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LiDAR based retrieval algorithm and its verification using SCADA wind data

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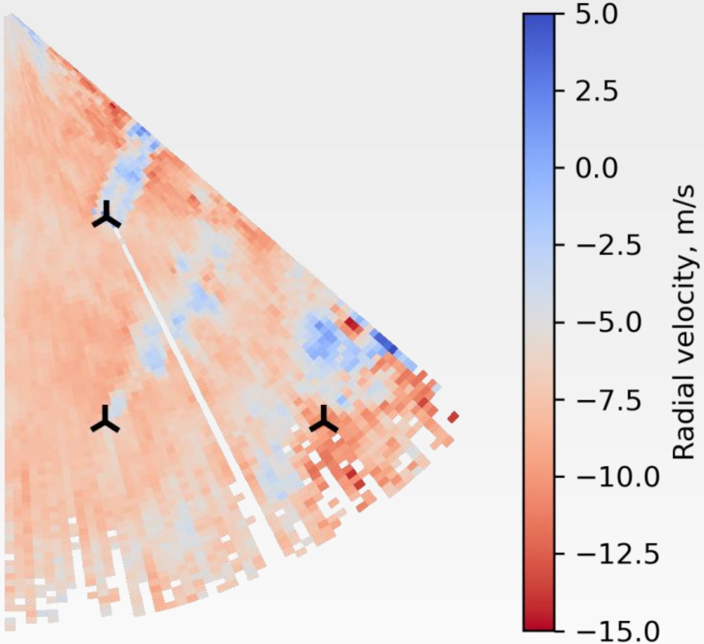
Outline

- Motivation
- Site and measurements description
- Lidar retrieval
  - Volume Velocity Processing (VVP)
  - Radial velocity reprojection
- Results
- Conclusions

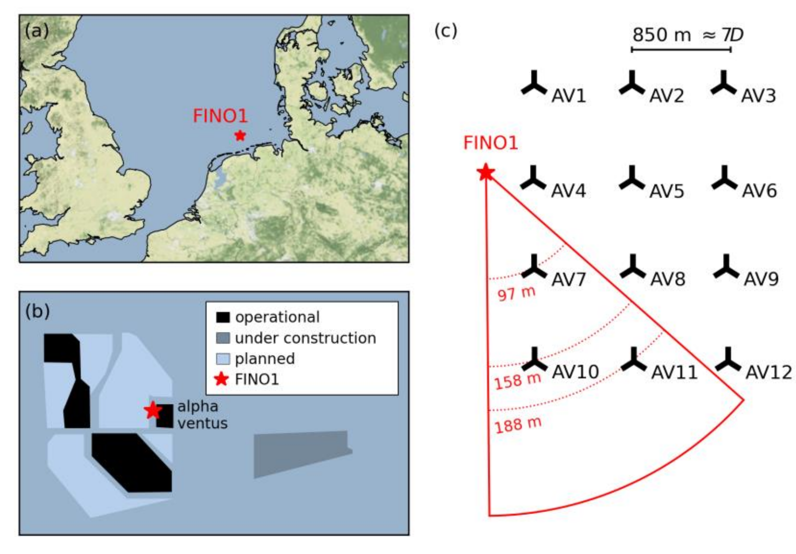
Motivation

- With a lidar, we can get **the wind field** around the turbines.
- However, the lidar measures **the radial velocity** instead of the actual wind speed.
- Numerous retrieval methods exist.
- The reconstructed wind field requires verification.



Site and measurement setup

- SCADA system (installed at each turbine).
- Cup anemometer, vane and lidar at FINO1.
- Lidar: Leosphere WindCube 100S (OBLEX-F1)
  - Elevation angle: 4.62°
  - ~45 seconds per one scan
- Scanned turbines:
  - **AV7 (at hub height)**,
  - AV10 (at blade top tip),
  - AV11 (above blade top tip).

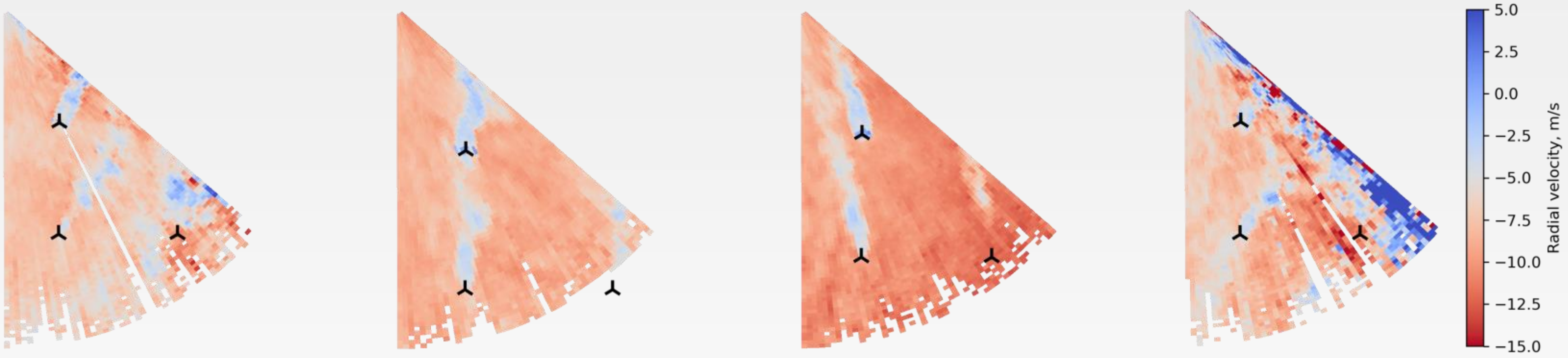


Data overview

Input data		
Lidar	Radial wind speed	Grid-based: resolution ~25 m
Reference data		
FINO1	Wind speed and direction	Point-based: 920 m away from AV7
SCADA	Wind speed and direction	Point-based: in front of AV7
NORA3 [1]	Reanalysis wind direction	Grid-based: resolution ~3 km
Wake detection [2]	Wind direction estimate	Approximated from the centerline fit

Lidar scans

- September 24, 2016. Data set: 600 scans



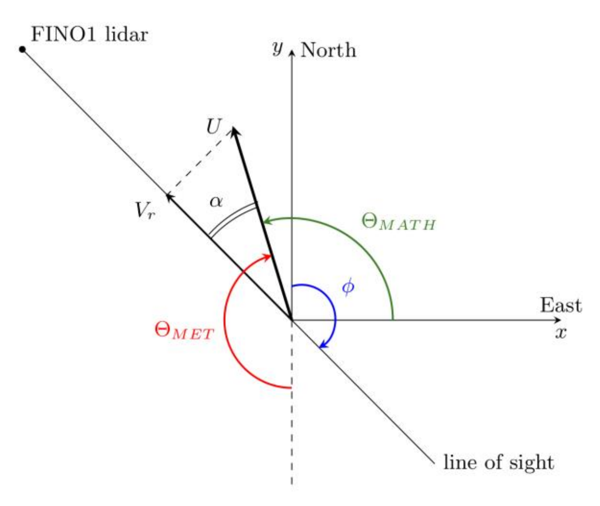
Medium noise	Low noise	Low noise	High noise
No wake-wake interaction	AV7 is subjected to a wake	FINO1 is subjected to a wake	No wake-wake interaction
	FINO1 -- AV7 mismatch	**FINO1 -- AV7 mismatch**	**Unreliable measurements**

Lidar measurements

- The lidar measures not the actual wind speed U, but the **radial velocity** $V_r(u, v, w)$:

  $V_r = u \sin\varphi \cos\psi + v \cos\varphi \cos\psi + w \sin\psi$

  where φ – azimuth, ψ – elevation angle.
- If $\varphi \approx \Theta_{MET}$, then $Vr \approx U$.
  - Lidar measurements represent the actual wind field rather well.
- However, if $|\varphi - \Theta_{MET}| \approx 90^o$, then $Vr \perp U$ or $Vr \approx 0$.
  - Lidar measurements are unreliable (crosswind).
- Lidar data requires retrieval procedure to reconstruct the wind field

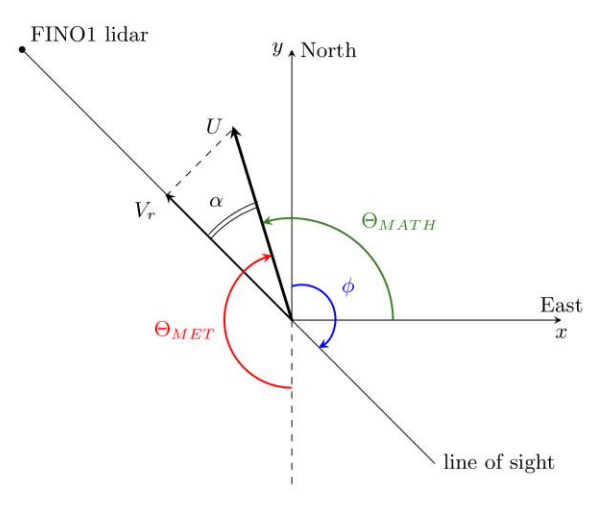


Simple retrieval

- The lidar measures the radial velocity $Vr(u, v, w)$:
  - $Vr = u \sin\varphi \cos\psi + v \cos\varphi \cos\psi + w \sin\psi$
  - where φ – azimuth, ψ – elevation angle
- Angle between V_r and U: $\Theta_{MET} - \varphi$
- Then

  $V_r = U \cos(\Theta_{MET} - \varphi)$
- Assume, wind direction Θ_{MET} is equal for all points.
- The actual wind speed is then

  $U(x,y) = V_r(x,y) / \cos(\Theta_{MET} - \varphi(x,y))$
- **Coarse** but quick approximation, one scan is enough.
- No information on the local wind direction.



Volume velocity processing (VVP)

- The lidar measures the radial velocity $V_r(u, v, w)$:

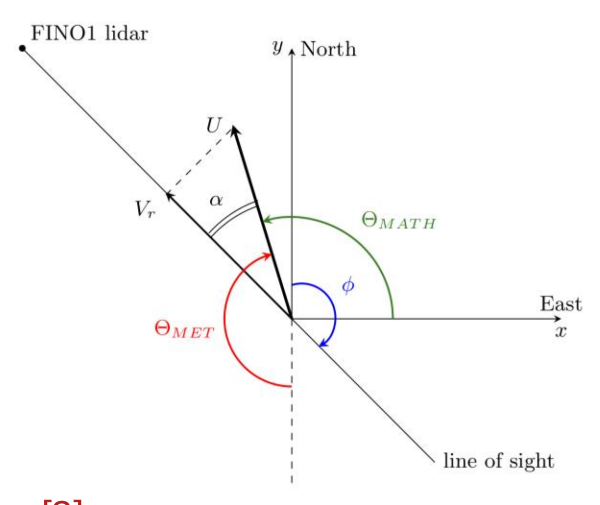
  $V_r = u \sin\varphi \cos\psi + v \cos\varphi \cos\psi + w \sin\psi$

  where φ – azimuth, ψ – elevation angle
- Assume $w = 0$ and small elevation angle ($\cos\psi \sim 1$).
- Then

  $V_r = u \sin\varphi + v \cos\varphi$
- Two unknowns: u and v; one lidar scan.
- **Solution**: fit for two consecutive scans (i) and ($i+1$).

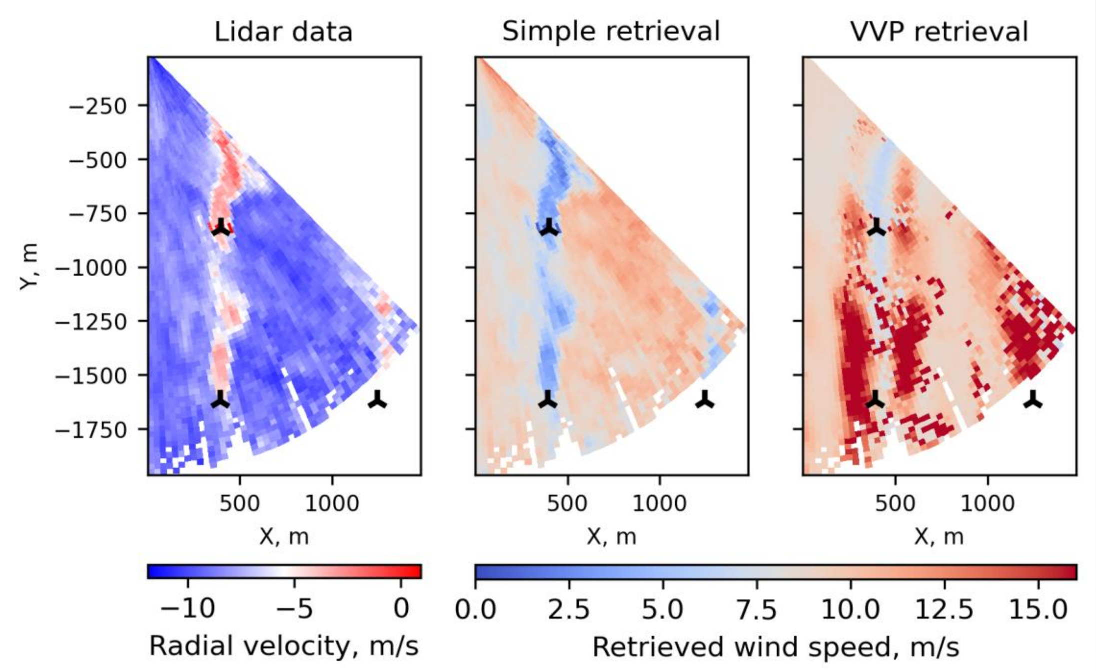
  $V_r^{(i)} = u \sin\varphi + v \cos\varphi$

  $V_r^{(i+1)} = u \sin\varphi + v \cos\varphi$

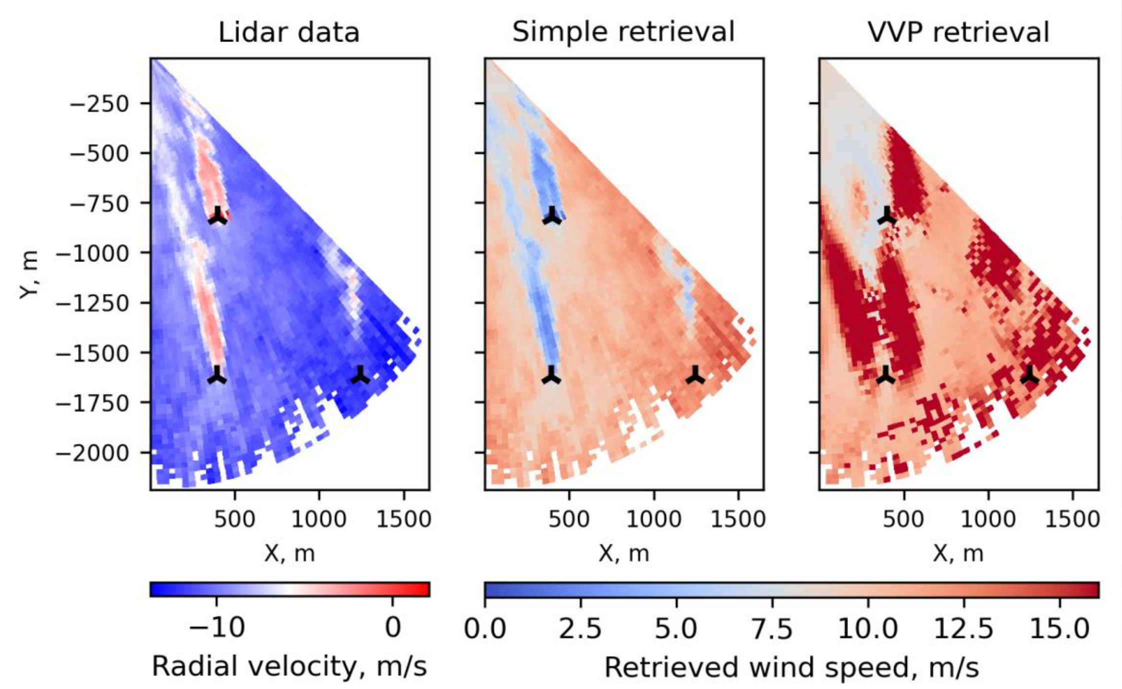


- The method assumes **uniform flow** and mostly ignores wakes [3].

Sample scan #1

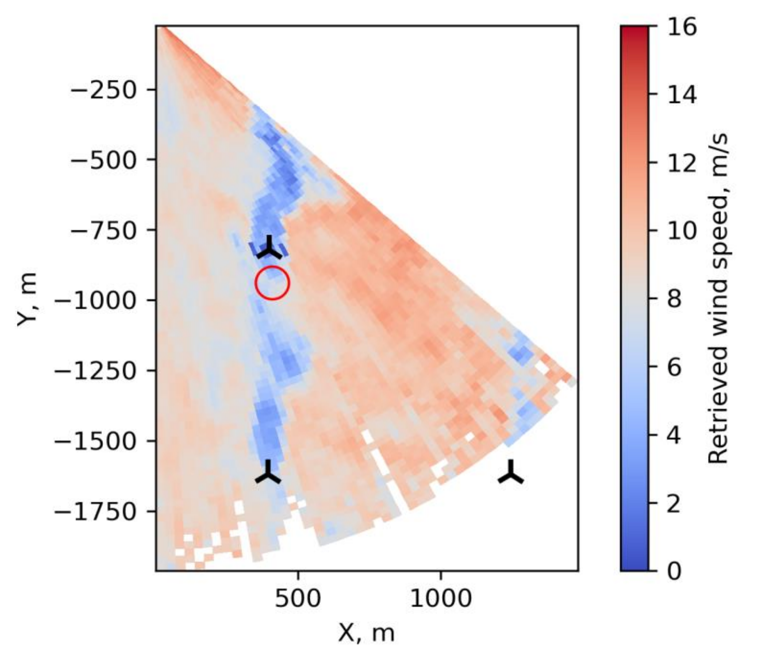


Sample scan #2



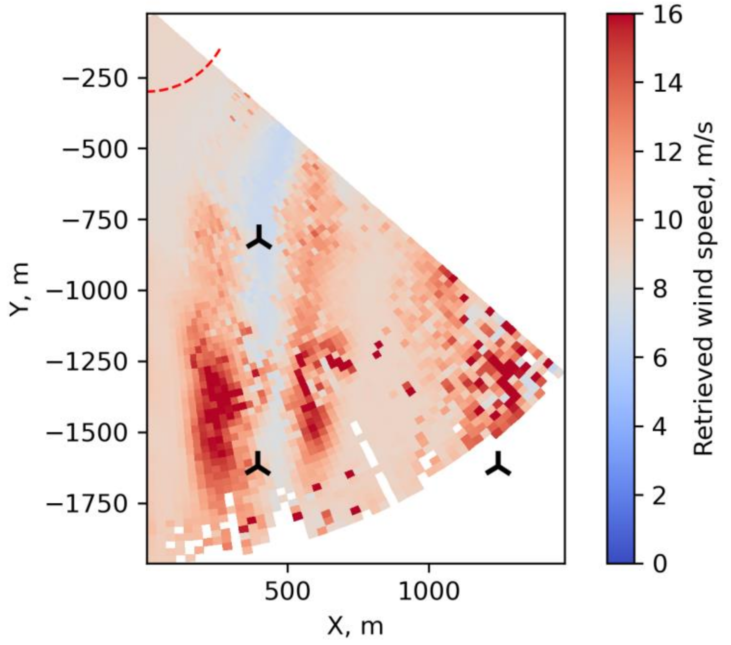
Verification: Simple retrieval

- Point measurements: FINO1 and AV7.
- Exclude scans with the high rate of erroneous measurements (>1% radial velocity above 30 m/s).
- Grid measurements:
  - **Simple retrieval**: calculate average wind speed in a circular area of $r = 0.5D$ at $1D$ upstream of AV7.

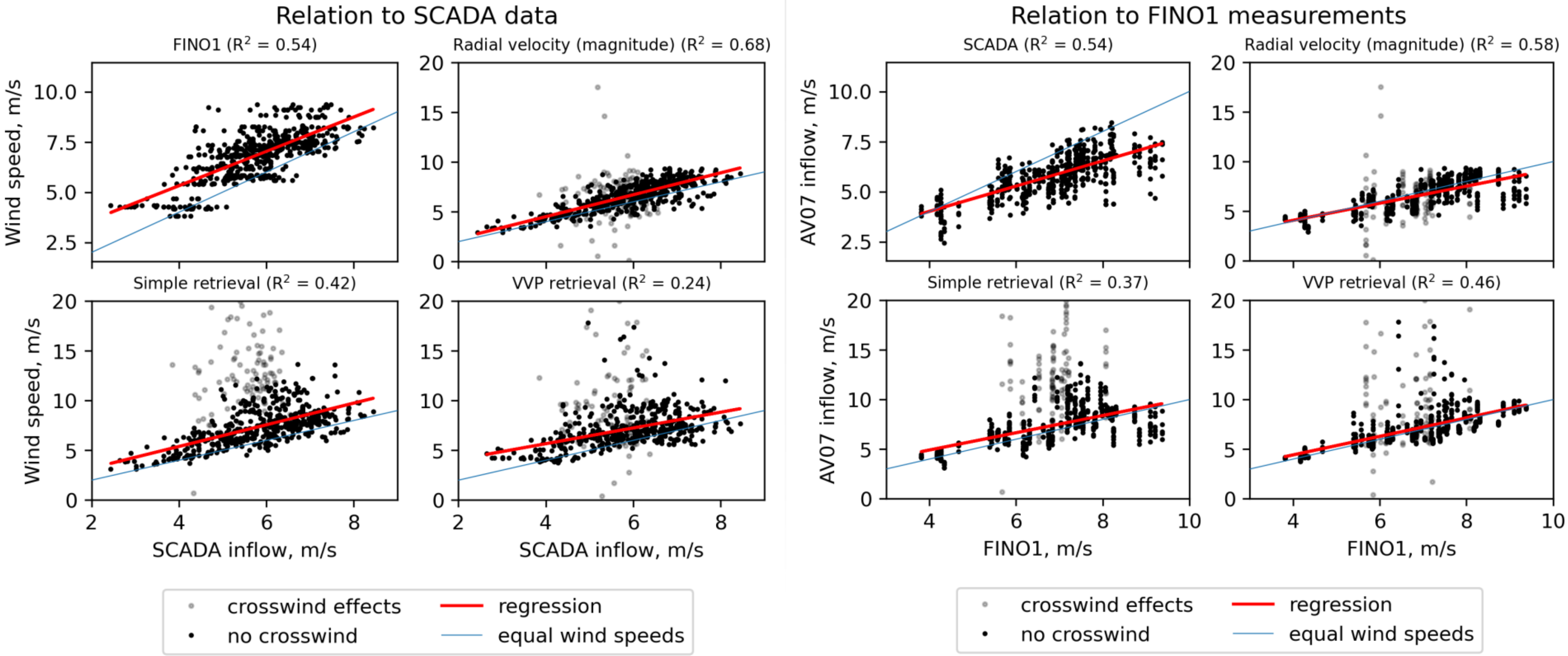


Verification: VVP

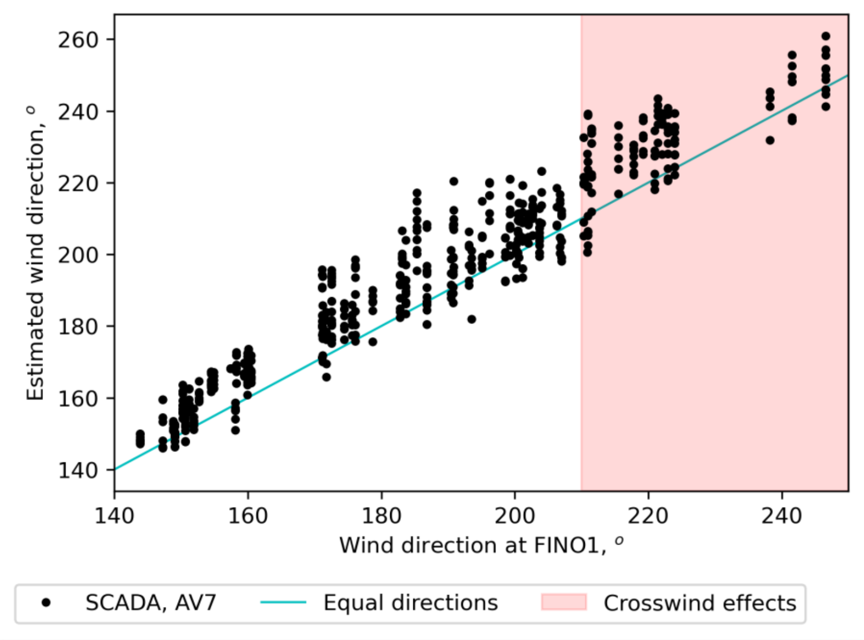
- Point measurements: FINO1 and AV7.
- Exclude scans with the high rate of erroneous measurements (>1% radial velocity above 30 m/s).
- Grid measurements:
  - **Simple retrieval**: calculate average wind speed in a circular area of $r = 0.5D$ at $1D$ upstream of AV7.
  - **VVP retrieval**: calculate average wind speed and direction in a uniform region up to 250 m near the lidar.



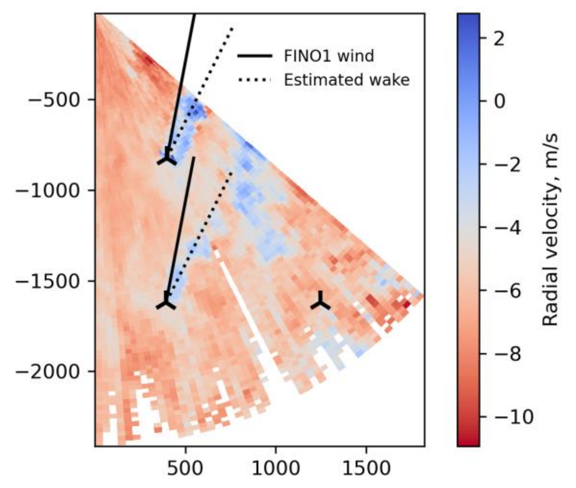
Wind speed comparison



Wind direction comparison



- An offset between FINO1 and SCADA.
- The offset does not depend on the wind direction or wind turbine
  (AV7 and AV10 are scanned at different heights)



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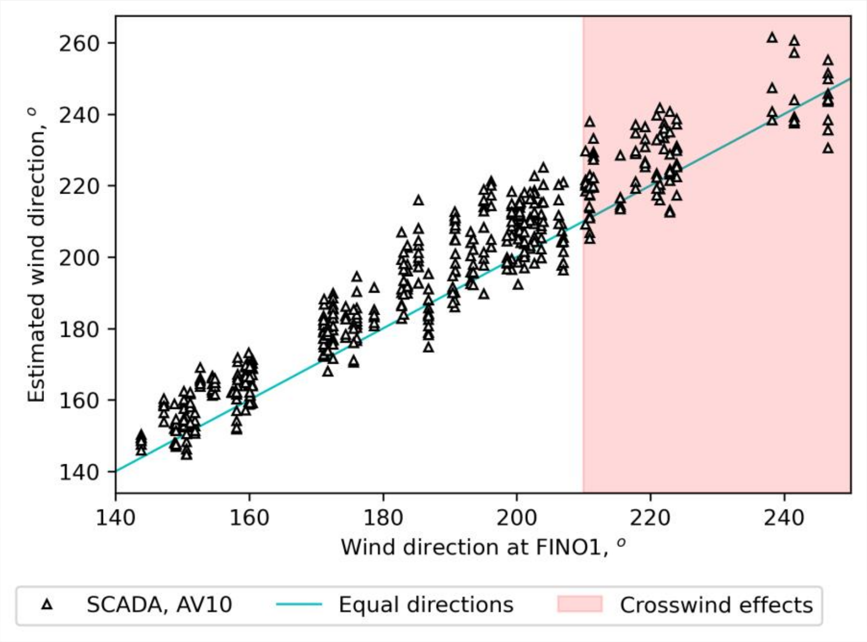

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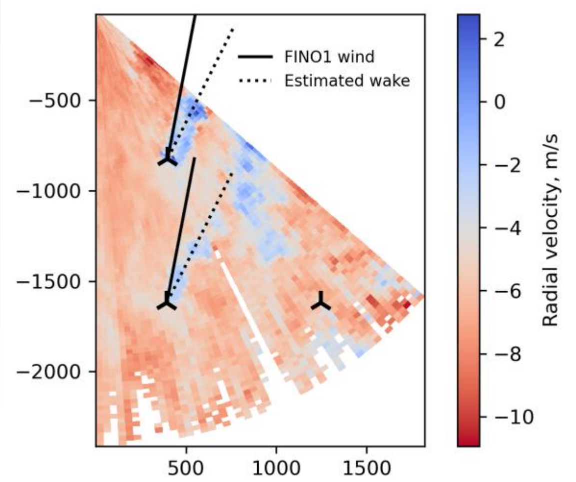

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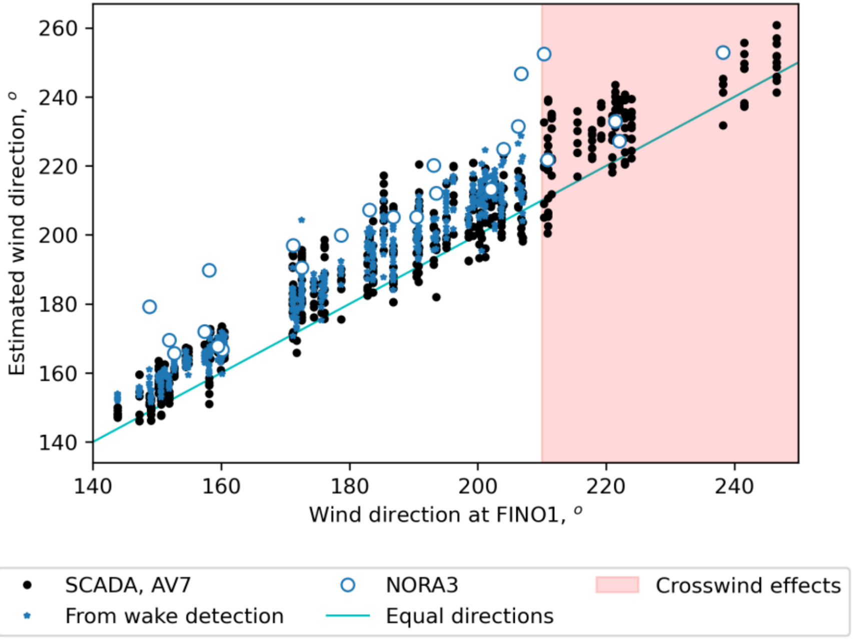

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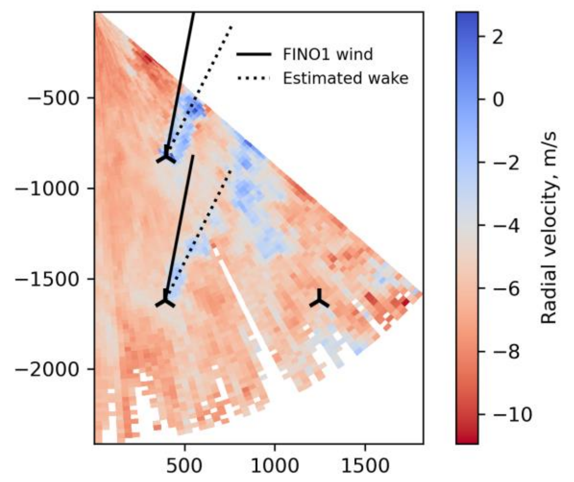
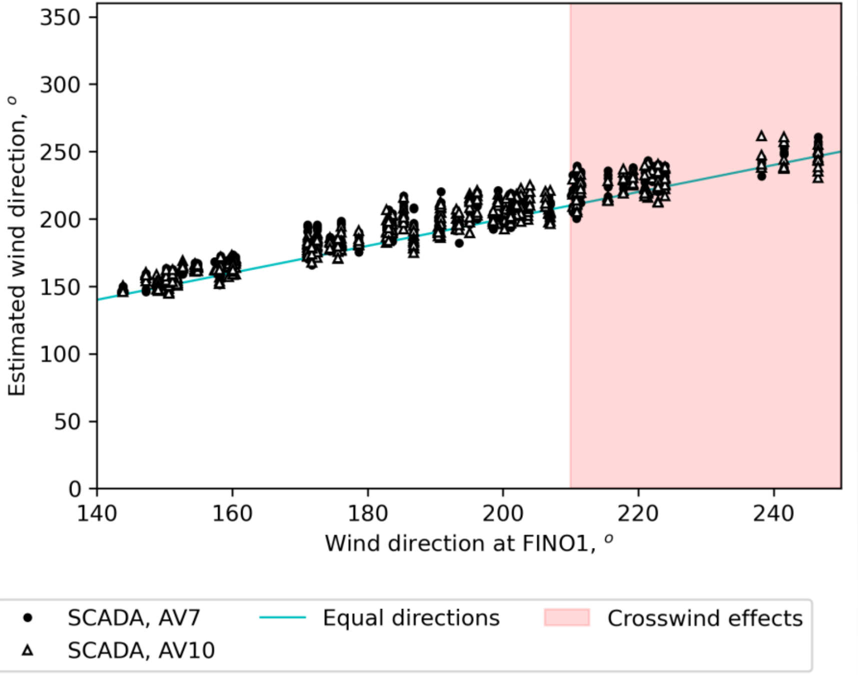
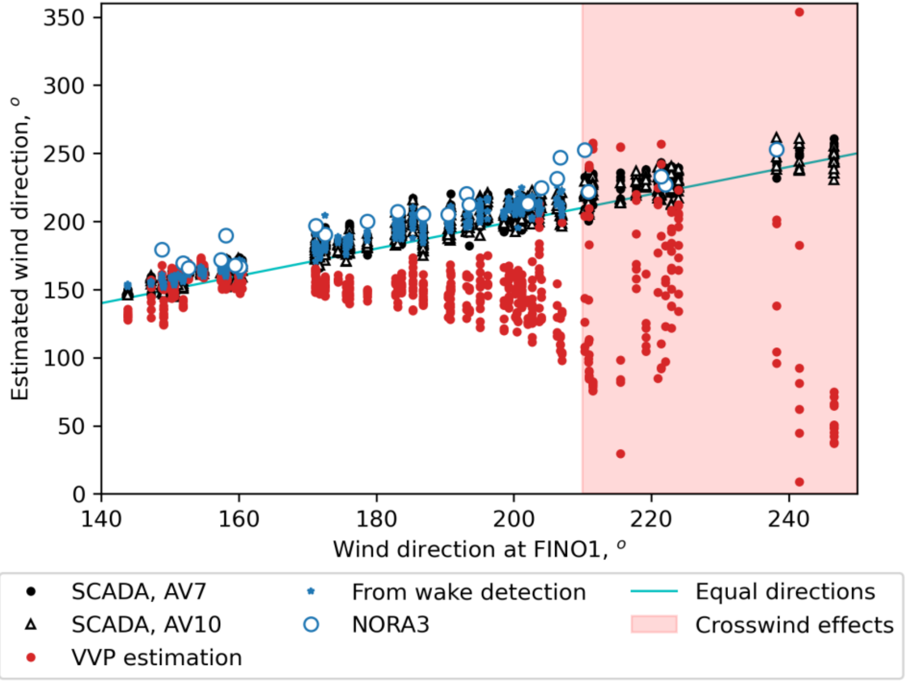


Wind direction comparison





Conclusions

- **Simplified retrieval** is decent for quick approximations of the wind speed magnitude when we are not interested in the local wind direction.
- **VVP method**
  - Produces a uniform region in lidar near range regardless of the flow structure – good for the free-flow estimation, but not for the local fluctuations.
  - The method overestimates the free-flow speed in some cases, but mostly agrees with SCADA and FINO1 data.
  - The wind direction shows a decent agreement when the wind blows towards the lidar, but then strongly diverges – more precise retrieval method may be needed.
- The divergence near for directions close to the crosswind can be caused by increased uncertainty of the lidar measurements.

References

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3. Cherukuru, N. W., Calhoun, R., Krishnamurthy, R., Benny, S., Reuder, J. and Flügge, M.: 2D VAR single Doppler lidar vector retrieval and its application in offshore wind energy, Energy Procedia, 137, 497–504, doi:10.1016/j.egypro.2017.10.378, 2017.

Thank you!

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