West of Orkney Windfarm

# Comparison of classical and drone based hard-target methodologies applied to scanning lidar for offshore wind

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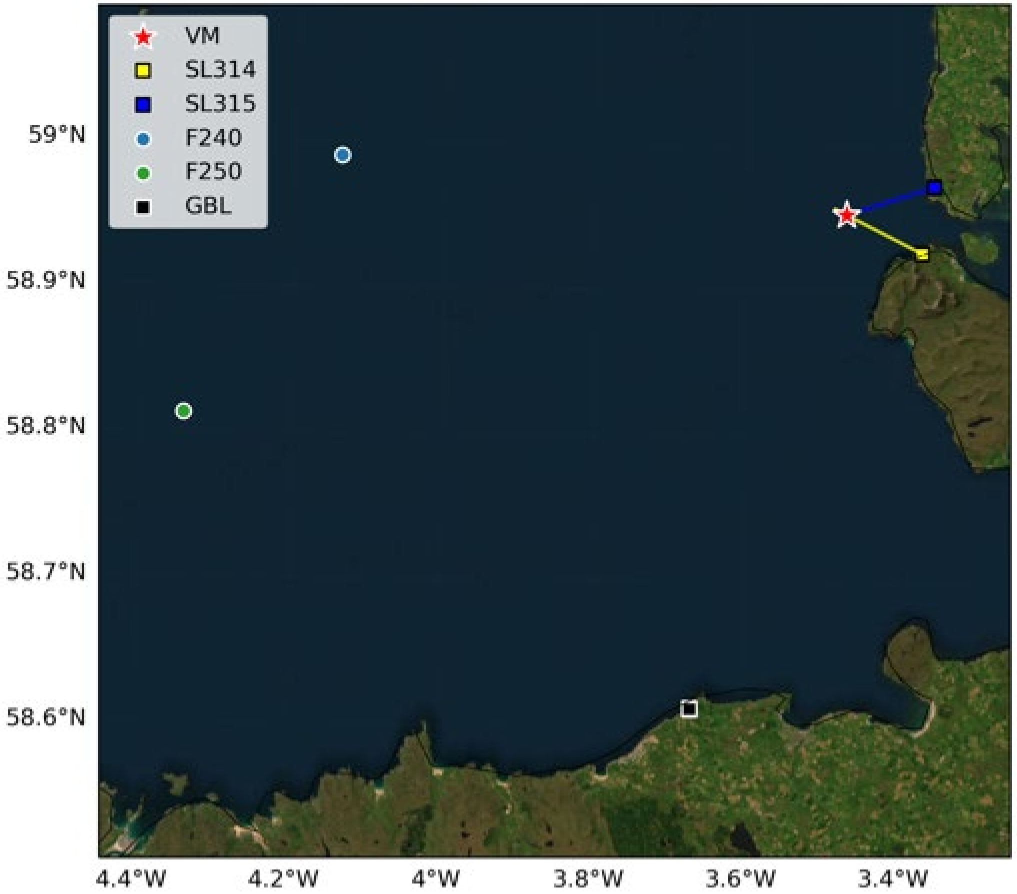
1. Oldbaum
2. IWES Fraunhofer
3. K2Management
4. TotalEnergies

With thanks to OWPL and West of Orkney Windfarm

# 1. Motivation- Campaign Overview




- Due to the location, OWPL have taken a responsible, comprehensive approach to data
  - 4 measurement locations
  - 2 onsite – positioned SW and NE in zone
  - GBL reference onshore – gradient
  - Dual-Scanning on Orkney – offshore TI and gradient @7km

# 1. Motivation

- Scanning Lidar extremely powerful measurement tool
- Can answer multiple use-cases
- In this case we are particularly interested in Turbulence
- Accurate Turbulence Intensity assessment is a major factor when looking to reduce LCOE

# 1. Motivation

Standard Approach:

I. Install system
II. Level and check system output
III. Identify hard targets....

Why?

To ensure positional accuracy or you know where the lidar is pointing

# 1. Motivation

Standard Approach:

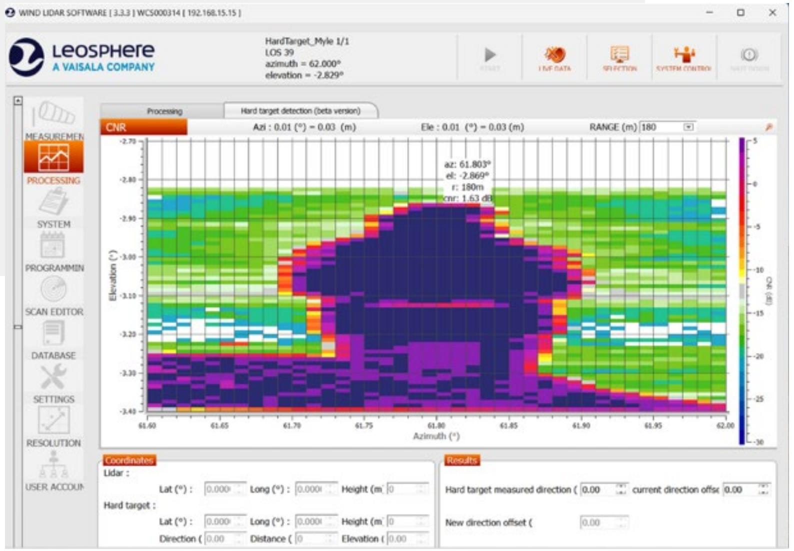
I. Install system
II. Level and check system output
III. Identify hard targets….

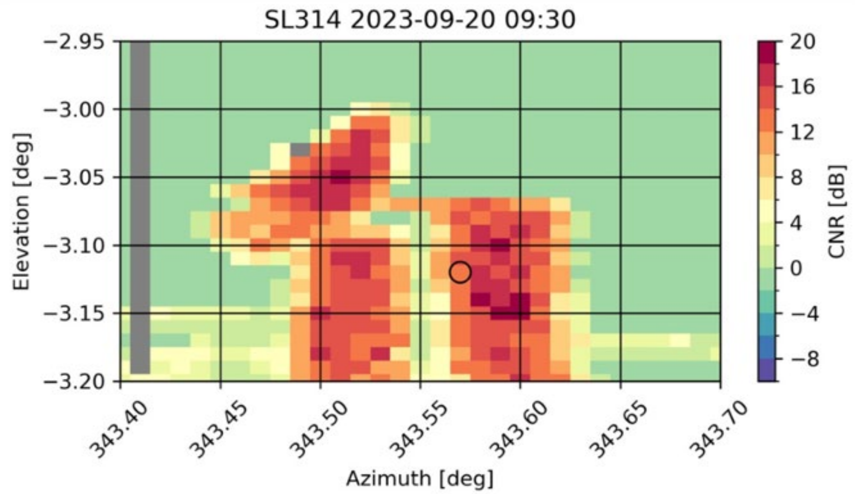
Why?

To ensure positional accuracy of the measurement - you know where the lidar is pointing

# 1. Motivation - Setup

1. Establish Hard targets on site
2. Acquire elevation and azimuth angle offsets using traditional methods (theodolite & CNR mapping)
3. Establish difference between reference measurement and SL readings
4. Programme in scan pattern with calculated offsets
5. Periodically (daily automated)check for alignment drift

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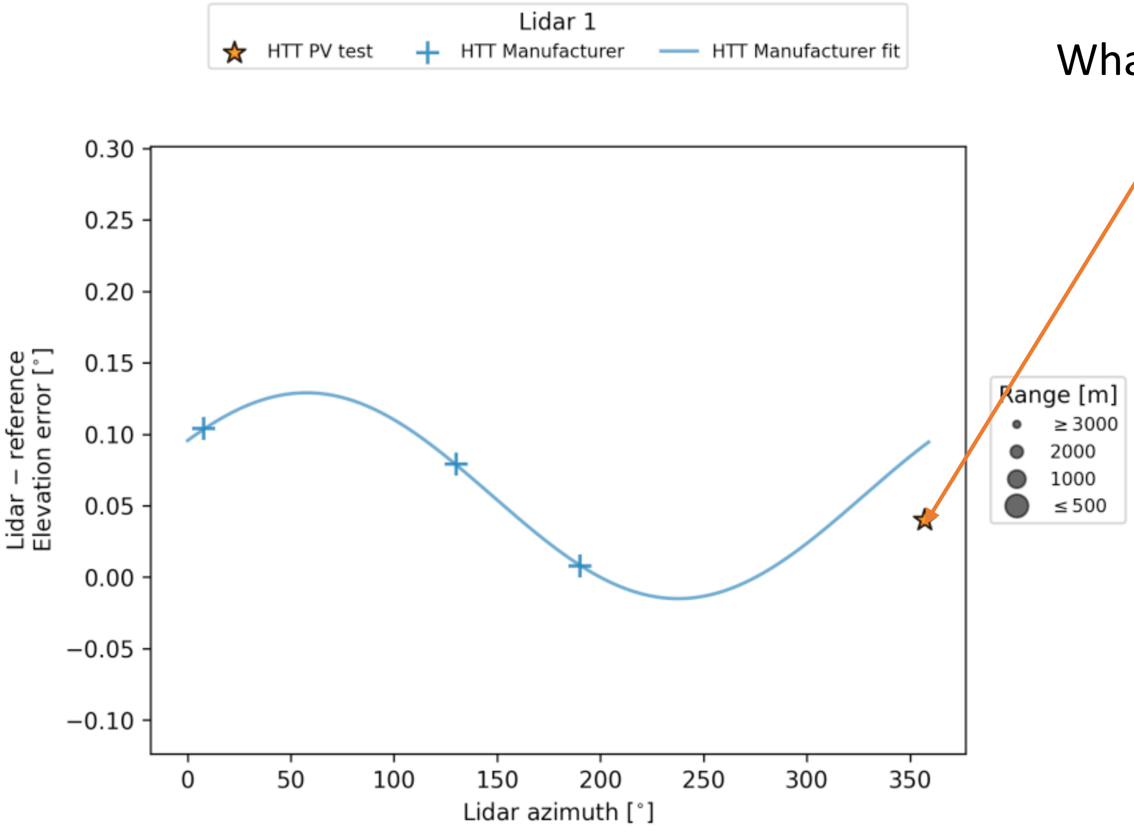
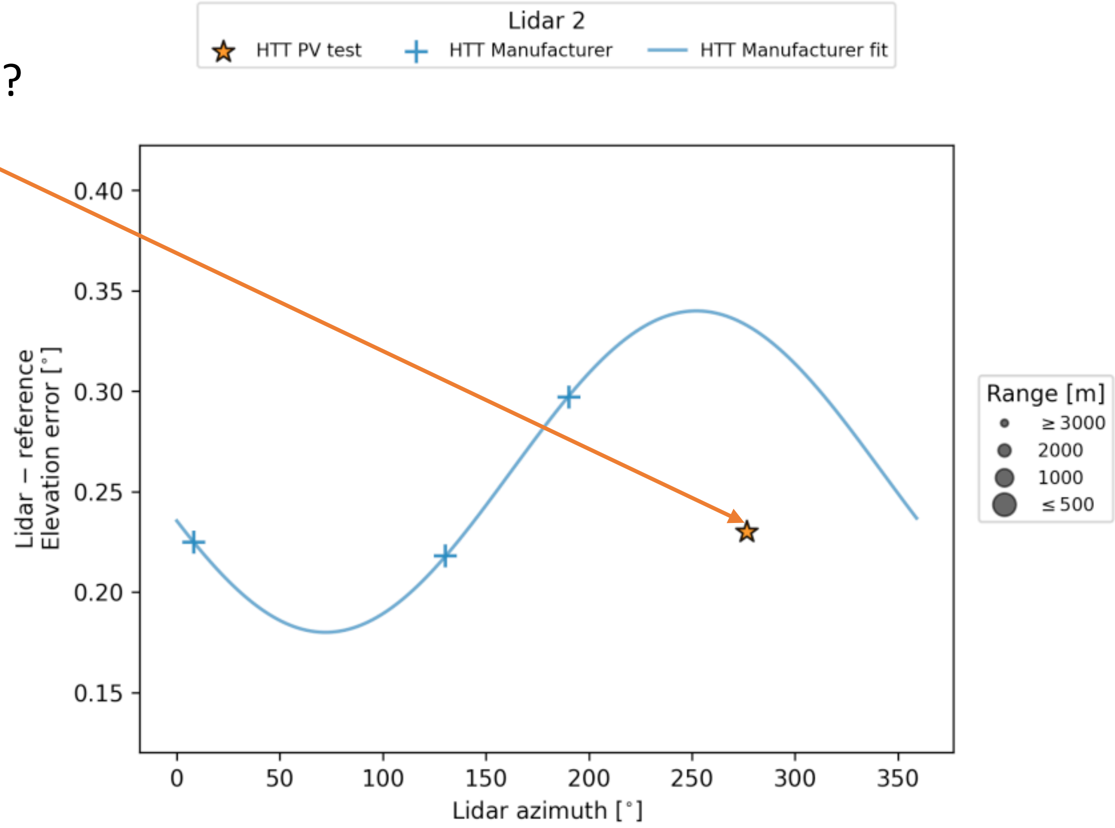
# 1. Motivation - Setup

## Then we got this…

What is that?

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# 2 Method - Setup

1. Systematic comparison of classical method – manufacturer & install
2. Based on GLOBE and NEDO documentation – Investigate Drone based methods
3. Repeat method in Germany on a different system using a similar Drone setup
4. Work out what's going on…….

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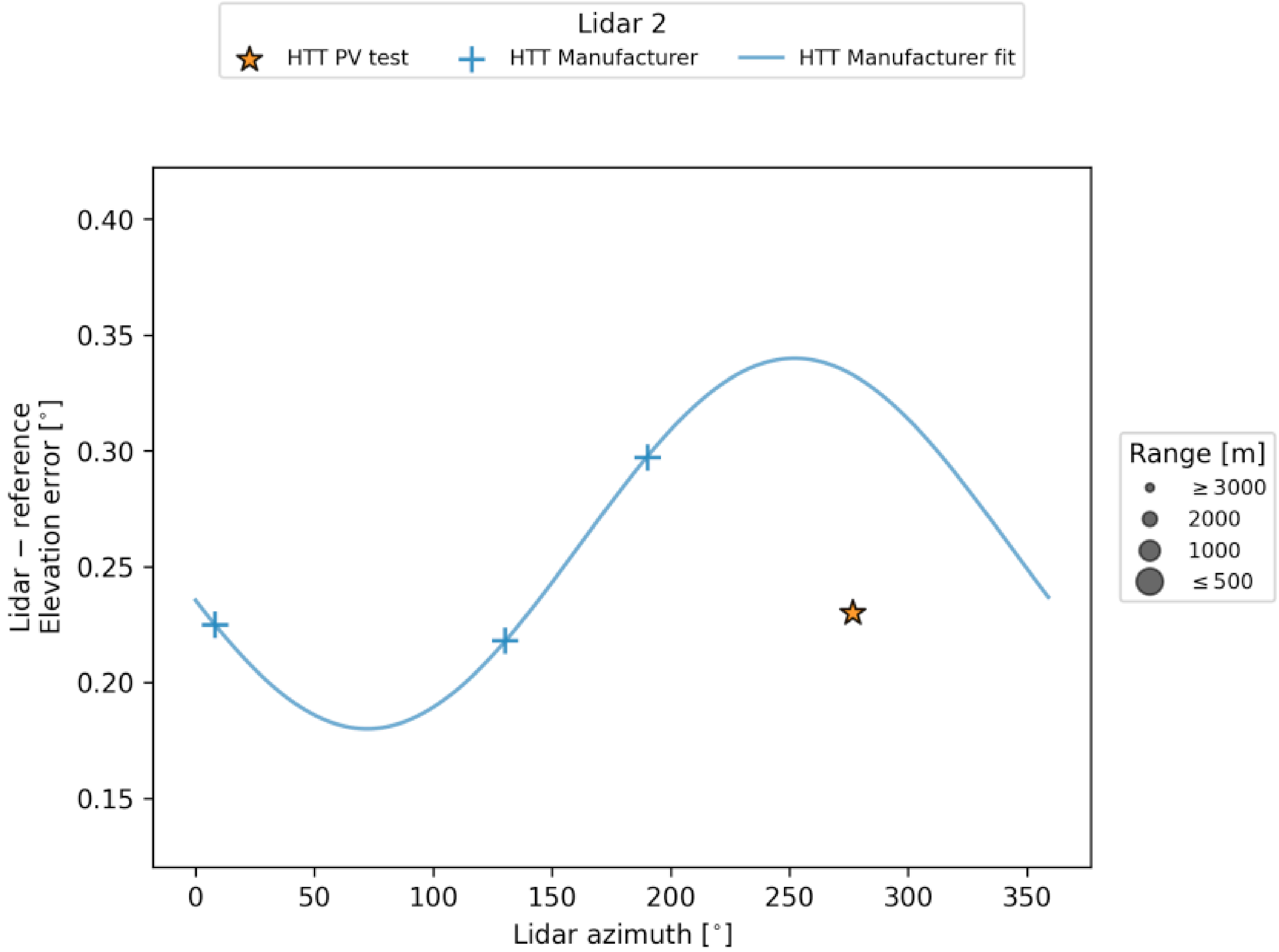
# 2. Method - Classical

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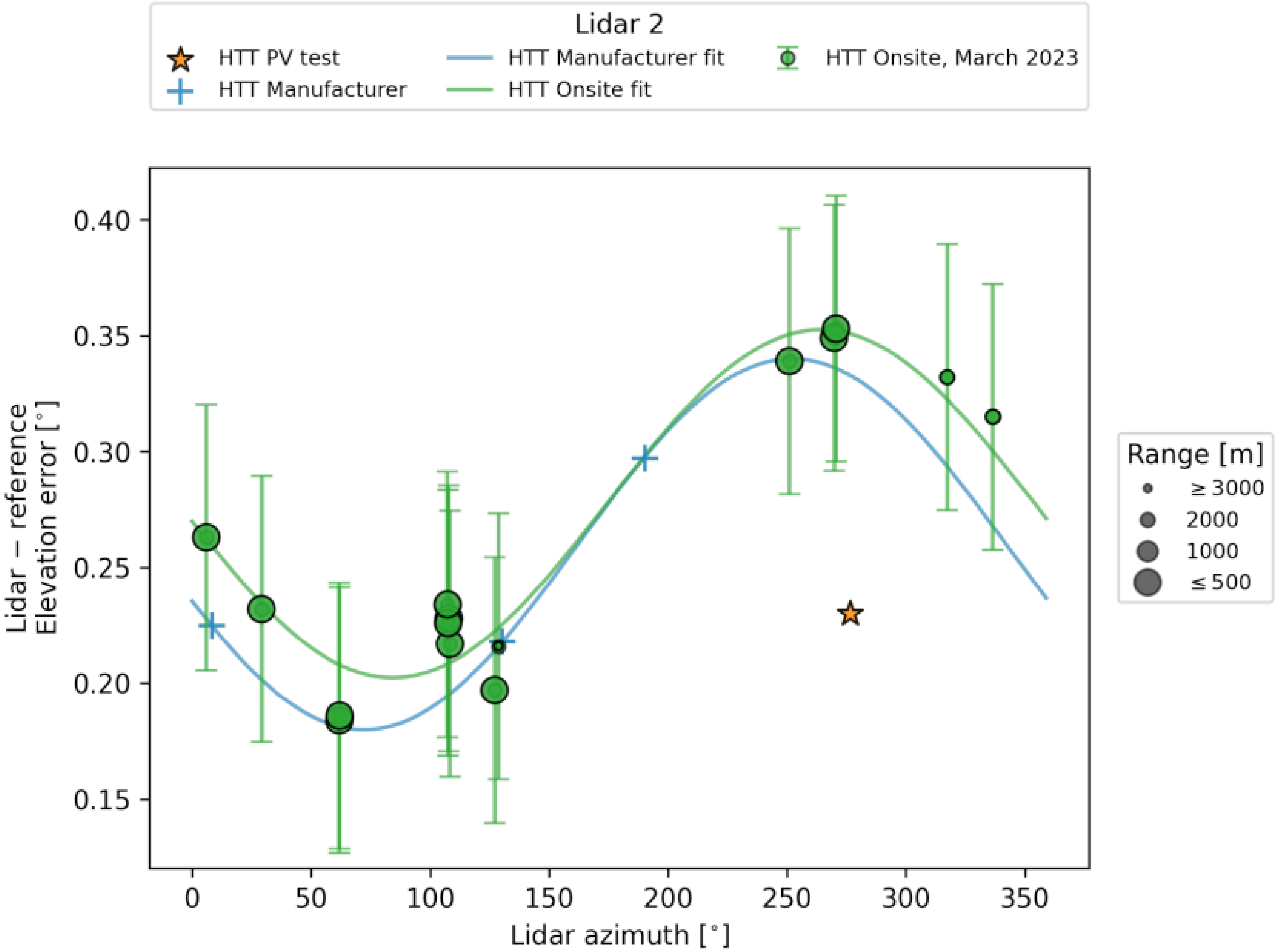
# 2. Method - Classical

OEM Blue
Install Green

Error estimate included

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# 2. Method - Classical

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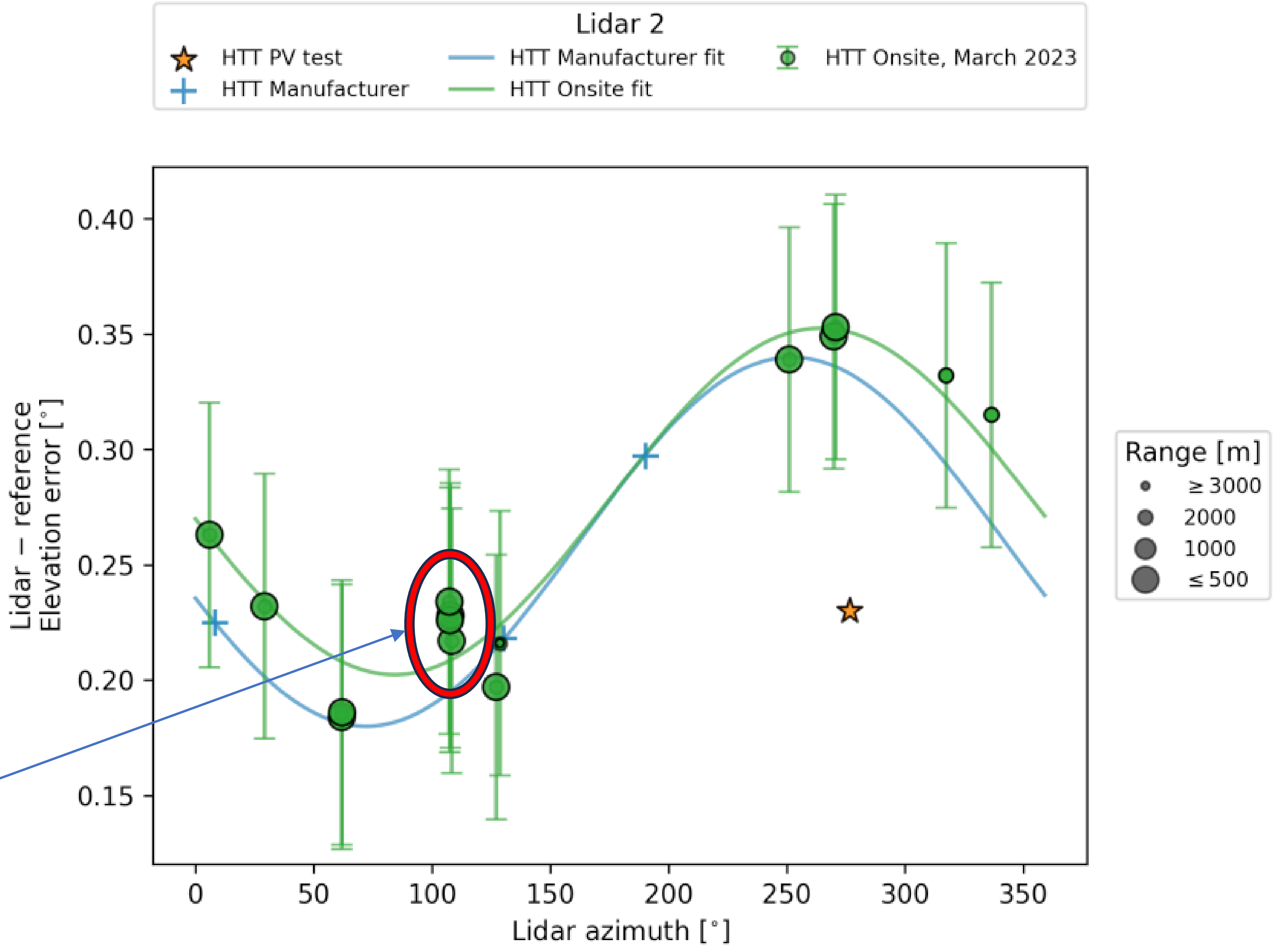


When targets are too close

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# 2. Method Uncertainty process

| Source | Uncertainty | Definition | Value |
|---|---|---|---|
| Lidar | $\delta_{SL-pos}$ | scan head movement (pitch/roll) | $\pm 0.02°$ |
| | $\delta_{SL-ext}$ | Drone extent from CNR mapping | $\pm 0.05°$ |
| Theo | $\delta_{Ref-acc}$ | Instrument accuracy | $\pm 0.0014°$ |
| | $\delta_{Ref-pos}$ | Uncertainty due to scan head – theodolite height difference | $\pm 0.01°$ |
| Curve fit | $\delta_{CF}$ | Uncertainty due to curve fit on points | |

Total uncertainty:

$$\delta = \sqrt{\delta_{SL-pos}^2 + \delta_{Ref-acc}^2 + \delta_{Ref-pos}^2 + \delta_{CF}^2}$$

$\delta = \pm 0.06°$ classical

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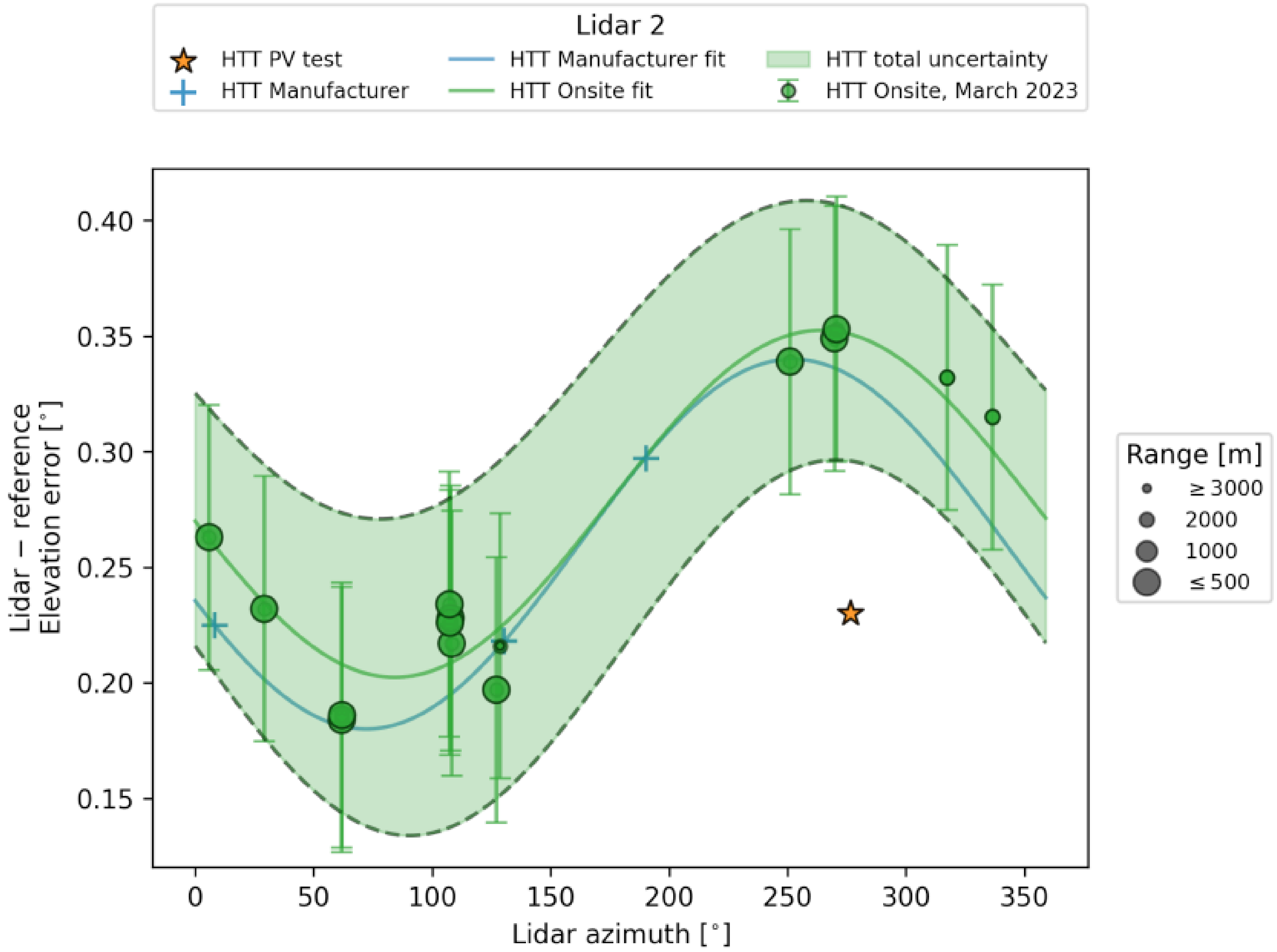
# 2. Method - Classical

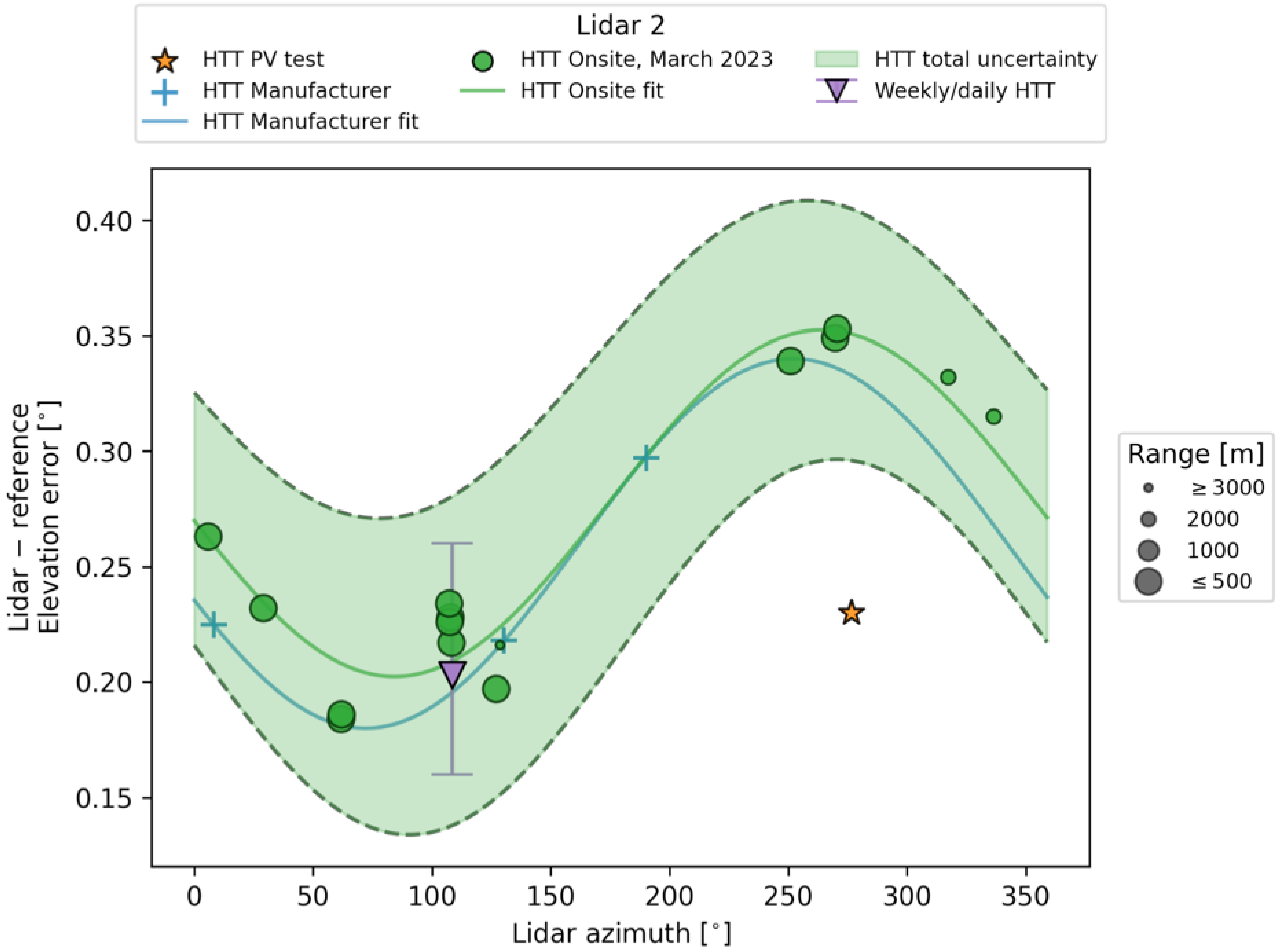
OEM Blue
Install Green

Blue and green
Reasonably close



# 2. Method – Classical – Daily check

Daily check gives confidence

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# So what about the drone
# Easy right?

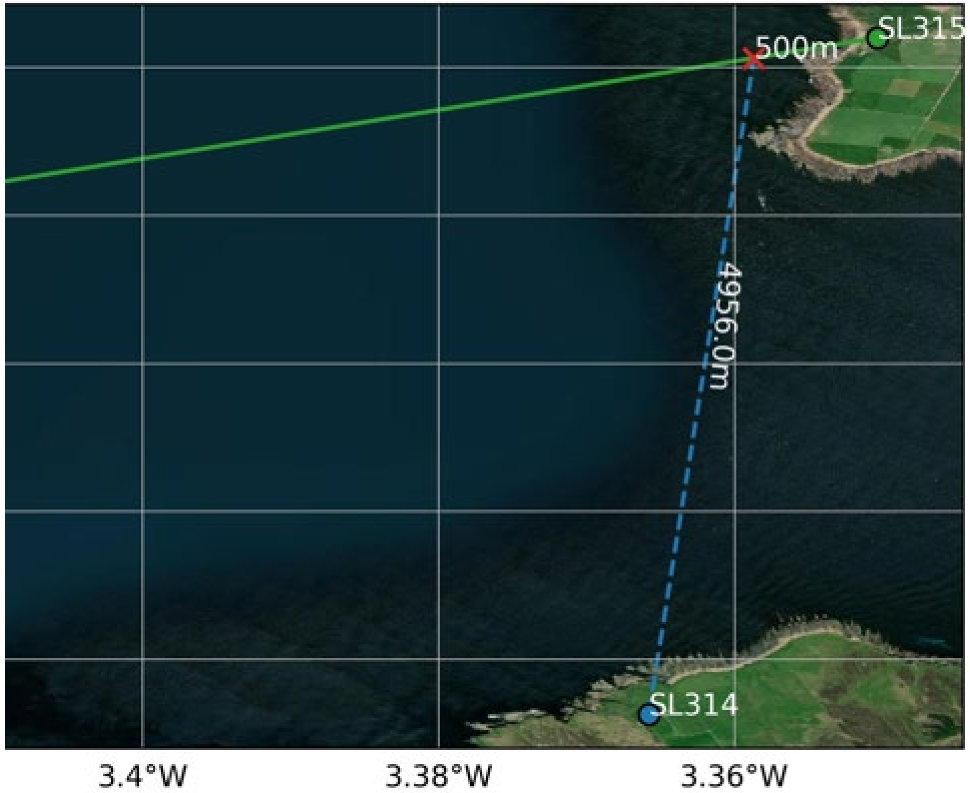
# Target acquisition method definition

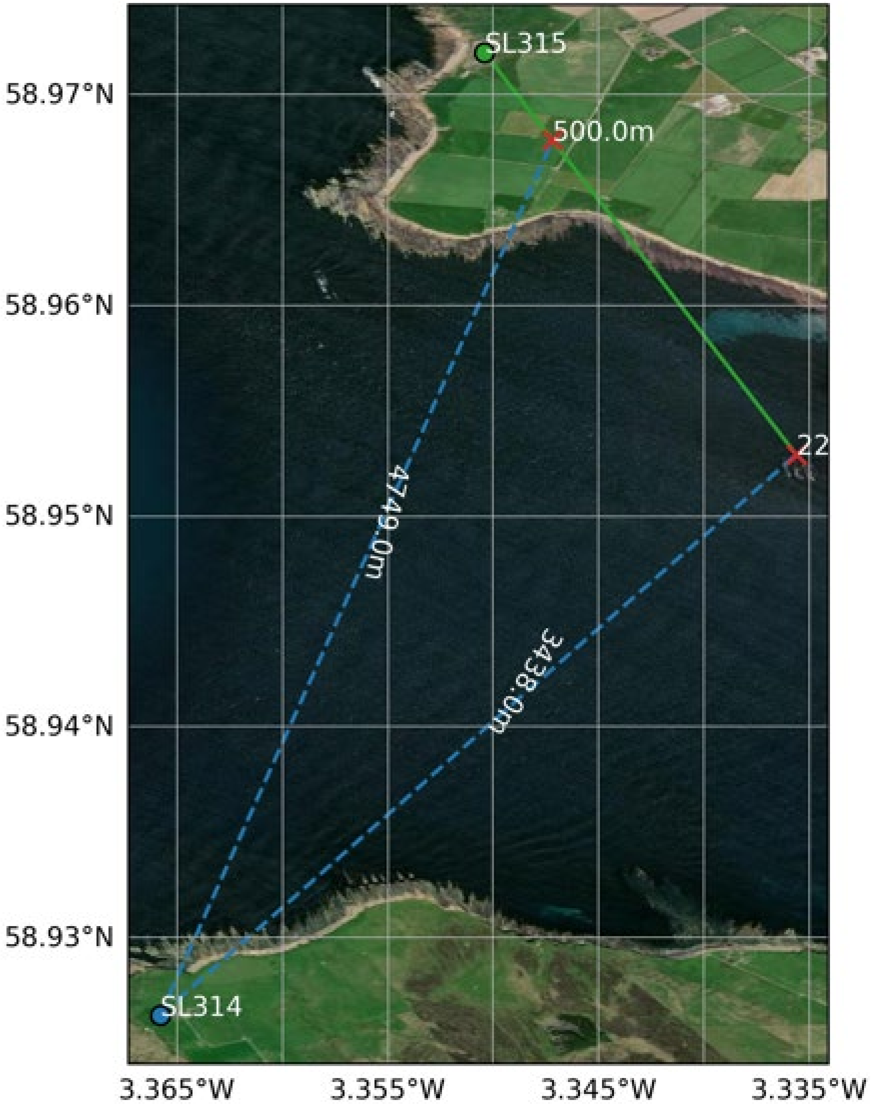
Two methods will be used and compared

1. **Method 1: Drone acquisition (DA):** The beam position co-ordinates and elevation will be calculated at specified ranges from SL1. The drone will be flown to that position and the SL CNR response checked. If there is no CNR spike, the Scanner will be moved till the drone is acquired. The GPS location and height of the drone will be recorded.
2. **Method 2: Beam acquisition of drone (BA):** The drone will be flown to a fixed position. The SL will be operated and the CNR map checked to acquire the drone. Once a position is defined the elevation and azimuth angle will be recorded.

# Test setup

- 2-day test in Orkney

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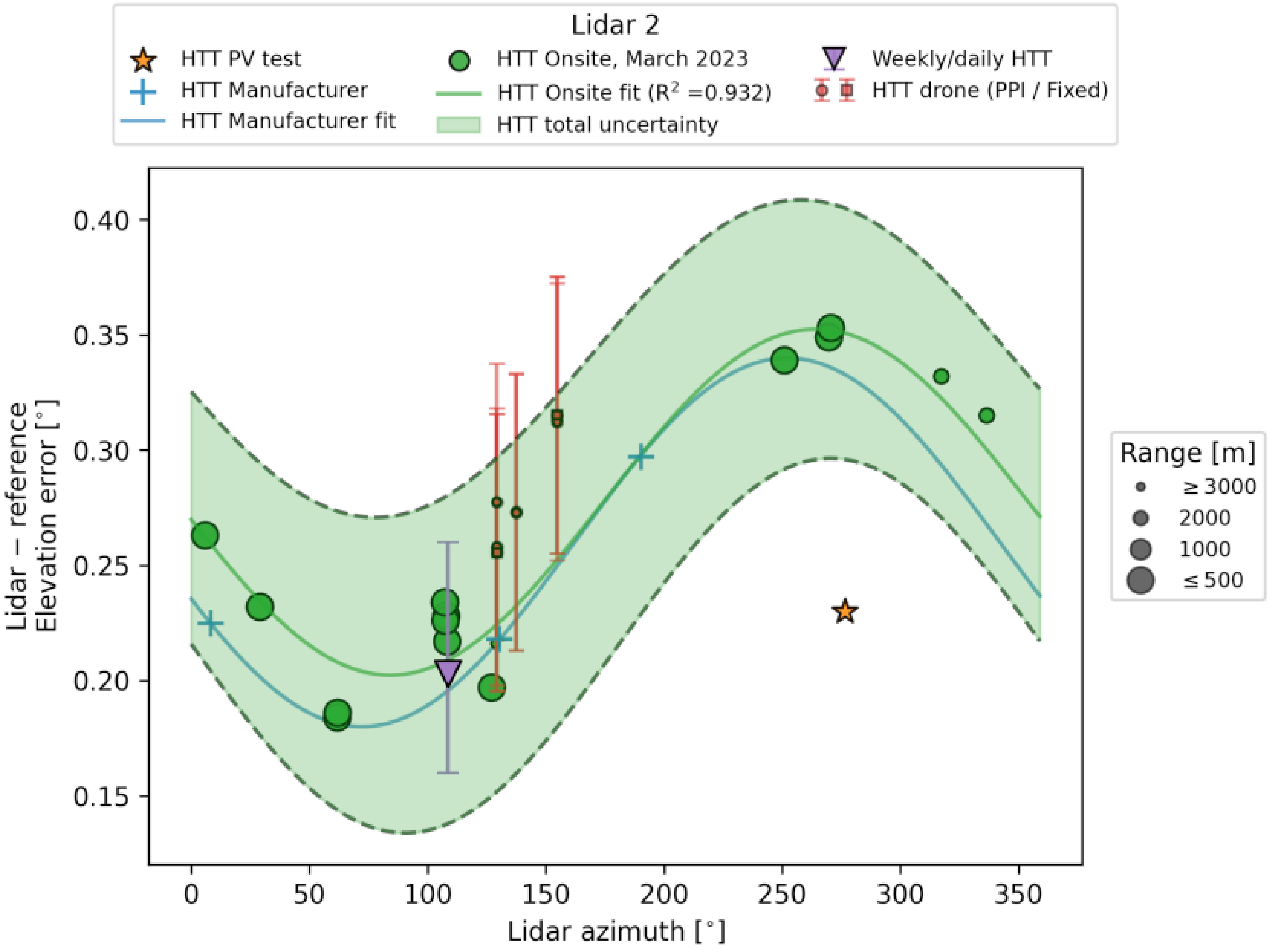
# 2. Method - Drone

Drone results
Clear offset
But encouraging

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# Uncertainties

| Source | Uncertainty | Definition | Value |
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| | $\delta_{Ref-pos}$ | Uncertainty due to scan head – theodolite height difference | $\pm 0.01°$ |
| Drone | $\delta_{HT-pos}$ | Drone positional uncertainty | $\pm 0.17°$? |
| Curve fit | $\delta_{CF}$ | Curve fit on points | |

Total uncertainty:

$$\delta = \sqrt{\delta_{SL-pos}^2 + \delta_{SL-ext}^2 + \delta_{Ref-acc}^2 + \delta_{Ref-pos}^2 + \delta_{HT-pos}^2 + \delta_{CF}^2}$$

$\underline{\boldsymbol{\delta = \pm 0.18°}}$

$\delta = \pm 0.06°$ without drone positional uncertainty

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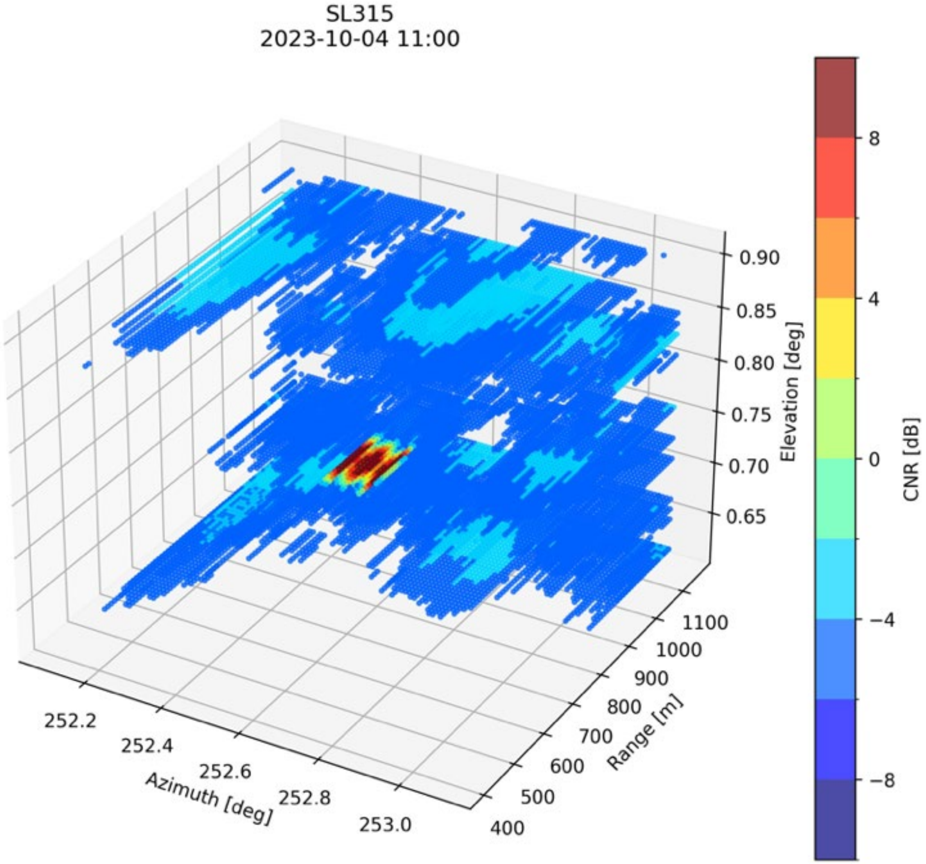
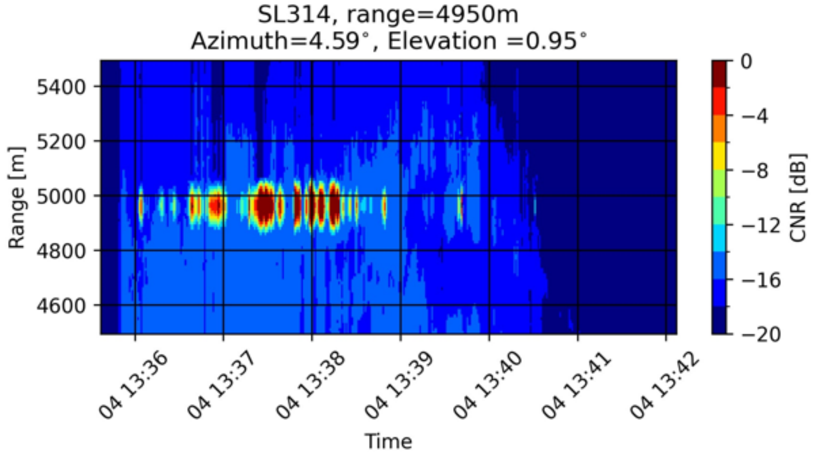
# Factors?

- Positional accuracy
- Positional stability
- Weather conditions
- Pitch and roll factors
- Pixel picking

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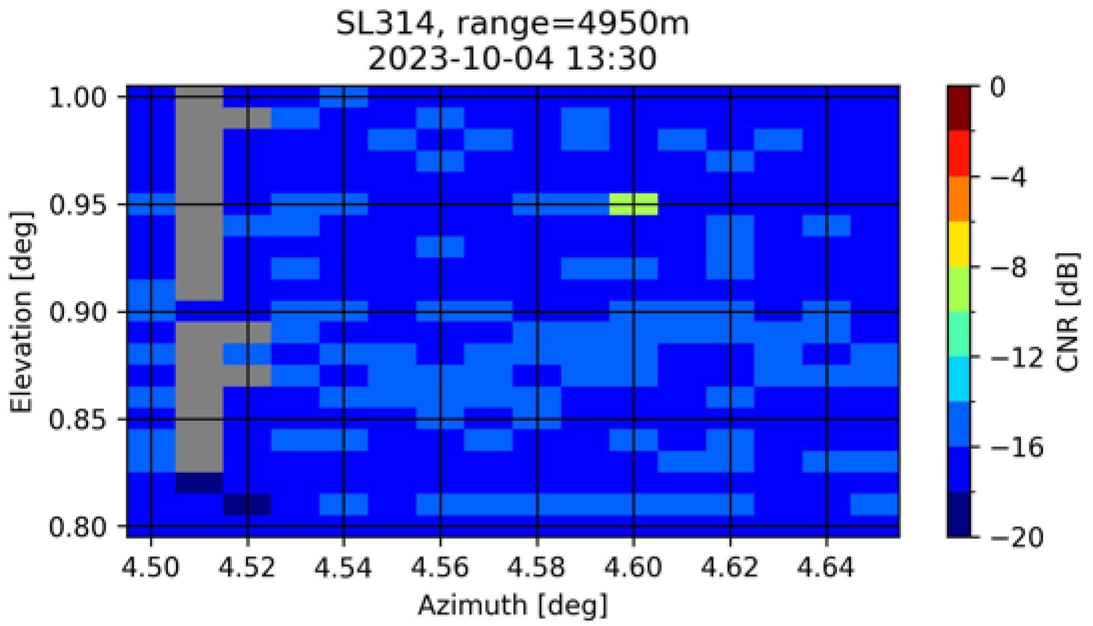
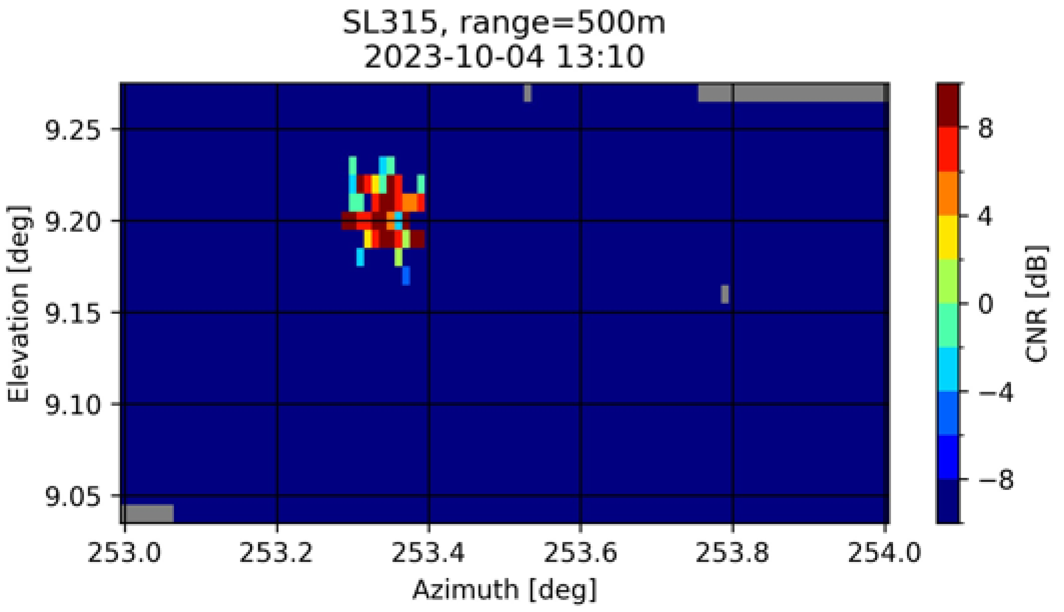
# Pixel picking example

At longer range – resolution means location is clear




At closer range – harder to define drone centre

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# Mean while in Germany

**Method 1: Find the lidar beam (fixed) with the drone**

was not feasible within flight time constraint:

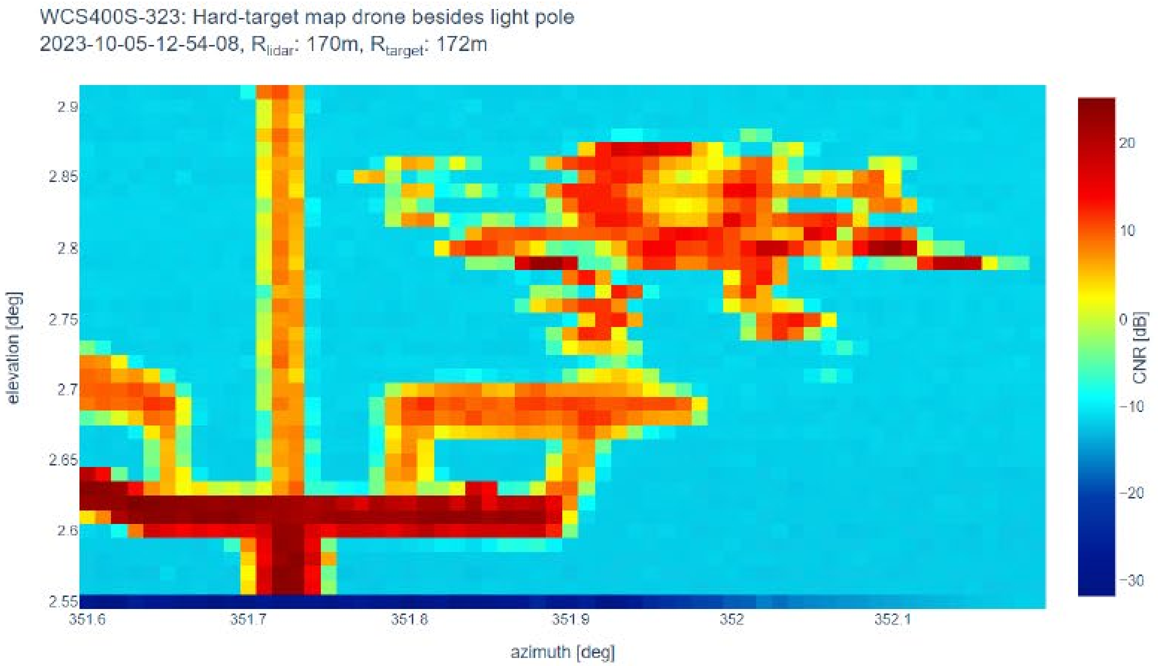
- passing time of the drone at the lidar beam was too short so that the lidar software GUI does not even have time to update. (updated only every ~1s)
- size of a drone is relative small compared to the lidar beam with normal flight speed
- drone flight speed has to be pretty slow to ensure detection
- drone hovering position stability problem (worsen when the wind speed is higher)

**Method 2: Find the drone (fixed) with the scanning lidar**

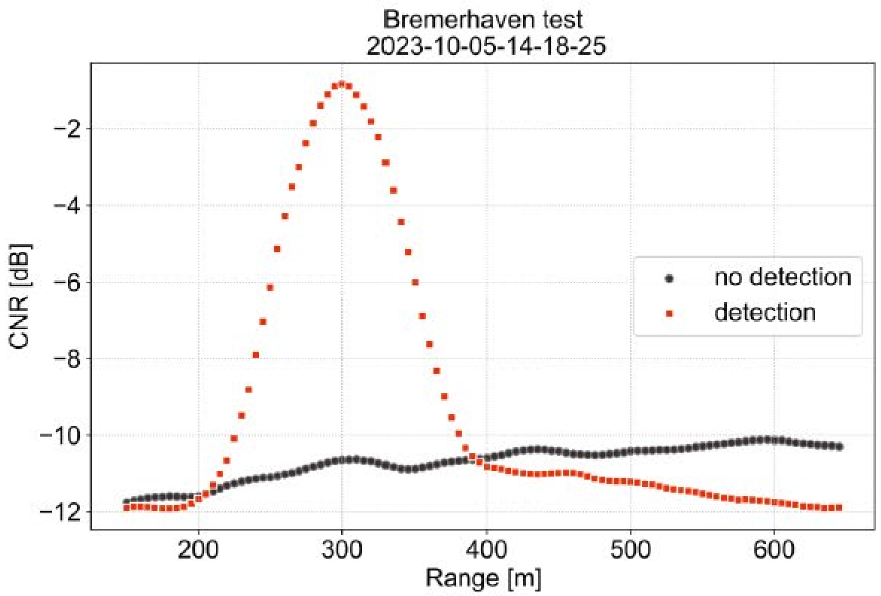
- Found the drone at a close distance (~170m)
- Detect the drone after switching to fixed-beam scenario
- extrapolate to 300 m and 600 m

# Method 2 : Results - Germany

- The drone was found




- Extend to 300m and the drone was detected (step7 in method 2)

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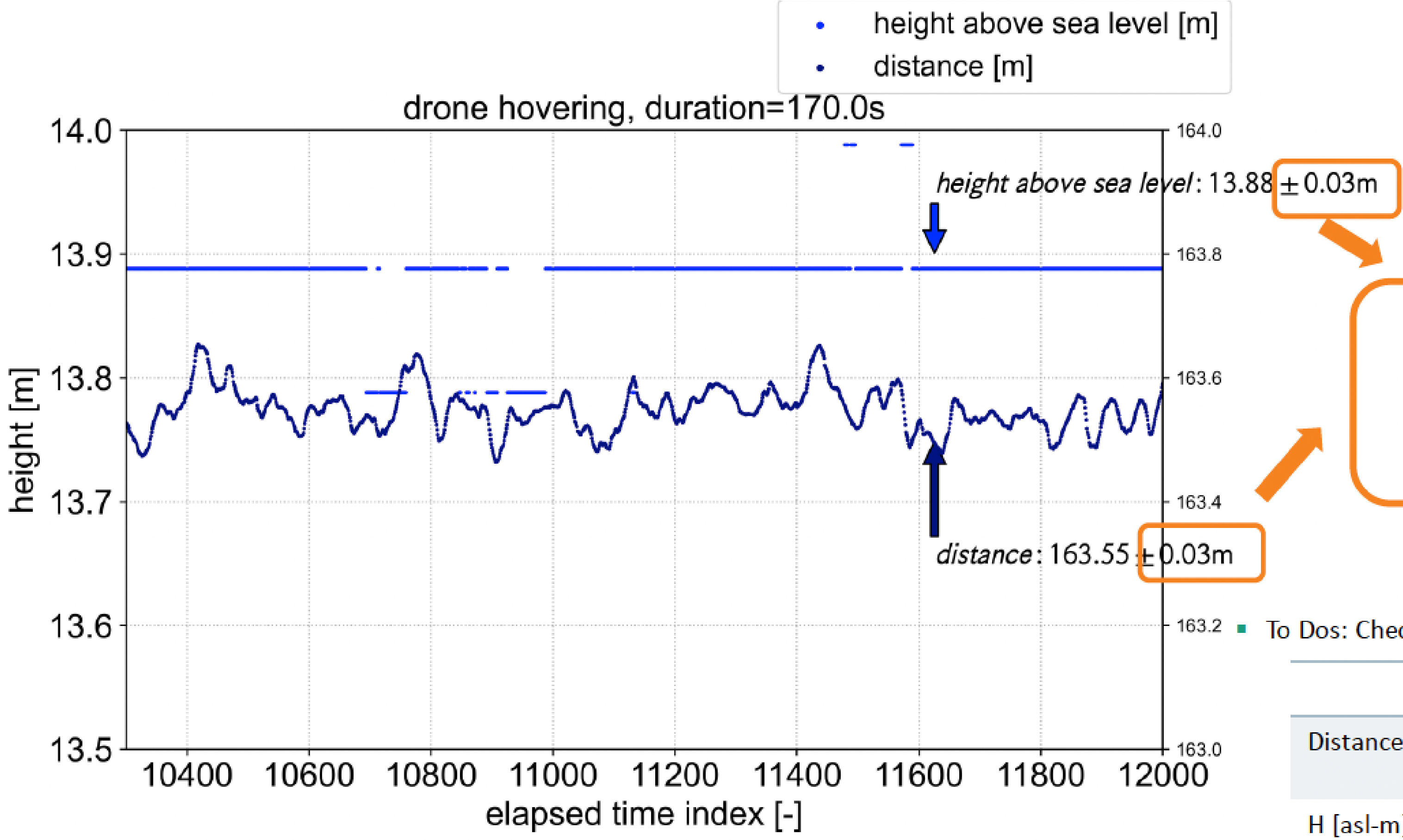
# Method 2: Results - Germany




low movement ($\sigma_{std}$=3cm) during drone hovering in height and total distance when connected to DRTK station

- To Dos: Check if the DRTK positions match with total station

| | mean | std | max | min |
|---|---|---|---|---|
| Distance [m] | 163.55 | 0.03 | 163.65 | 163.46 |
| H [asl-m] | 13.88 | 0.03 | 13.99 | 13.79 |

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# Procedure?

1. Establish short range hard target test to align reference frames between SL, Drone and Theodolite
    1. Datum and orientation
2. Use Drone acquisition method to establish offsets
3. At long range re-acquire drone
4. Calculate long range hard target using offsets and perform beam acquisition
5. Reset SL and set a beam position use beam acquisition to confirm

# Conclusions

- There is no clear advantage to drone HTT versus classical
- Weather conditions were very challenging
- Uncertainty is low for classical and needs improvement for Drone based to be equivalent
- A formal procedure is clearly needed
- Standard practice  shows repeatable results with low uncertainty

**<u>However</u>**

- Drones clearly show promise and are the only solution for far offshore application

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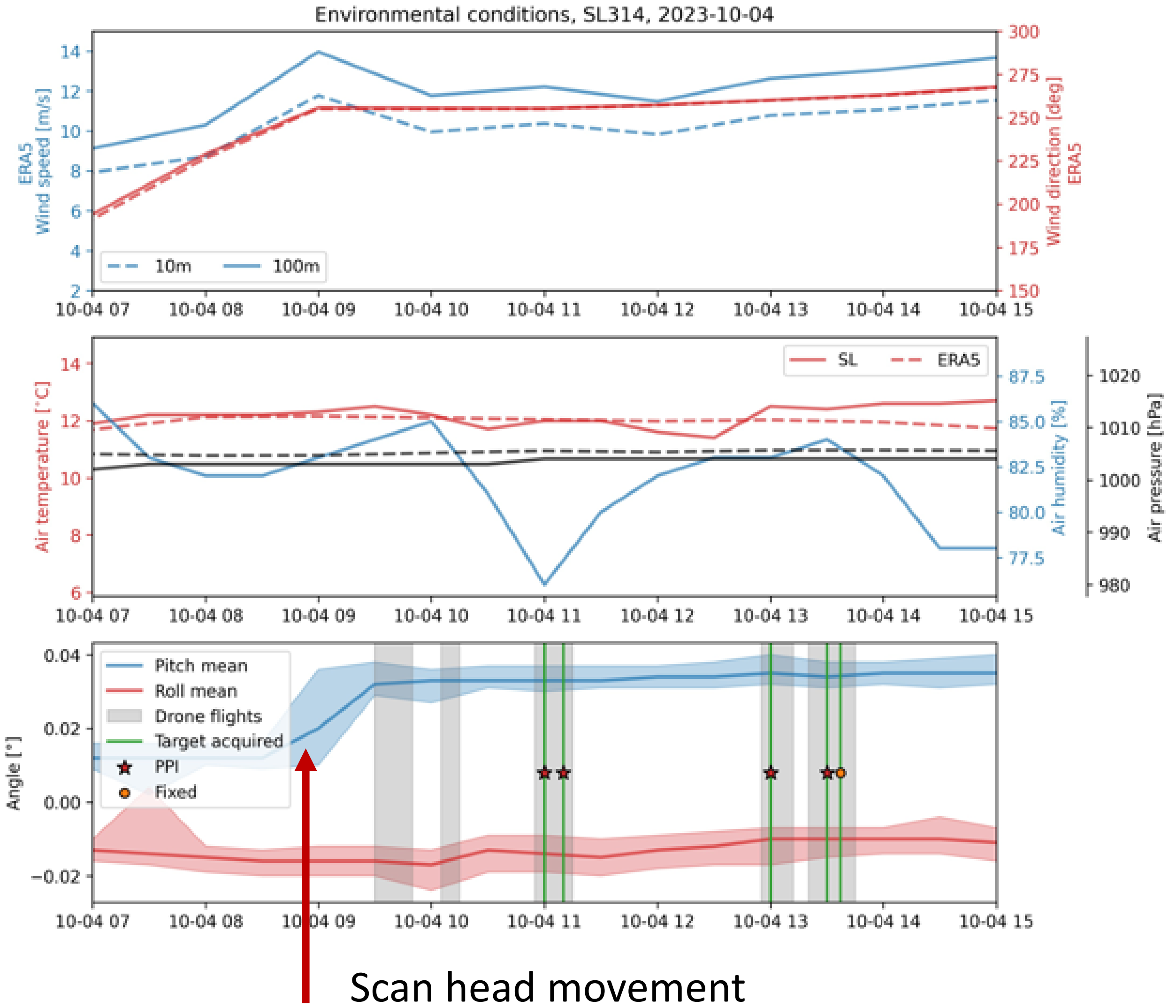
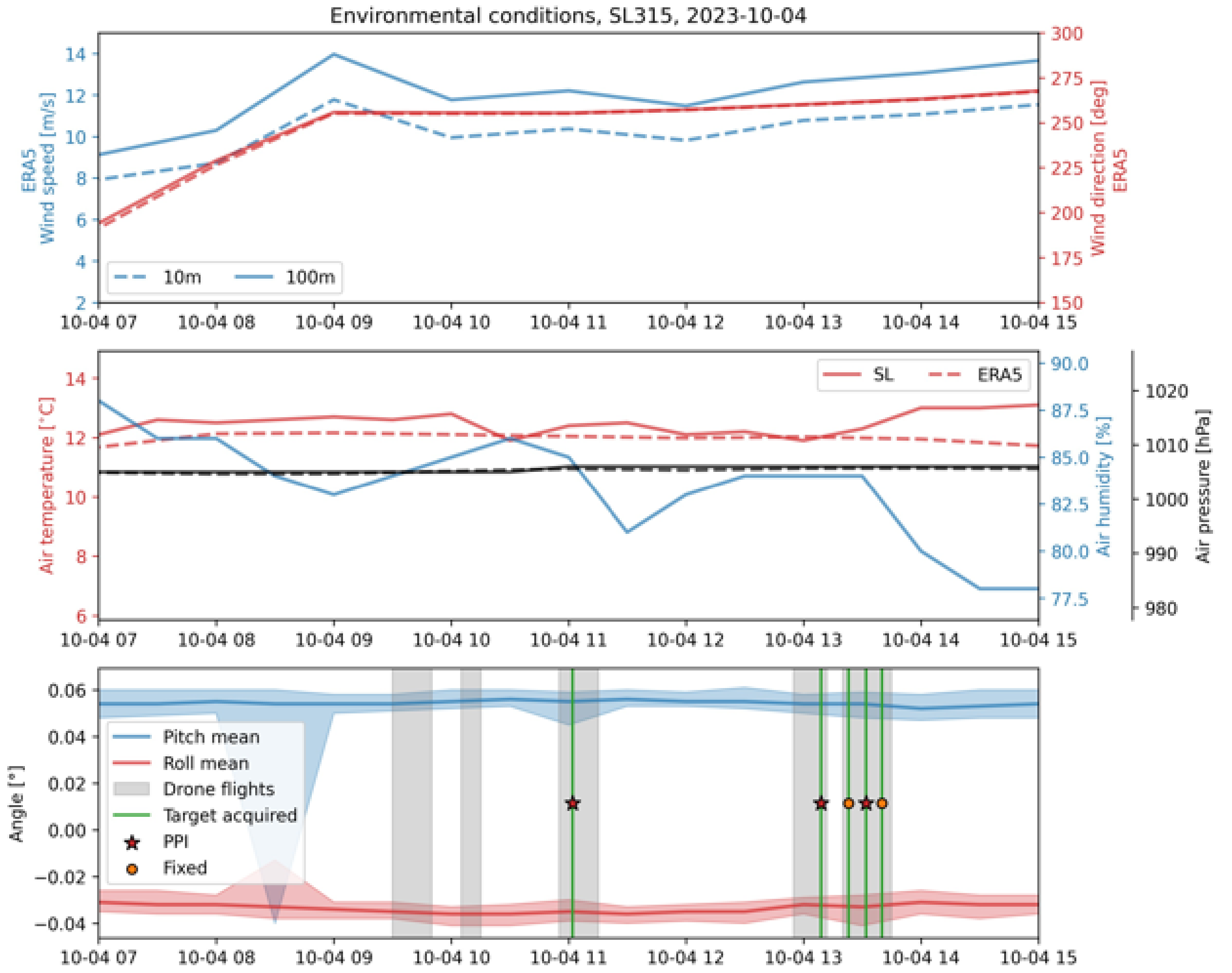
# Next steps

1. Revisit uncertainty evaluation – apples with apples check
2. Develop machine learning process for pixel selection (in progress)
3. Rerun HTT using updated method
4. Rerun HTT at sea using boat and compensated RTK method

# With thanks to OWPL and West of Orkney & Partners

# 2. Method – Drone - Challenges

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