Orientation correction of wind direction measurements by means of staring Lidar

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WindEurope Summit 2016

Any problem here for a Lidar?

www.windindustrie-in-deutschland.de

Any problem here for a Lidar?

www.windindustrie-in-deutschland.de

Yes, we need highly accurate direction data to calculate the correct Lidar wind speed.

The situation now and how to improve it

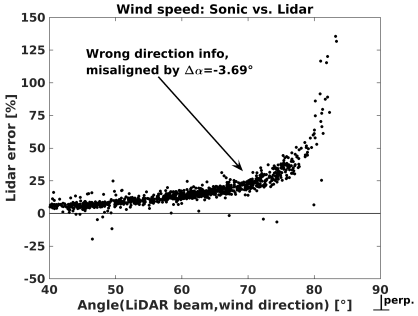
long-range Lidar,
PPI-, RHI-scans,
line-of-sight speed

+

Ultrasonic anemometer (e.g.),
wind speed magnitude and direction
usually misaligned by some degrees

The situation now and how to improve it

long-range Lidar, PPI-, RHI-scans, line-of-sight speed + **Ultrasonic anemometer (e.g.), wind speed magnitude and direction usually misaligned by some degrees** → **defective Lidar wind speed, errors depend on wind direction**



The situation now and how to improve it

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Ultrasonic anemometer (e.g.), wind speed magnitude and direction usually misaligned by some degrees

→ defective Lidar wind speed, errors depend on wind direction

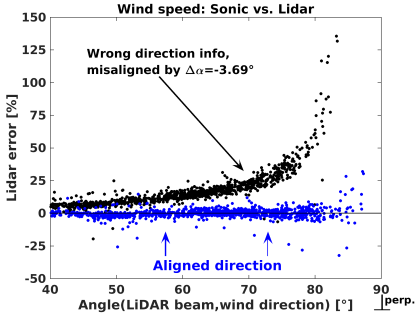
Comparison of staring mode Lidar line-of-sight speed, with Sonic wind projected onto line-of-sight

↓

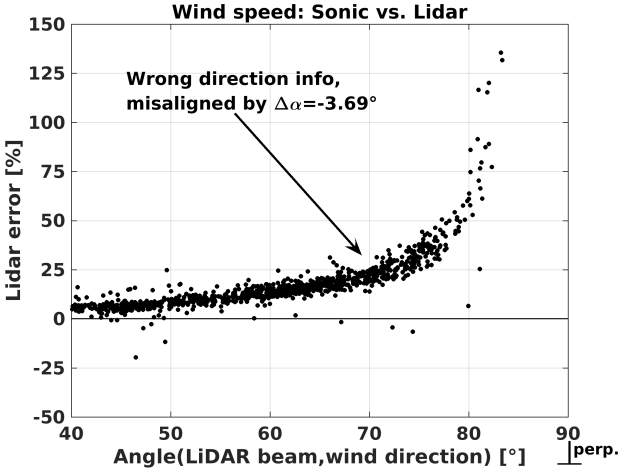
corrected direction data, misalignment <1°

↓

corrected Lidar wind speed, no Lidar-to-Sonic bias, (standard deviation 0.15-0.35m/s)



Alignment error introduces Lidar wind speed error



Error $\sim 1/cos^2(\alpha) \times \Delta\alpha$

↑ misalignment

"Error theory" in EWEA 2016 paper:

Orientation correction of wind direction measurements by means of staring Lidar

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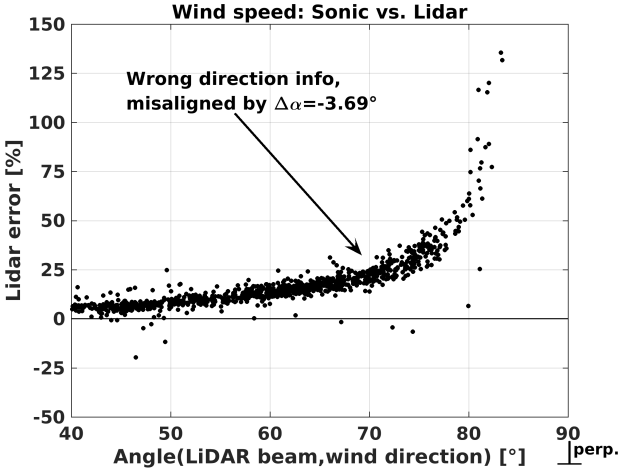

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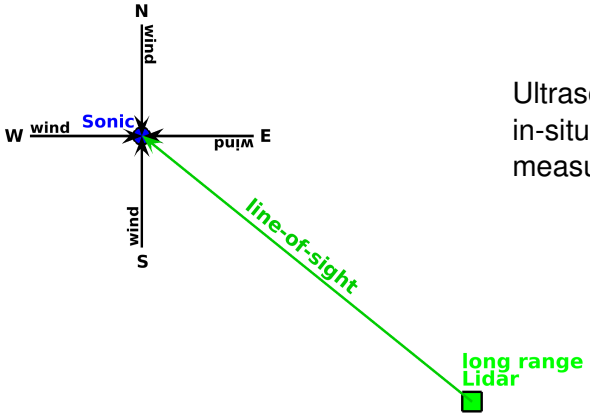
Orientation correction of wind direction measurements by means of staring Lidar

Two benefits of the method:

a) improved Lidar data quality,
b) accurate information about wind direction (error $< 1°$).

V_{los} = projection of wind speed magnitude on line-of-sight



Ultrasonic anemometer (“Sonic”) in-situ, and Lidar from far distance: measure at same point.

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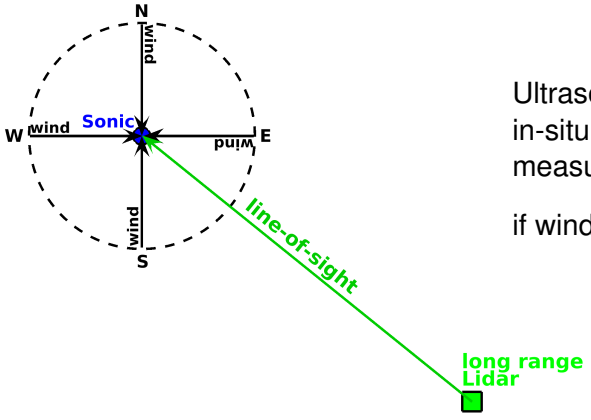

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if wind speed constant

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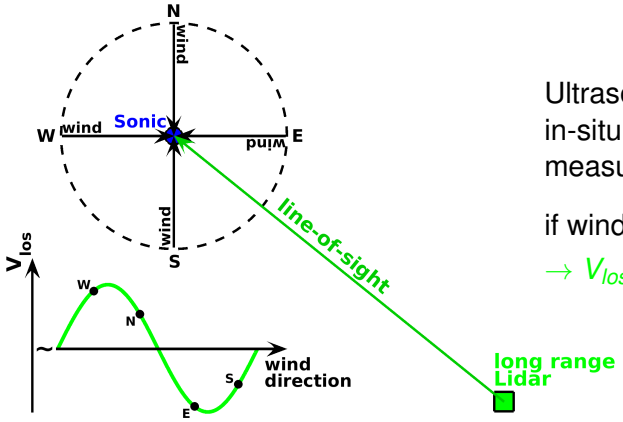

Ultrasonic anemometer (“Sonic”) in-situ, and Lidar from far distance: measure at same point.

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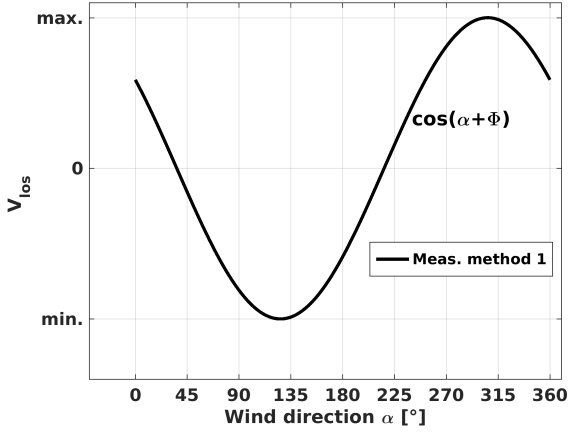
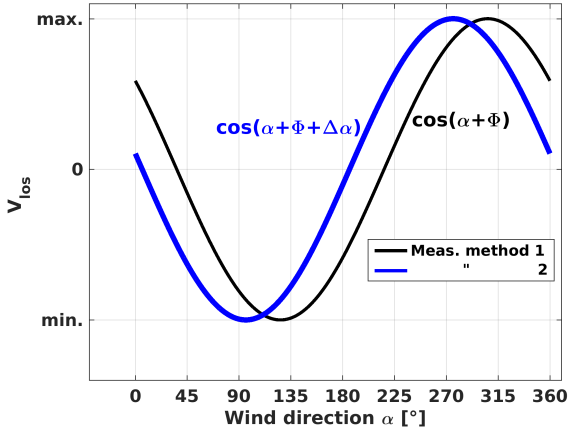
$\rightarrow$ V_{los} sinusoidal

Shift of the V_{los} – *sinusoidal*



Maximum V_{los} at line-of-sight: sinusoidal shifted by Φ,

Shift of the V_{los} – *sinusoidal*



Maximum V_{los} at line-of-sight: sinusoidal shifted by Φ,

different orientations of devices will introduce shift $\Delta\alpha$,

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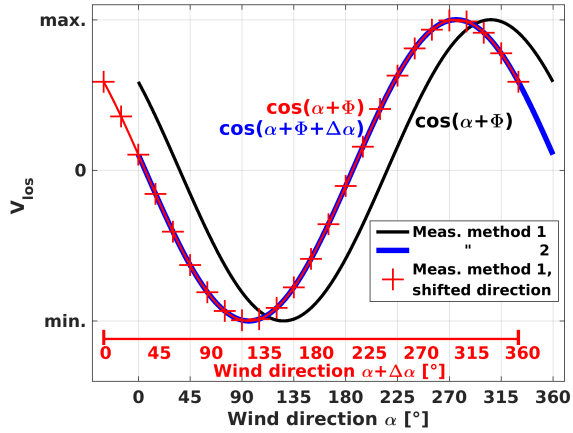
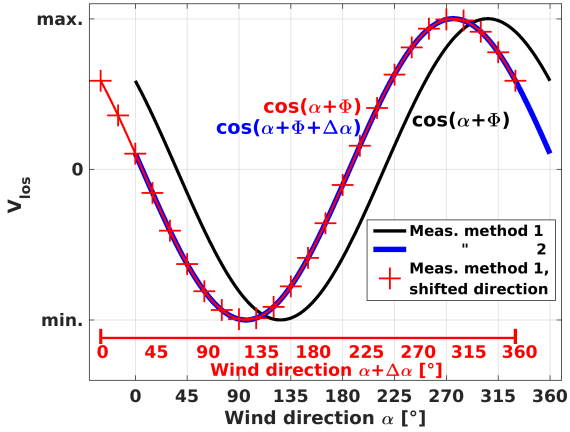


Maximum V_{los} at line-of-sight: sinusoidal shifted by Φ,

different orientations of devices will introduce shift $\Delta\alpha$,

α: shift of wind direction scale by $\Delta\alpha$ maps the black curve over the blue one.

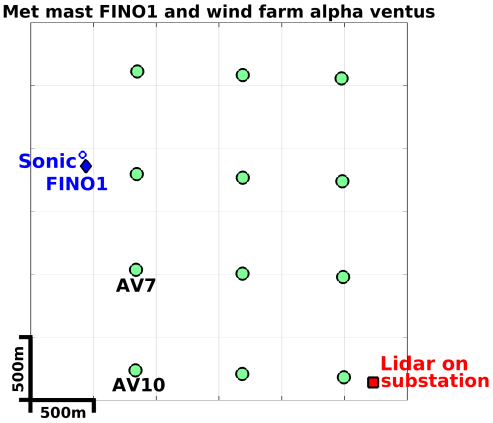
Shift of the V_{los} – *sinusoidal*



Tasks:

1. Find $\Delta\alpha$,
2. find out: which method is misaligned, or is the direction axis shifted?

Measurement setting in wind farm alpha ventus



12 $\times$ 5-MW turbines in North Sea,

Leosphere Windcube 200S-600 long-range lidar on substation,

Gill R3-50 Sonic at FINO 1 mast

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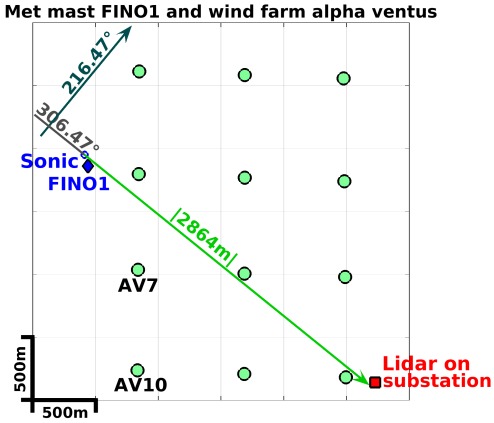


12 × 5-MW turbines in North Sea,

Leosphere Windcube 200S-600 long-range lidar on substation,

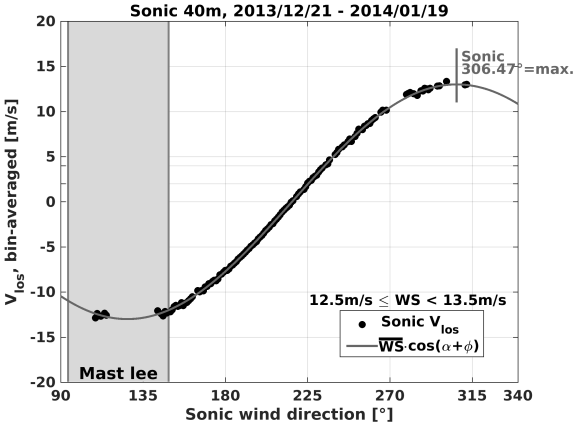
Gill R3-50 Sonic at FINO 1 mast,

Lidar to Sonic **distance: 2864 m**,

line-of-sight direction:
306.47° ± **0.28°** (compass system).

1243 × **10-min mean values** (≈10 days) measured in range 140° − 300°.

$V_{los,Sonic}$ is fine, isn't it?



Sonic's wind speed ($12.5 - 13.5 m/s$) projected onto line-of-sight ($306.47°$) $\rightarrow$ $V_{los,Sonic}$.

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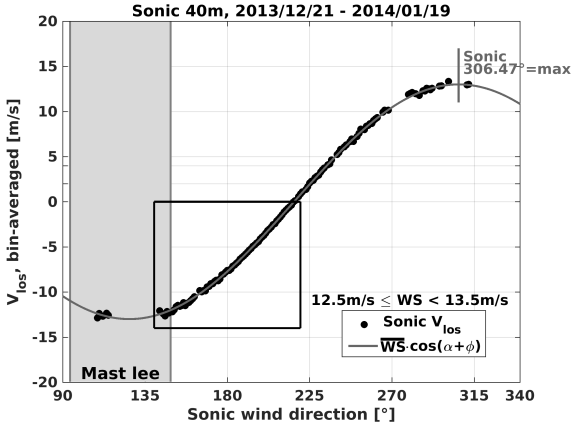
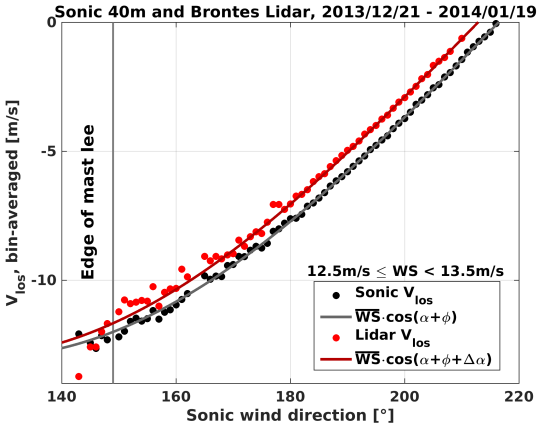
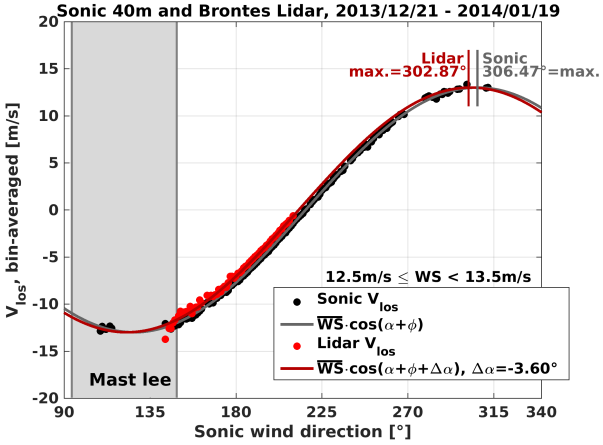




Sonic's wind speed (12.5–13.5m/s ← example) projected onto line-of-sight (306.47°) → $V_{los,Sonic}$.

Lidar's $V_{los,Lidar}$ (in Sonic's range 12.5–13.5m/s) are shifted to the left. Cosine fit yields $\Delta\alpha = -3.60°$.

$V_{los,Sonic}$ is fine, isn't it? It's not.



Max($V_{los,Lidar}$) at 302.87°: impossible!

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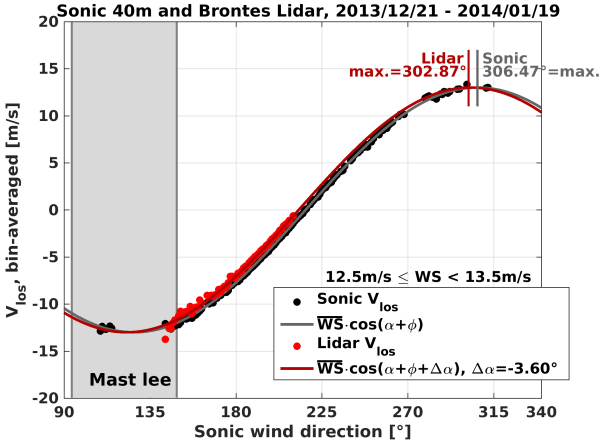

Max($V_{los,Lidar}$) at 302.87°**: impossible!**

The **Sonic is misaligned**, and therefore the scale "Sonic wind direction" is shifted.

Line-of-sight direction is well-known $\rightarrow$ the **Lidar is the reference** method.

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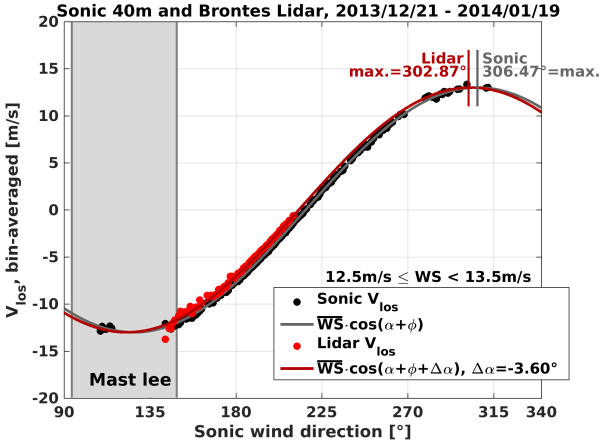

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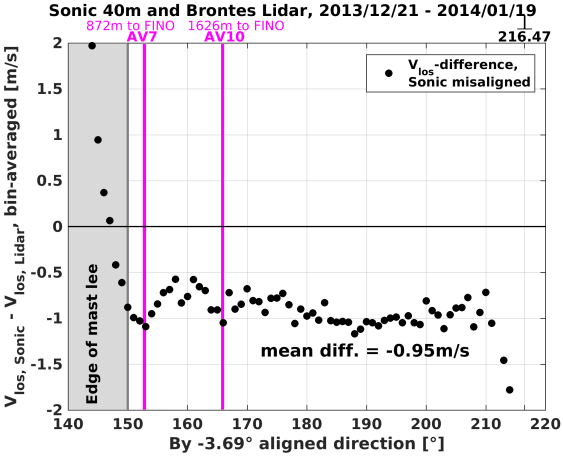
Apply method to all wind speed bins: $\overline{\Delta\alpha} = -3.69°$.

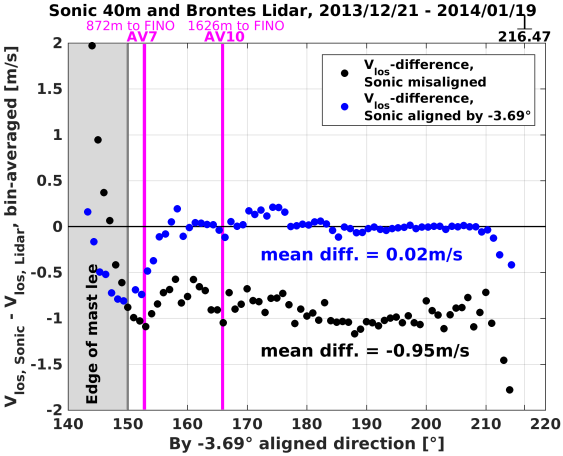
V_{los}: Lidar vs. Sonic



Lidar-Sonic bias in sector $170° - 210°$ (no turbine wake, apart from line-of-sight $\perp$ wind direction) before alignment:

$$-0.95 m/s$$

V_{los}: Lidar vs. Sonic



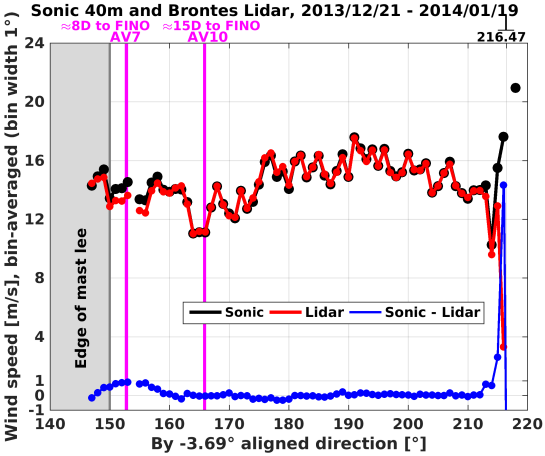
Lidar-Sonic bias in sector $170° - 210°$ (no turbine wake, apart from line-of-sight $\perp$ wind direction) before alignment:

$$-0.95 m/s$$

Bias after alignment:

$$0.02 m/s$$

Wind speed: Lidar vs. Sonic



After aligning,

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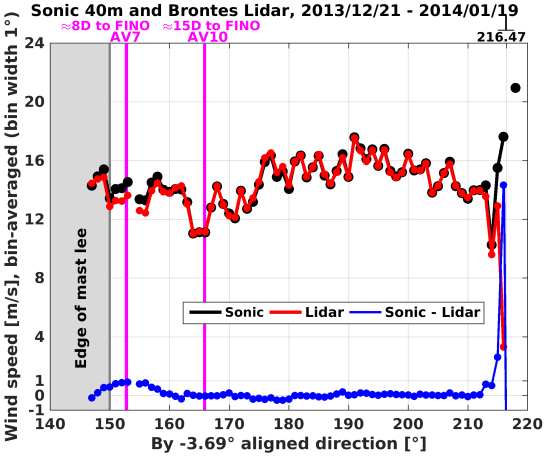
Wind speed: Lidar vs. Sonic



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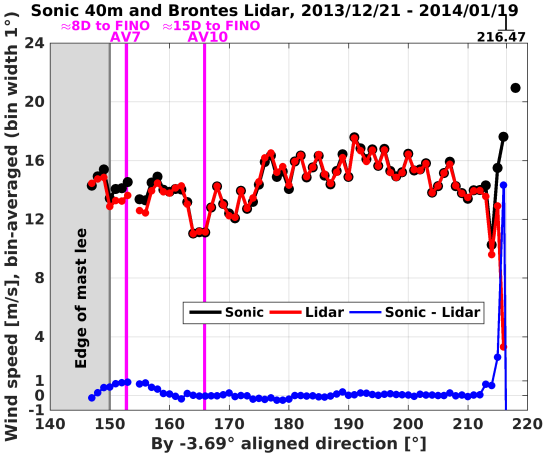
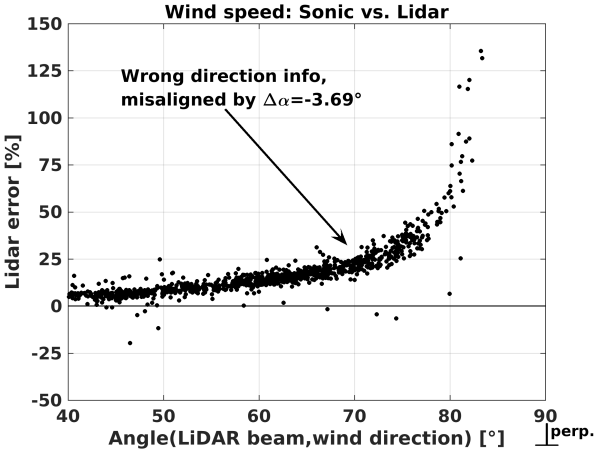


After aligning,

- Lidar vs. Sonic bias in sector 170°–210° is $\approx 0 m/s$,
- close to 216.47°, the error is still big due to the line-of-sight $\perp$ wind direction problem, and
- turbine AV 7's wake (but not AV 10) affects Lidar stronger than Sonic data (by max. $1 m/s$), due to:

  Sonic's point measurement vs. Lidar's volume averaging meas.

Misalignment $\Delta\alpha \rightarrow$ LiDAR wind speed error



Lidar's wind speed error grows up to infinity,

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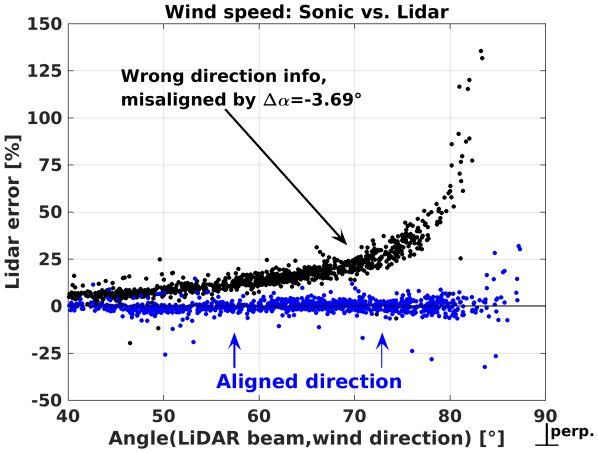

Lidar's wind speed error grows up to infinity,

after alignment, the wind direction range of usable Lidar data is extended from 0° to $80 - 85^\circ$.

Conclusions

A **long-range Lidar** – operated in staring mode – **is able to reduce direction measurement errors to below** $< 1°$**.**

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After aligning of direction data, **we don't find a significant Lidar-to-sonic bias** anymore.

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A **long-range Lidar** – operated in staring mode – **is able to reduce direction measurement errors to below** $< 1°$**.**

After aligning of direction data, **we don't find a significant Lidar-to-sonic bias** anymore.

Outlook:

- **Minimum number of data** for successful alignment?
- **Effect of met mast shadow** on Lidar data?
- Useful to **determine wind speed- and direction-depending misalignment angles?**

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Thank you.

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