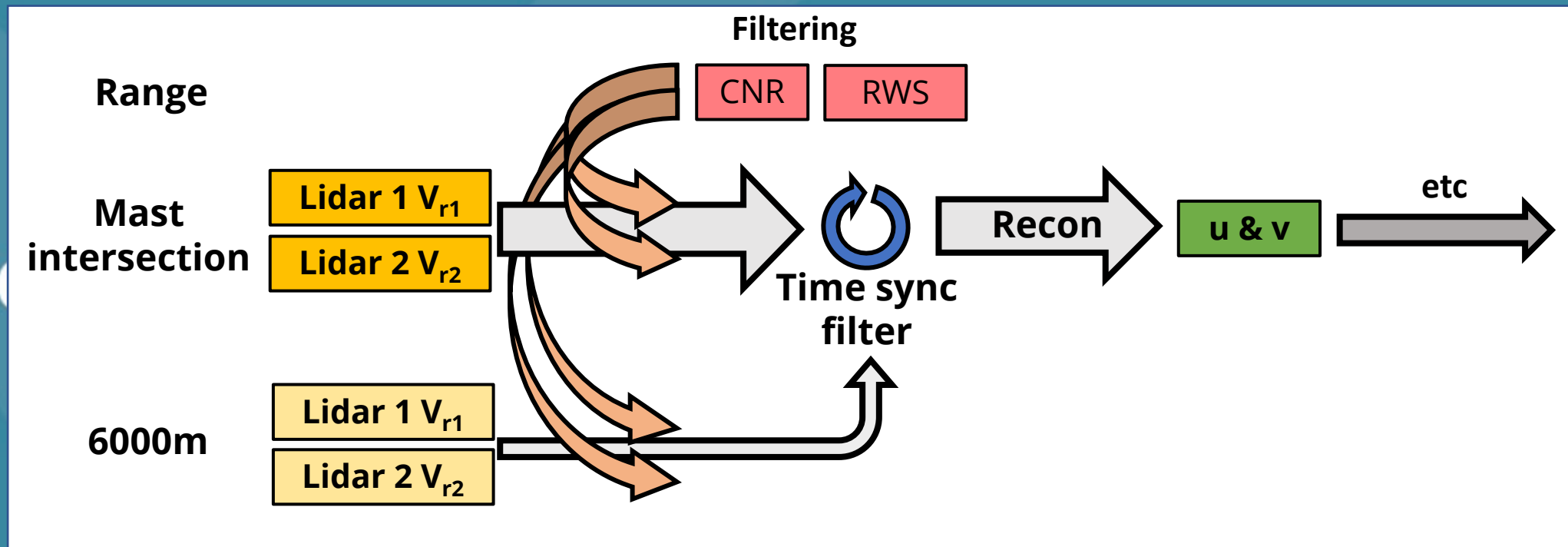
1. Turbulence Intensity



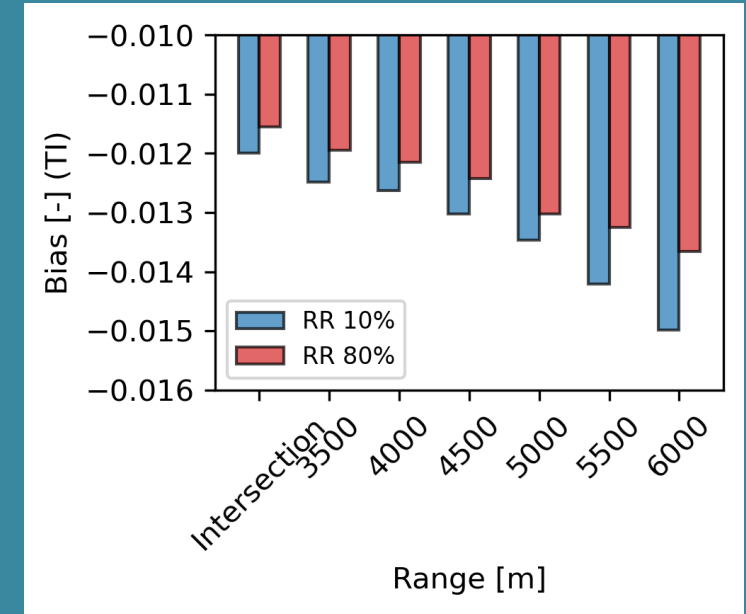
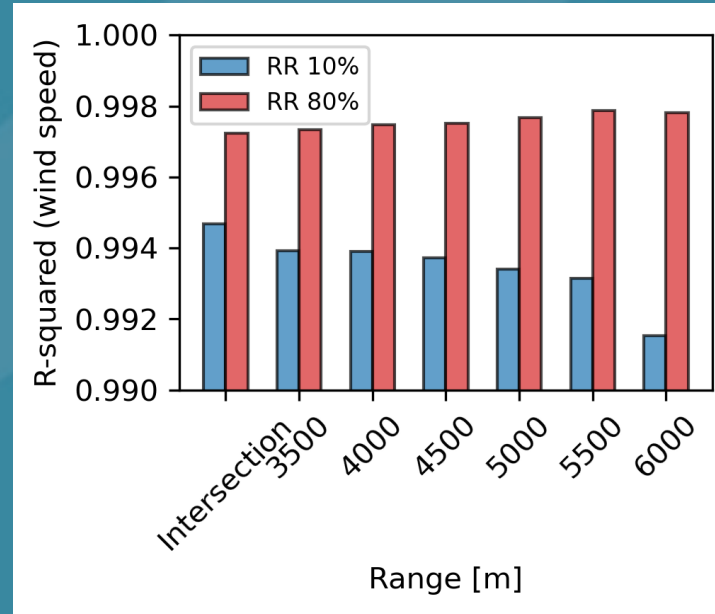
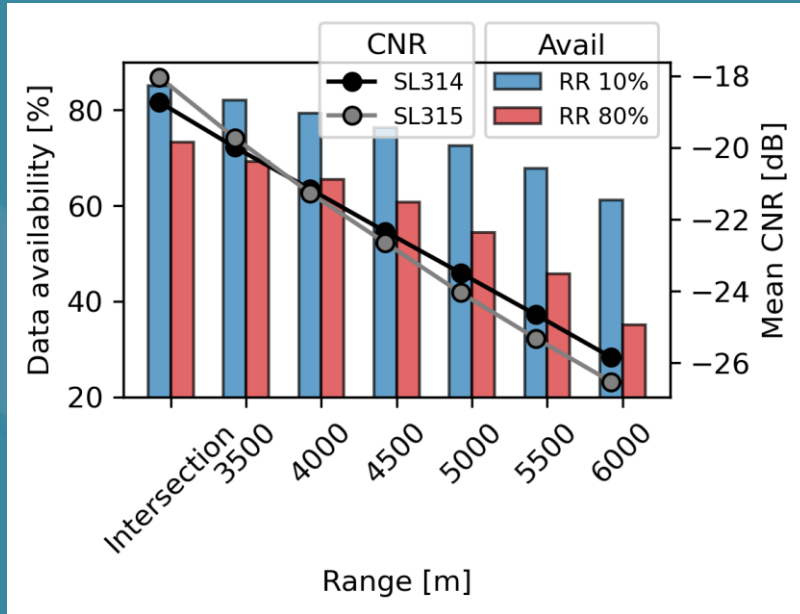
- 80% recovery rate
- Similar results for mean TI and representative TI (I90)
- Underestimation a constraint of probe length (100m)

2. What is the impact of range?

- For measurement campaigns, larger measurement ranges than the range tested may be desirable particularly offshore
- To examine range sensitivity, radial velocities at mast intersection are concurrently filtered based on filtering applied at longer ranges



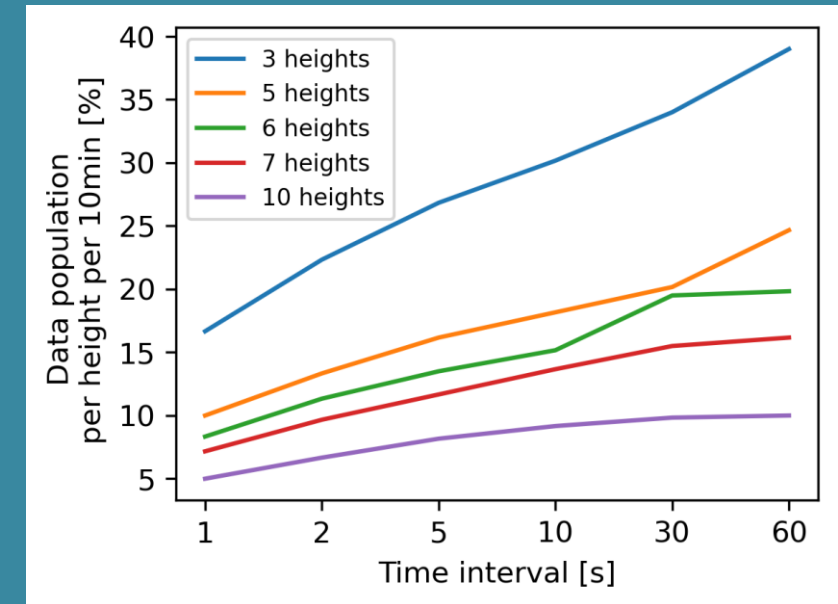
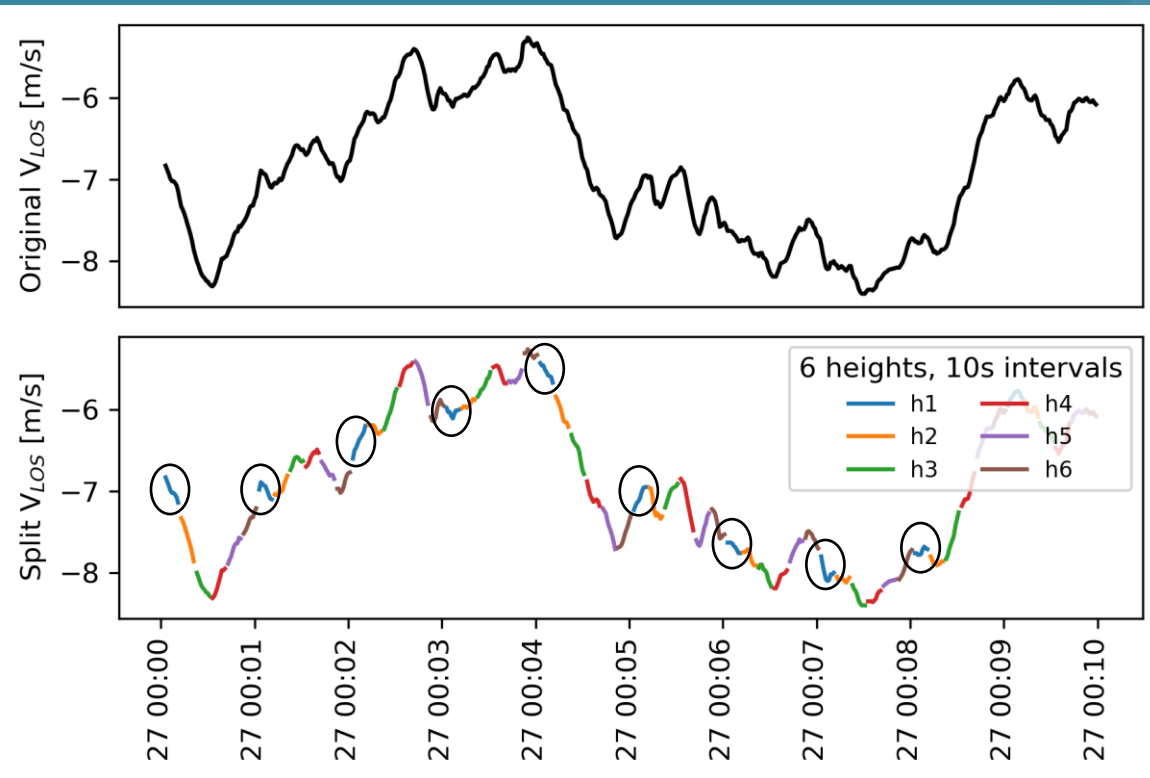
2. What is the impact of range?



- Main impact on 10-min wind data availability (84% at MM to 64% at 6km)
- Small impact on measurement accuracy

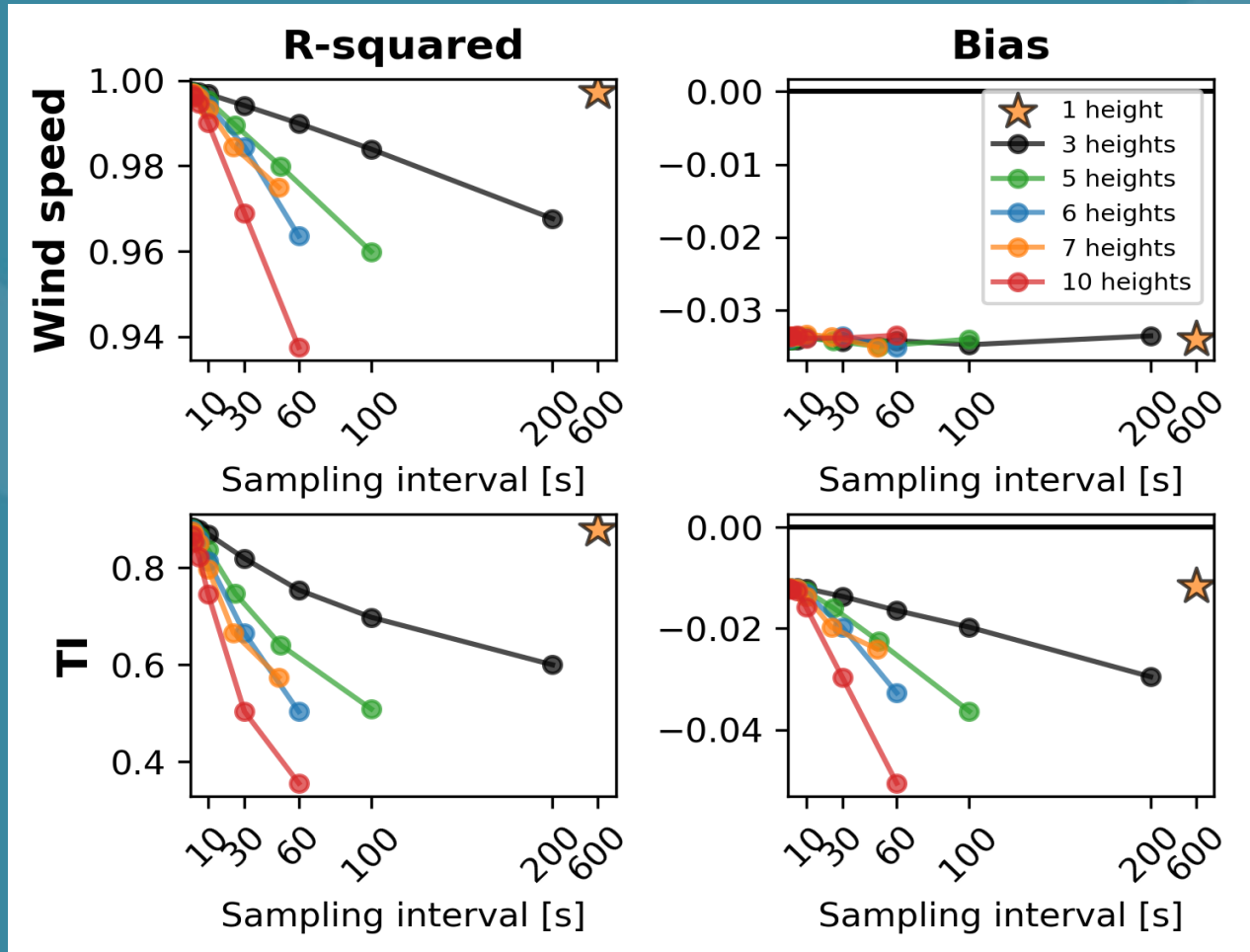
3. What is the potential impact of multi-height scanning on temporal equivalence?

- Apply splitting method to 1Hz data following Watanabe et al., (2021)
- Data subset by N 'heights', sequentially sampled using a specified time interval/dwell
- 1s switch time between heights incorporated to simulate data loss due to scan head movement
- Mast data not touched



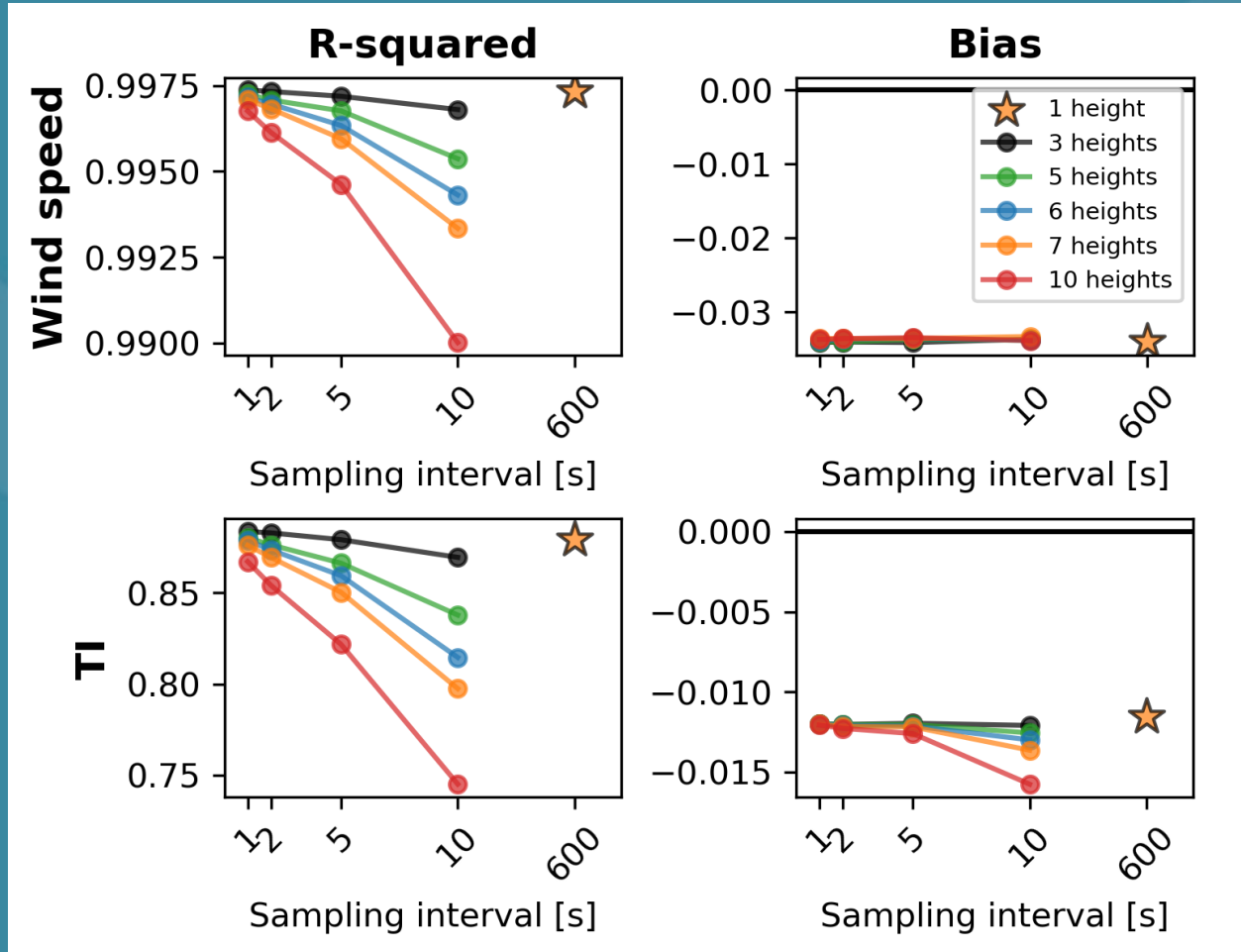
Watanabe, K., Takakuwa, S., Hemmi, C., Ishihara, T., A study of offshore wind assessment using dual-Doppler scanning lidars, *Journal of Wind Energy, JWEA*, Vol. 45, No.2, pp.40-48, 2021 (in Japanese).

3. Importance of sampling interval for multi-height scans



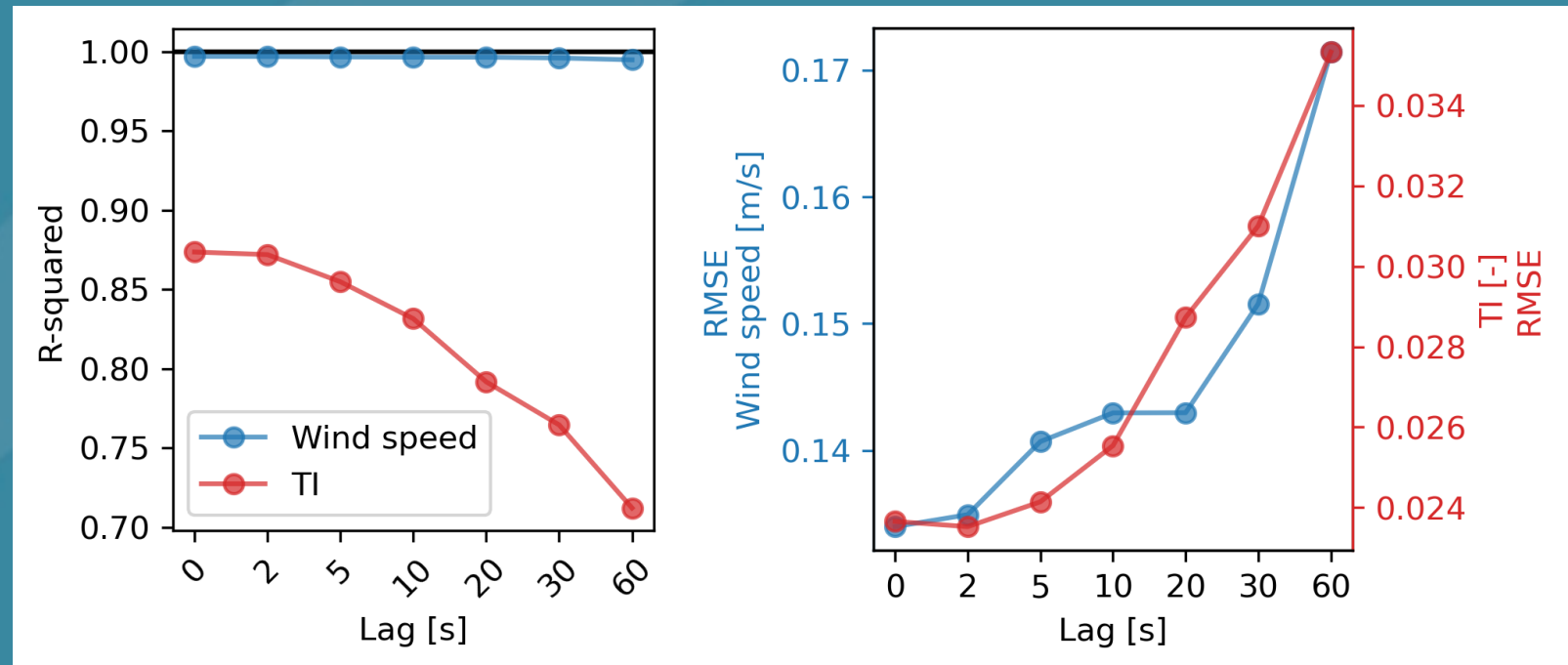
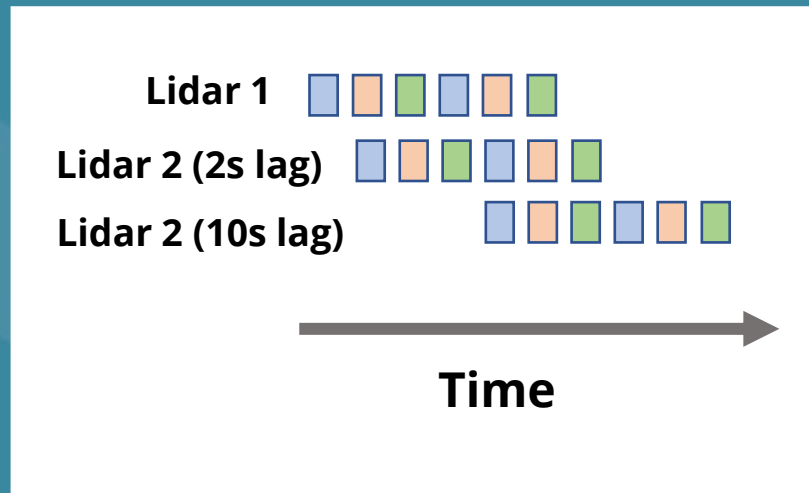
- Shown are average scores across 3, 5, 6, 7 and 10 heights per interval
- 10-min sampled more evenly by short intervals compared to long intervals
- Measurements with shorter intervals closer to cup equivalence
- Greatest impact on TI

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3. Tolerance of reconstruction to dual lidar synchronisation during multi-height scanning



- Mimic sampling sequence of a 6 height scan with 2s intervals per height
- Temporal lag applied to 1Hz measurements from second lidar
- Dual lidar synchronisation needs to be kept within ~2s for TI

Summary

Dual scanning lidar measurements at Janneby have been used to examine:

1. Overall wind measurement performance

- Wind speed and direction are cup equivalent and high accuracy can be achieved even with relatively low 10-min data availabilities (>10%)
- TI is underestimated, highlighting setup limitation of 100m probe length

2. Impact of long-range:

- Reduced data availability, small effect on KPIs

3. Measurement equivalence for a multi-height scan setup:

- short sampling intervals (<5s) important to optimise equivalence
- dual synchronisation needs to be kept within 2s for TI



Thanks for listening

- Thanks also to the Offshore Wind Power Ltd (OWPL) consortium and West of Orkney Wind Farm development

