Let's (Un)twist Again:

Hybrid Wind Field Reconstruction on Floating Lidar Systems

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Motivation

Fugro now offers the SEAWATCH Wind Lidar Buoy with Vaisala's WindCube profiling wind lidar

Status-quo for floating lidar data processing:

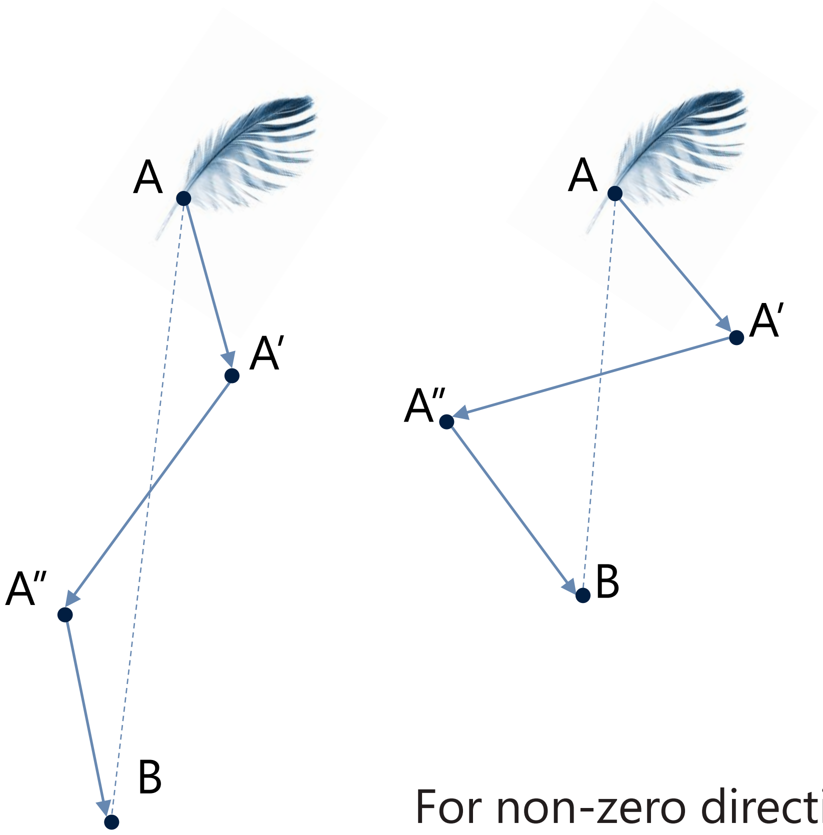
- Mean wind directions need compensation for buoy heading
- **Mean wind speeds are good to go even without any compensation**

This is true for mean wind speed measurements with ZX Lidars' ZX300 that are based on scalar averages.

➢ Floating lidar systems that use **WindCube need heading compensation for correct mean wind speed estimates**. This is because heading changes impact vector averages that are used in Vaisala's "Hybrid wind field reconstruction".

Scalar Averaging vs. Vector Averaging

Simple definition



Scalar averaging (U_{sca})

Speed along **actual indirect path** via A′ and A″ (**solid lines**)

Vector averaging (U_{vec})

Speed along **direct path** from A to B (**dashed lines**)

For non-zero direction changes, scalar averages are larger than vector averages. The larger the direction changes, the larger the difference.

Scalar Averaging vs. Vector Averaging

Formal Definition

Scalar averaging:

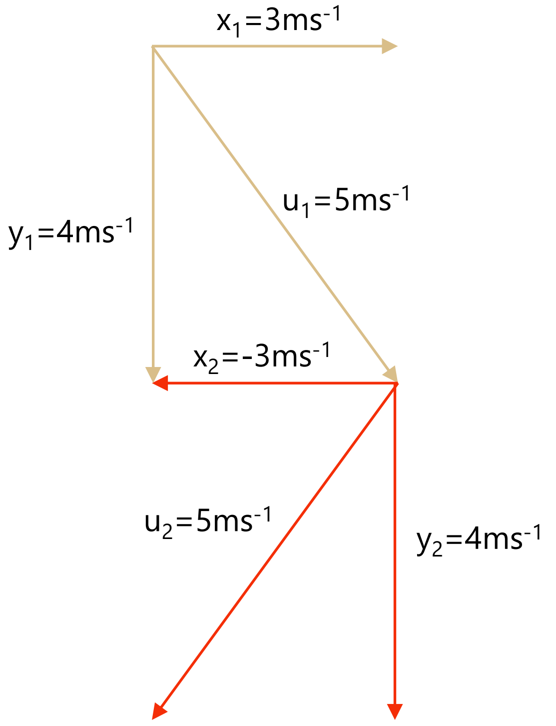
$$U_{sca} = \frac{1}{N}\sum_{n=1}^{N}\sqrt{x_n^2 + y_n^2}$$

Mean of **horizontal wind speed** samples

Vector averaging:

$$U_{vec} = \frac{1}{N}\sqrt{\left(\sum_{n=1}^{N} x_n\right)^2 + \left(\sum_{n=1}^{N} y_n\right)^2}$$

Geometric sum of horizontal **wind speed component** averages



$$U_{sca} = 5ms^{-1}$$

$$U_{vec} = 4ms^{-1}$$

Vaisala WindCube: «Hybrid wind field reconstruction»

$$U_{hyb} = \frac{2}{3} U_{sca} + \frac{1}{3} U_{vec}$$

- Default mean wind speed estimates generated by Vaisala’s WindCube (i.e., data in *.sta files) are linear **combinations of scalar and vector averaging.**
- This is called “Hybrid wind field reconstruction” and has been introduced to minimize sensitivity of mean wind speed estimates to influence of turbulence intensity.
- The theory behind it has been validated in trial campaigns for **fixed lidars.**
- A **floating WindCube** under the influence of yaw motion will provide smaller mean wind speed values than a fixed WindCube, unless heading changes are corrected for in the mean wind speed data processing.

➢ **Floating lidar systems that use the WindCube must consider platform heading changes for corrected mean wind speed estimates** and mean wind speed data in *sta files should not be used directly.

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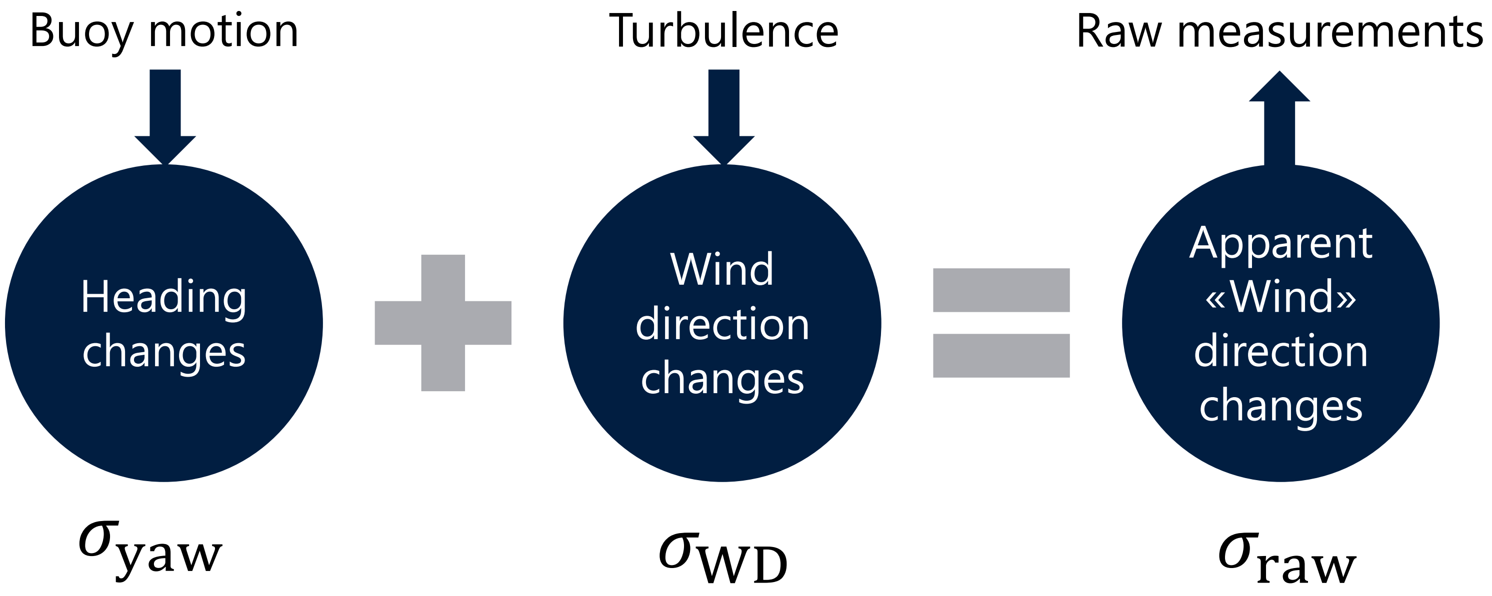
«Wind» direction changes



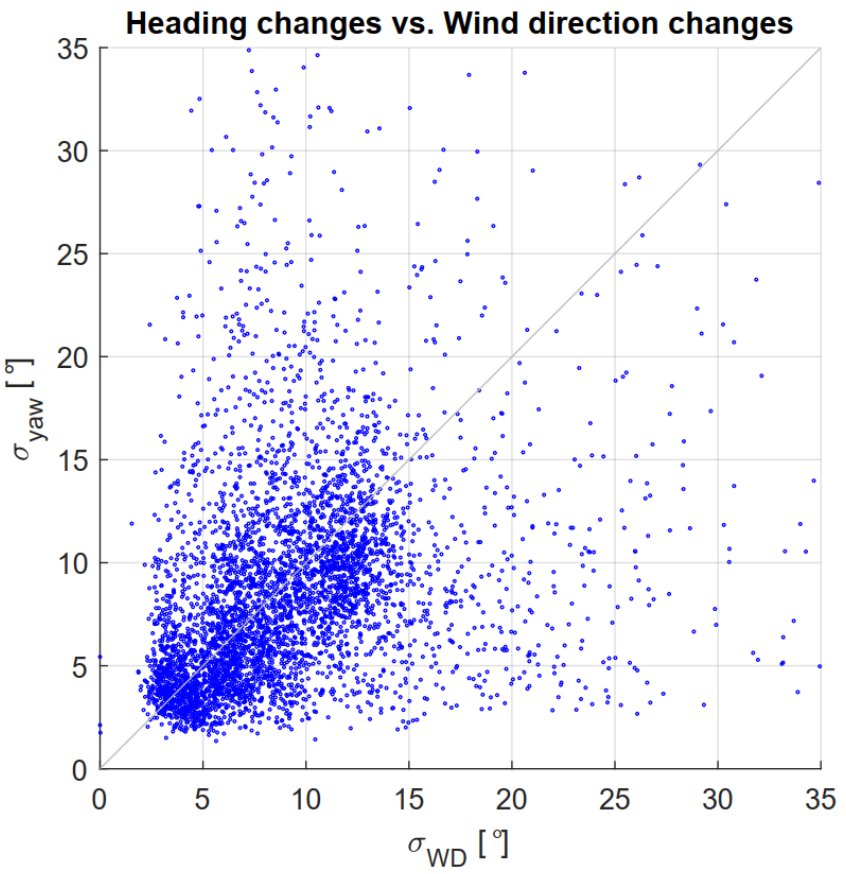
«Wind» direction fluctuations in floating lidar data (raw) have two sources:

1. Wind direction changes (σ_{WD}) → Accounted for in Hybrid Wind Field Reconstruction (WFR)
2. Platform heading changes (σ_{yaw}) → Reduces vector averages and contaminates Hybrid WFR

Apparent «Wind» direction changes

Atmospheric wind direction changes can be of the **same order of magnitude** as platform heading changes:

Important: Unwrap directional data before calculating standard deviations (i.e., 359°…0°=1°, not 359°)



Heading angle must be acquired with sufficient frequency to match unaveraged wind data, e.g., 1 Hz

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Heading correction

Calculating heading-corrected vector averages

Different methods can be applied:

1. Using each valid line-of-sight measurement with its actual azimuth angle instead of the default values (0°, 90°, 180°, 270°). Effectively creating and solving sets of 600 linear equations and 600 unknowns.
2. Using each valid reconstructed wind vector, rotating it by the platform heading and then calculating the vector averages. Effectively using the heading-compensated (untwisted) wind direction data for calculating vector averages.
3. …

Method 2. has shown to provide better results and is our recommendation

The required data is recorded in WindCube *.rtd files plus data from buoy-specific heading source

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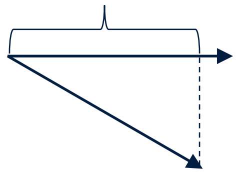
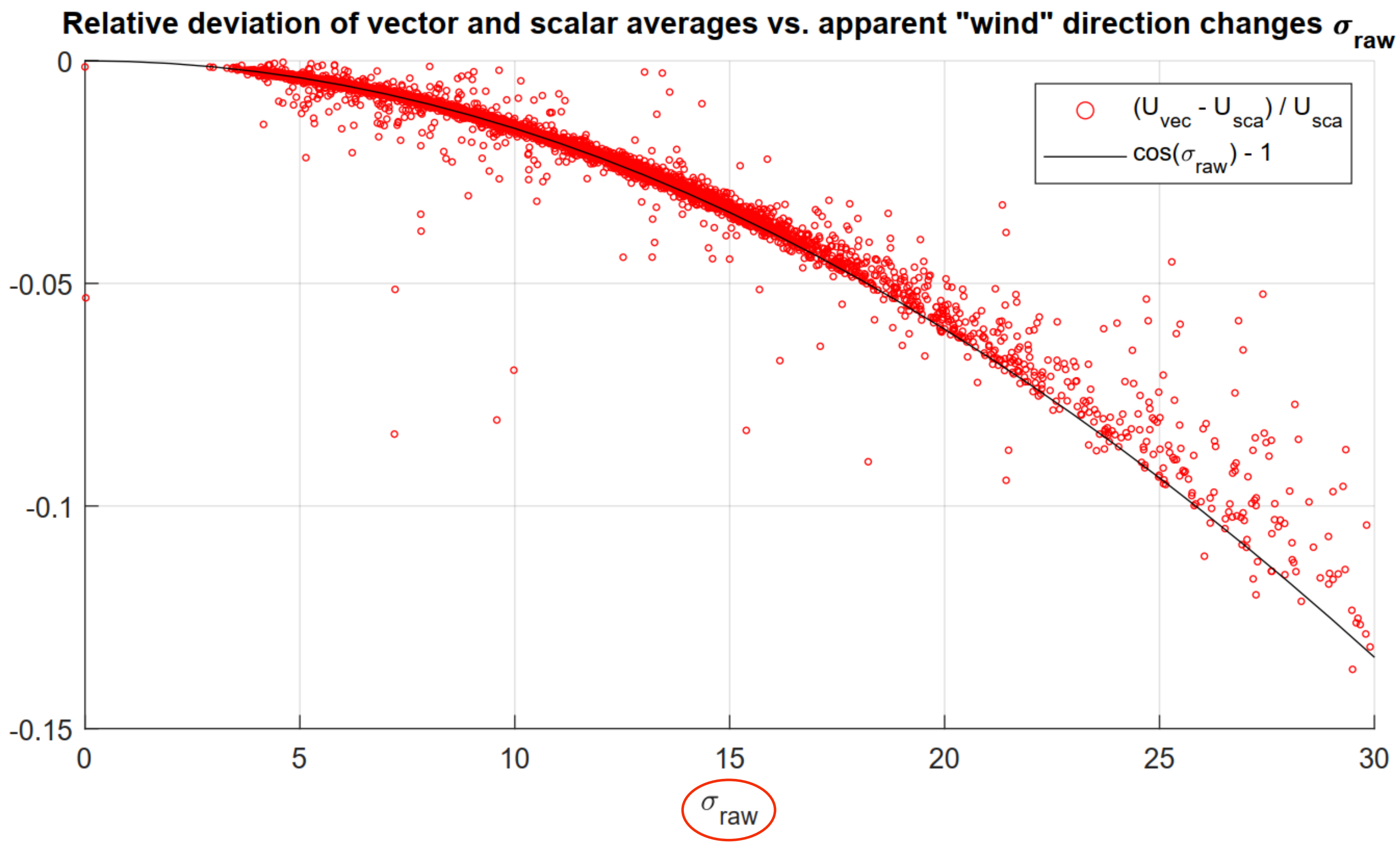
Measurement data

Sea trial data shows that the relative difference between scalar and vector averages **is** a function of the standard deviation of **apparent "Wind"** direction changes (σ_{raw} [°]).

Well approximated by:

$$\frac{U_{vec} - U_{sca}}{U_{sca}} = \cos(\sigma_{\text{raw}}) - 1$$





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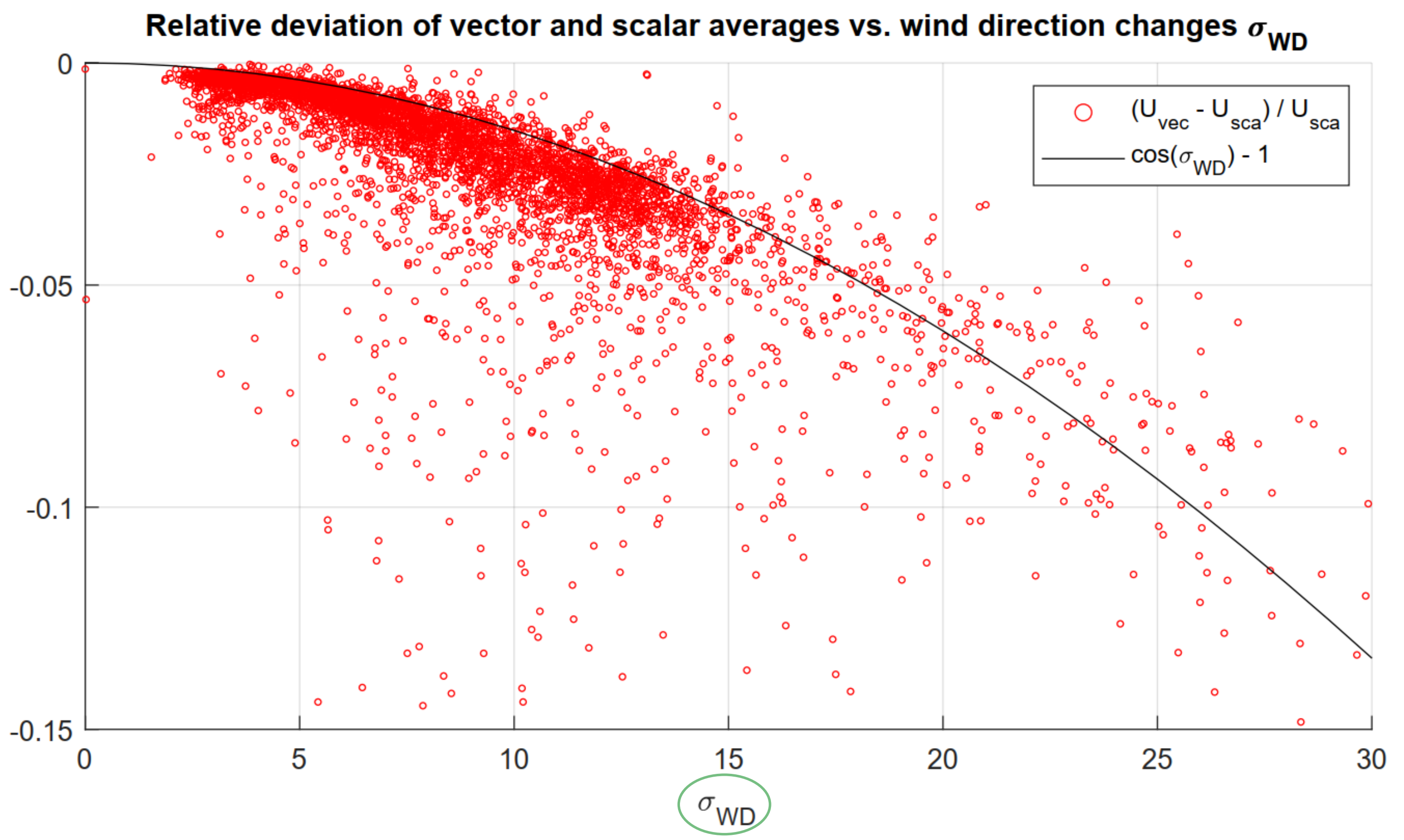
Measurement data

Instead, the relative difference between scalar and vector averages **should** be a function of the standard deviation of **atmospheric wind** direction changes (σ_{WD} [°]).

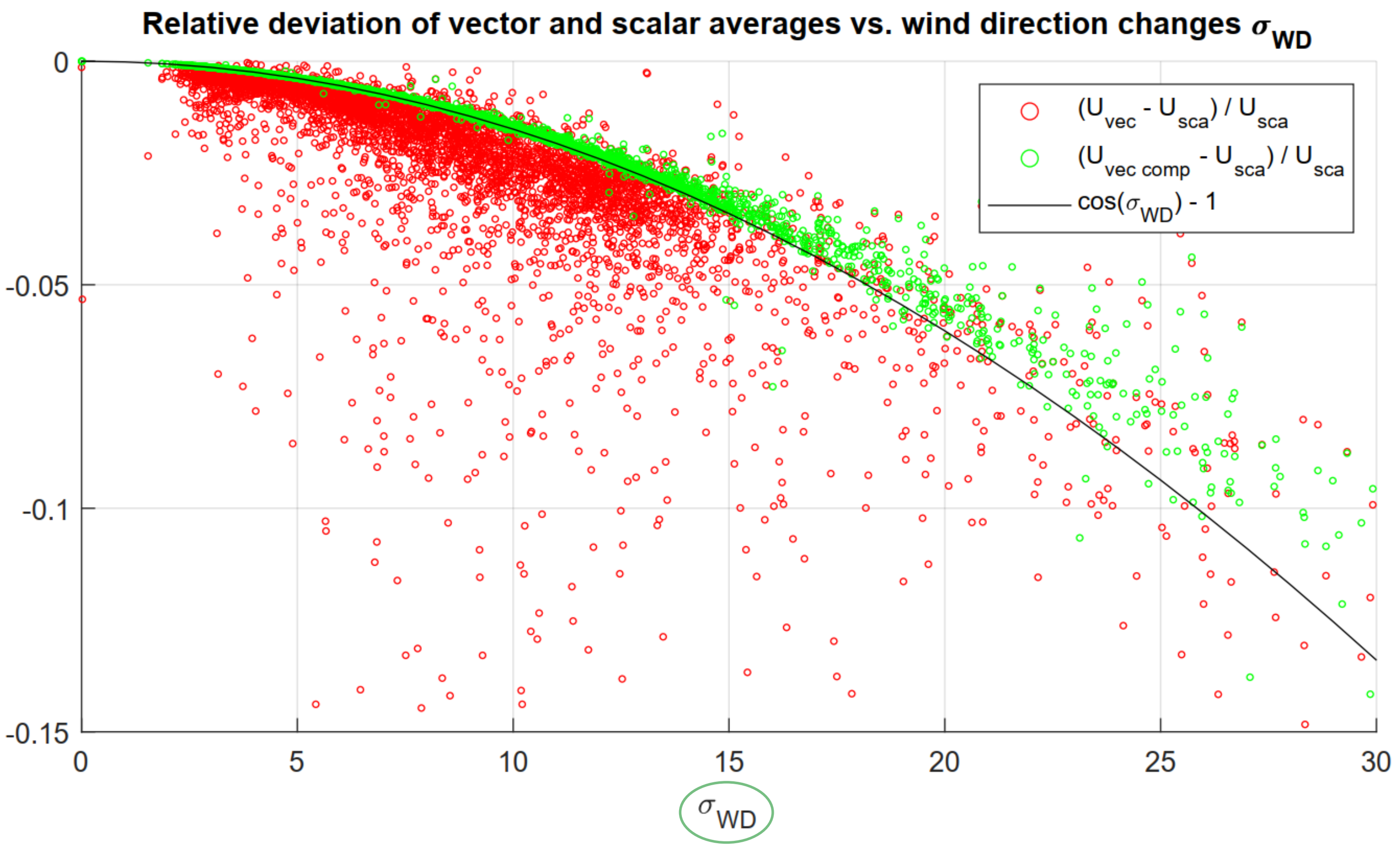
This is approximated by:

$$\frac{U_{vec}-U_{sca}}{U_{sca}} = \cos(\sigma_{\mathrm{WD}}) - 1$$



Measurement data

This is achieved by recalculating the **vector averages based on the heading-compensated reconstructed wind vector data**.



Conclusions

- Buoy yawing causes negative bias on mean wind speed data when hybrid (or vector) averaging is used
- Floating lidar systems with Vaisala WindCube have to compensate for the effect of heading changes on mean wind speed data
- The best method is rotating the unaveraged reconstructed wind vectors by the buoy heading and calculate the vector average of these rotated wind vectors to be used in the hybrid wind field reconstruction
- This is a simple and robust approach that only requires the unaveraged wind vector and heading data

Outlook

- Compare different methods versus measurement data from a fixed WindCube as reference
- Gain more operational experience with SEAWATCH Wind Lidar Buoy with WindCube

Unlocking **Insights**
from **Geo-data**