

Advancing ground-based remote sensing applications for retrieving mean winds, gusts and PBL structure

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Motivation

- **Profiles of winds, turbulence and thermal stability** within the PBL (Planetary Boundary Layer) are of great importance for understanding
 - PBL structure,
 - Diurnal cycle
 - Exchange processes near the surface
 - Observations are mostly performed using ground-based remote sensing
 - Data can be used for model evaluation and satellite validation
 - Data assimilation for improved forecasts of wind, gusts, and thermal stability
- **We will present novel retrievals for PBL observation and their potential impact on short-term forecasts**

PBL observations at U Cologne

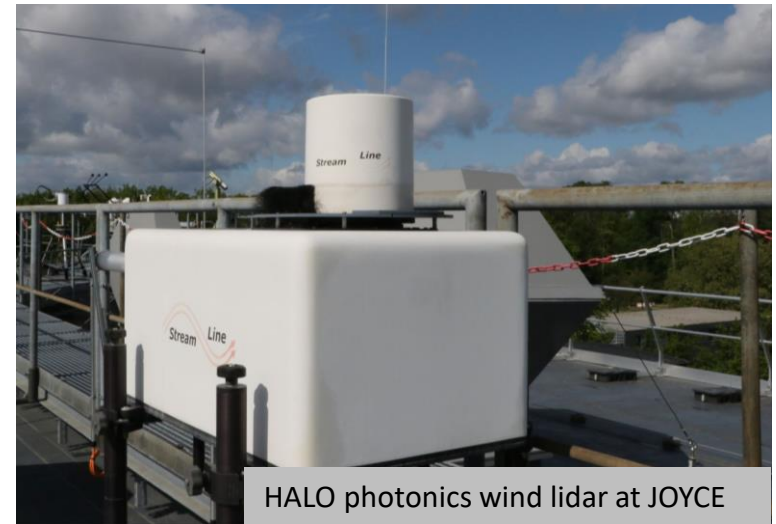
- University of Cologne has long experience in ground-based remote sensing of wind and PBL profiles.
- Operation of JOYCE supersite in Jülich (Western Germany)
- Synergy between different observation methods
- Testbed for LES model
- Part of European networks (ACTRIS, E-Profile)
- Measurement campaigns



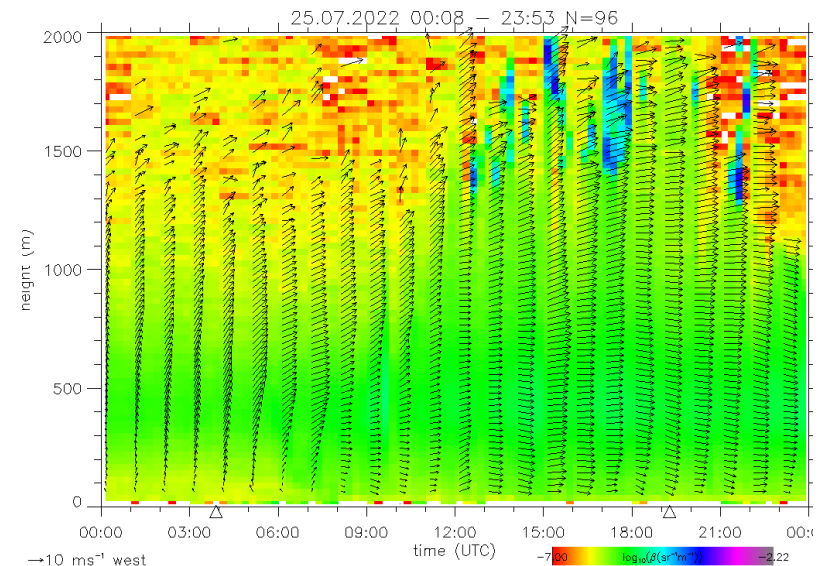
Main instrumentation

Doppler Wind Lidar (DWL)

- Provides profiles of 3D wind vector, turbulence and vertical exchange
- Benefits: continuous data close to the ground (resolution seconds to minutes)
- Limitations: Clouds, Absence of tracers (aerosols)



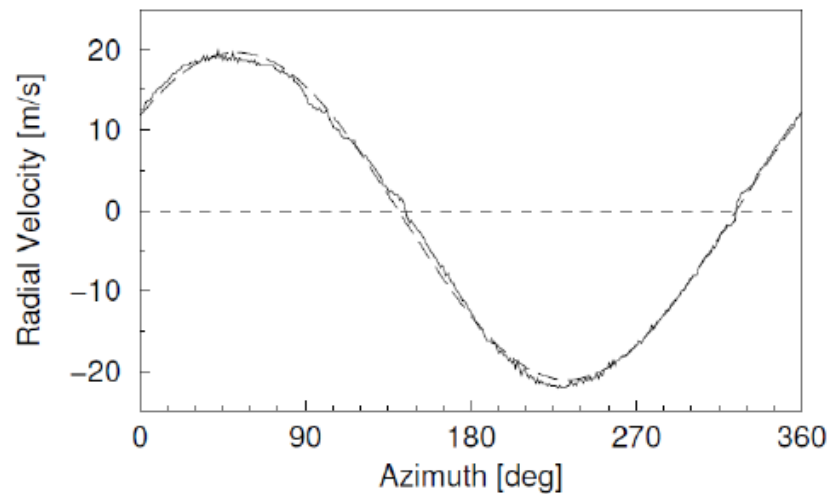
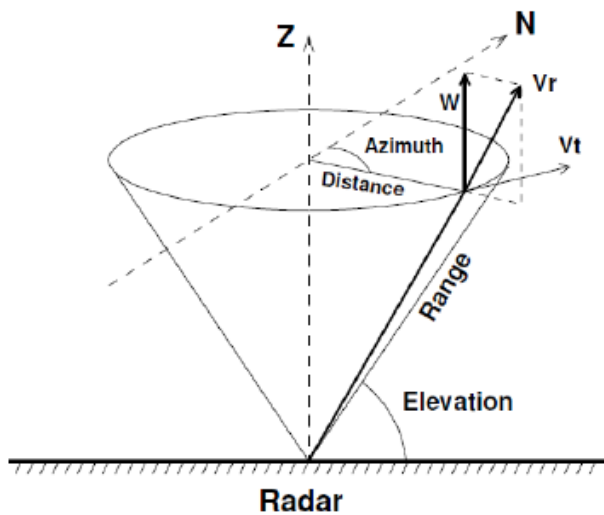
HALO photonics wind lidar at JOYCE



24h time series of horizontal wind

Wind profiles - Methodology

- 3D wind vector can be derived from off-zenith azimuth scans by analyzing the Doppler shift along the line of sight („VAD scan“ Velocity Azimuth Display)



Holleman et al., 2005

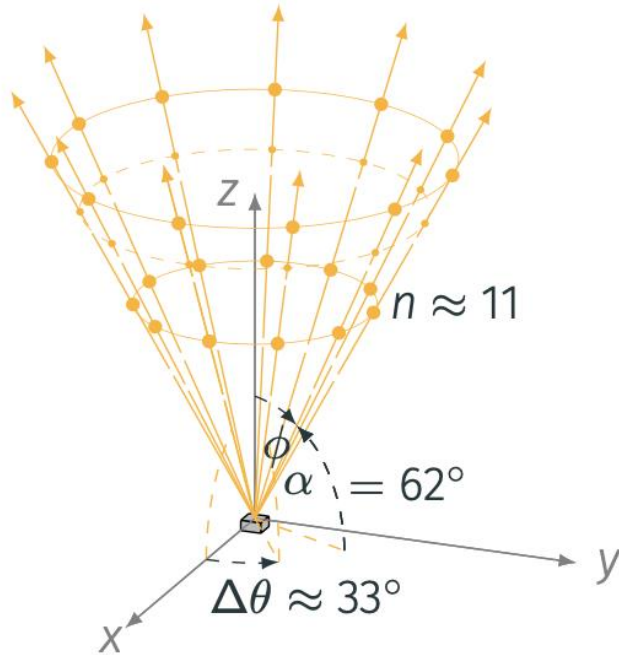
Retrieval of Gust Profiles with Doppler Lidar

Doppler Lidar for high resolution winds

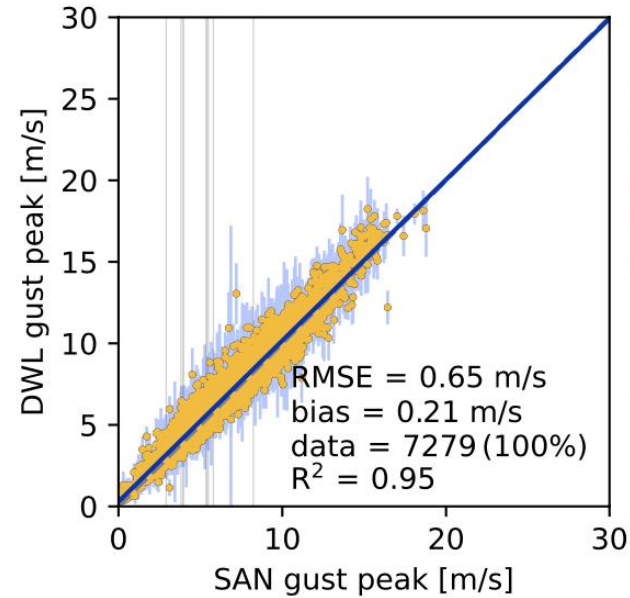
- Typical: Wind retrievals with time average of ~ 10 min
- **New:** retrieval method for resolving gusts (\sim secs)
- Additionally vertical winds
- Measurements performed during FESSTVAL campaign in 2021 at the Meteorological Observatory Lindenberg (Germany)



Retrieval of Gust Profiles with Doppler Lidar

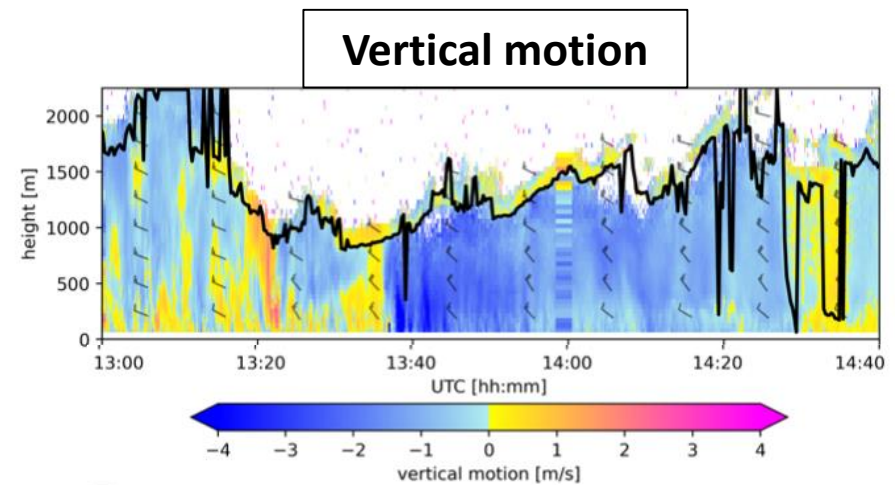
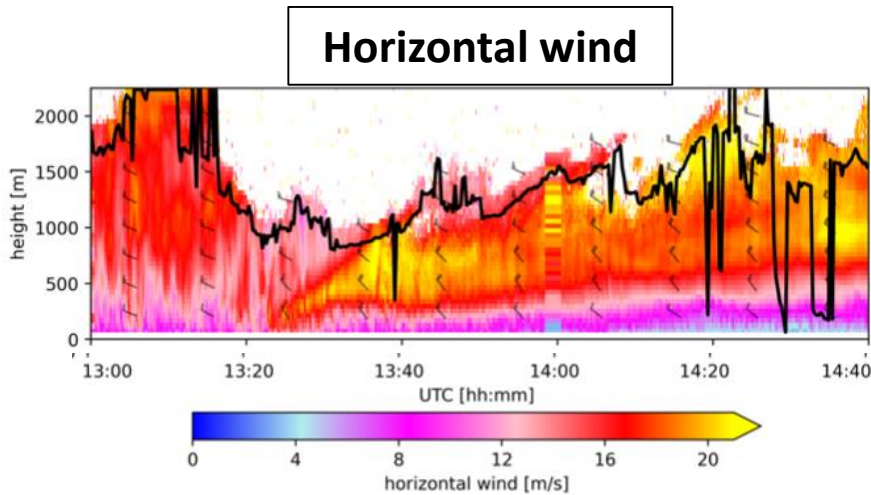


Quick Continuous Scanning: 11 observations in 3.4s and 3000 pulses per beam



Sonic anemometer (SAN) gust peak (3 s in 10 min) vs. DWL gust (3.4 s in 10 min)

Retrieval of Gust Profiles with Doppler Lidar



- Excellent performance for high-resolution (3.4s) as well as mean winds (10 min)
- Reliable gust detection from typical hub heights to top of ABL
- Resolve explicit features of fronts, nocturnal jets, cold pools, etc..

Steinheuer et al., 2023 (in prep.)

Doppler wind lidar for PBL classification

Development of an objective and site independent classification of the PBL regarding the presence of mixing and the origin of the turbulence using Doppler Lidar

Quantities used:

Attenuated backscatter β

Height of the aerosol layer
Cloud detection

Requires sufficient amount of aerosols as tracer for air motion

Vertical velocity skewness

Source of turbulence (surface or cloud)

$$s = \frac{\overline{w'^3}}{\overline{w'^2}^{3/2}}$$

TKE dissipation rate ε

Identify turbulent regions

Derived from vertical velocity variance (O'Connor et al., 2010)

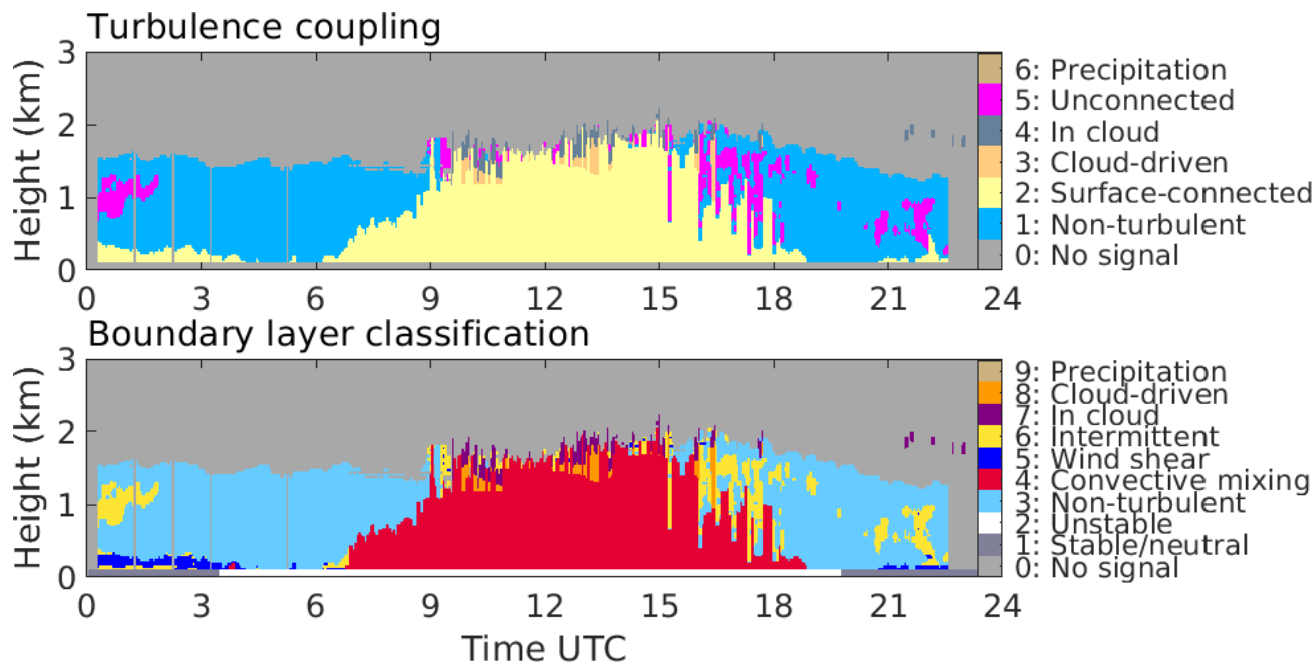
Vector wind shear

Indicates shear driven turbulence

$$U_{shear} = \frac{\sqrt{\delta u^2 + \delta v^2}}{\delta z}$$

Doppler wind lidar for PBL classification

- Identification of turbulent regions that are driven by surface fluxes or clouds.
- Better understand complex mixing processes and their evolution.



Manninen et al., 2018

Combination of DWL and MWR



- Horizontal and vertical wind in PBL until cloud base
- Turbulent properties



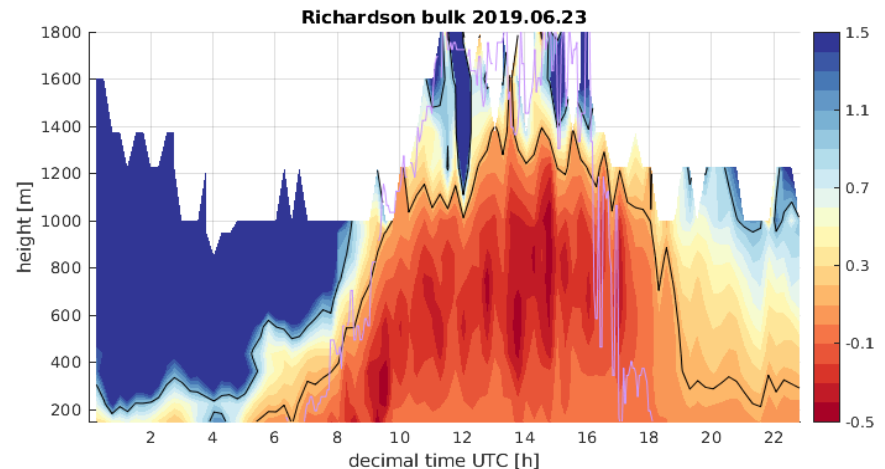
Synergistic product

combining dynamic and thermodynamic characteristics:

Richardson-Bulk number



- Temperature profiles
- Thermal stability



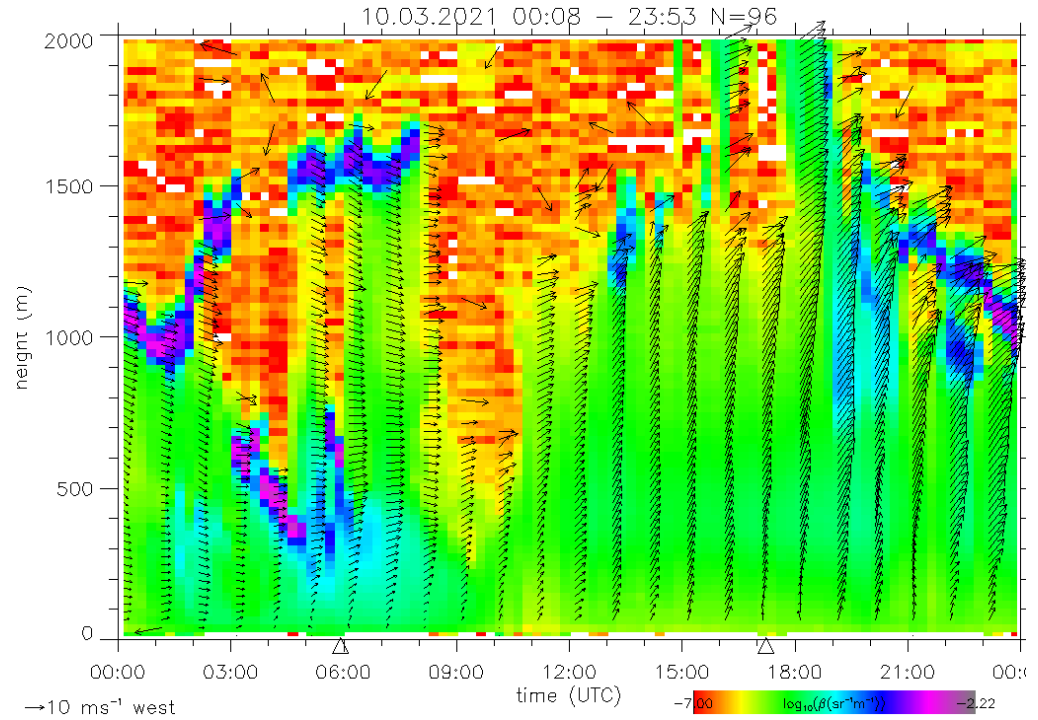
Wind profiles from lidar and radar

- Detection needs tracers that float with the air flow
 - Doppler cloud radar (DCR) tracers: Cloud particles, Insects
 - Doppler wind lidar (DWL) tracers: Aerosols
- **Problems/Limitations:**
 - Absence of tracers
 - Fall speed of particles (esp. rain)
 - Own movement of tracers (insects)
 - Attenuation of signal (esp. by clouds for DWL)
 - Assumption of homogeneous wind field (turbulence)
- **Combination of methods (DCR+DWL) increases coverage**

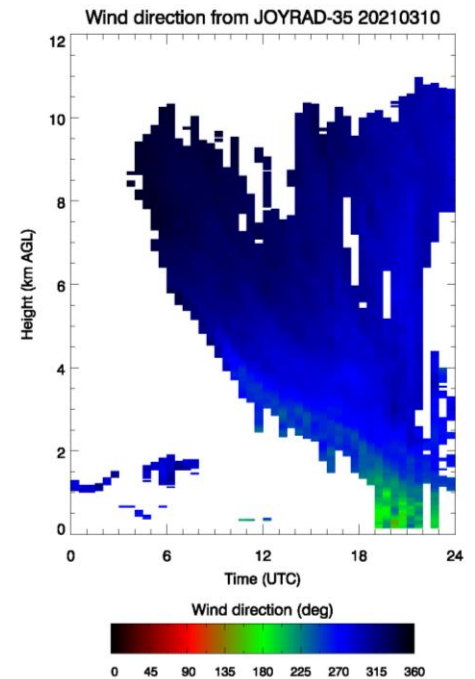
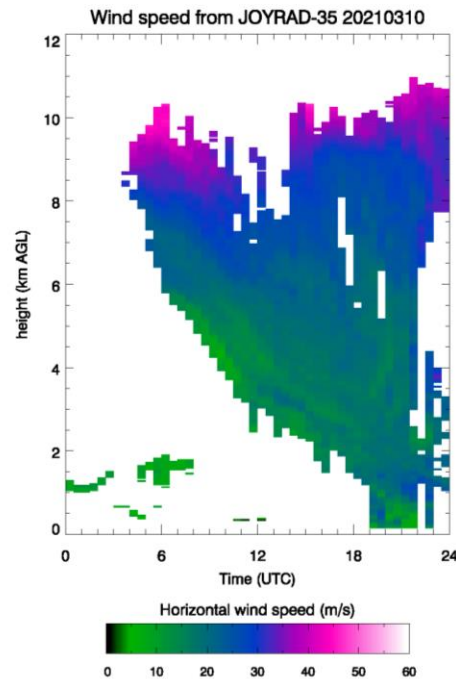


Example day 10 March 2021

- Wind lidar (0-2 km)

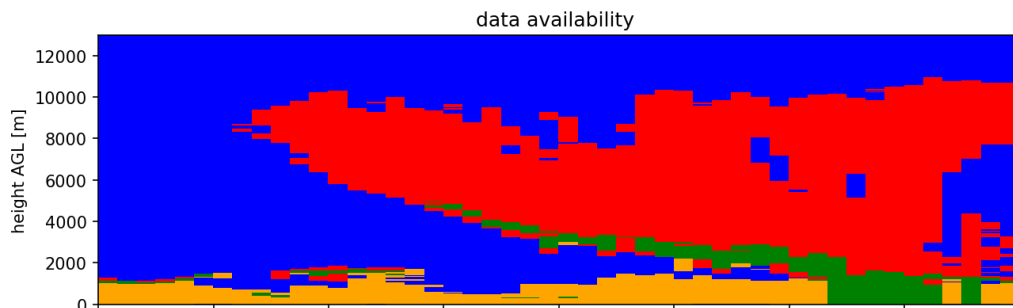


- Cloud radar (0-12 km)

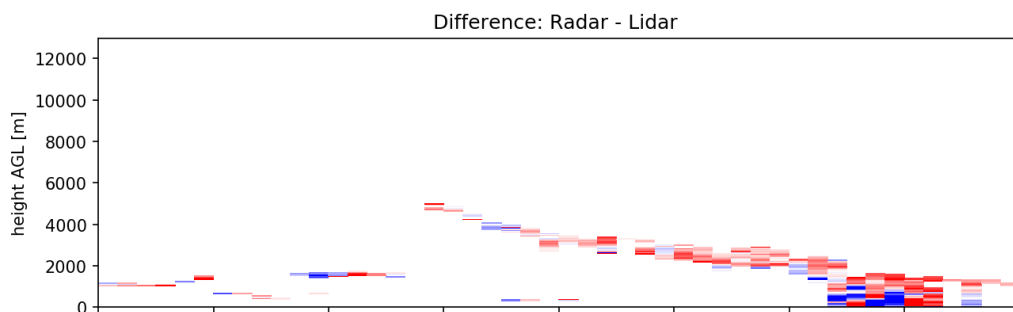


Example day - Wind direction

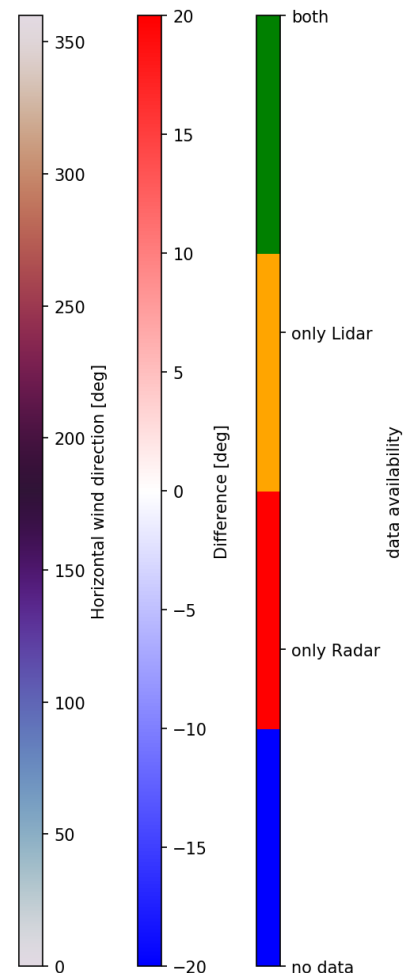
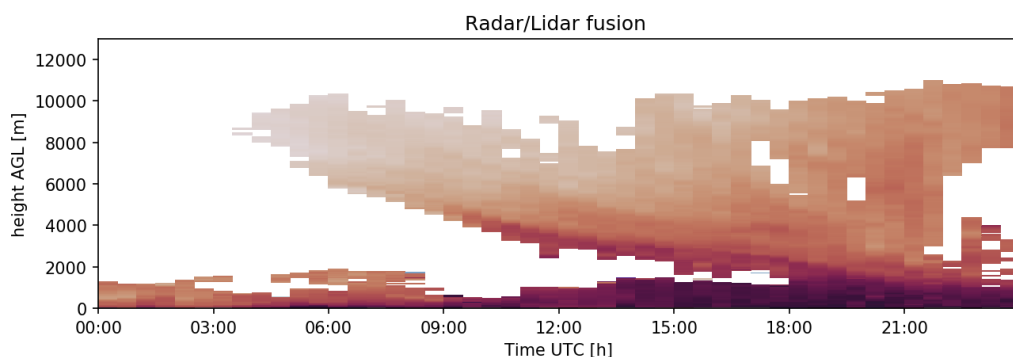
availability



difference
radar-lidar

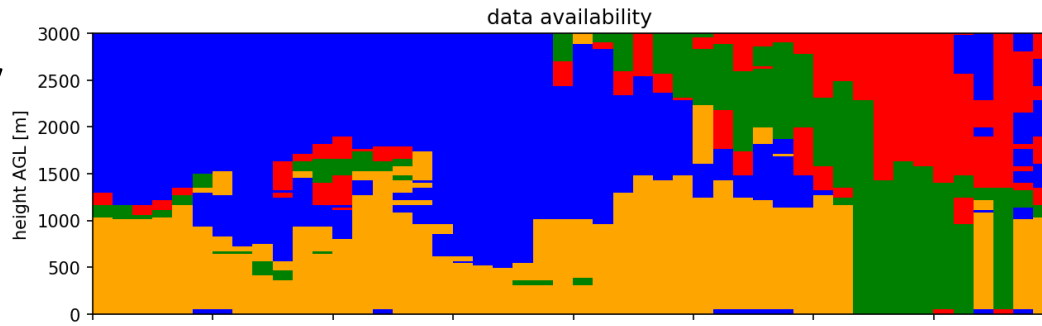


fusion

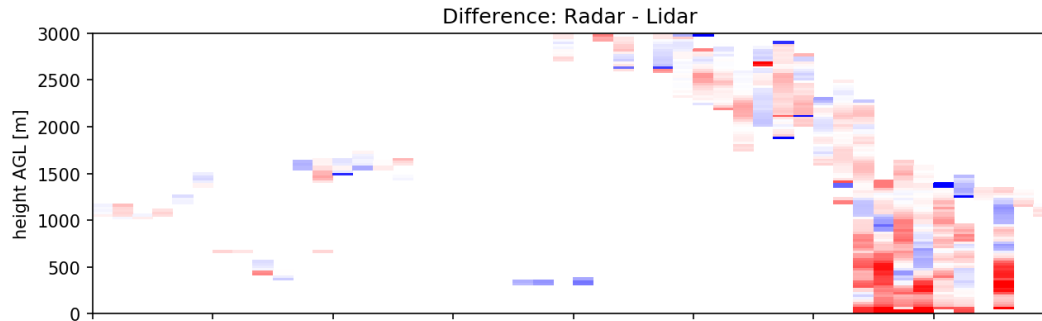


Example day - Wind speed boundary layer

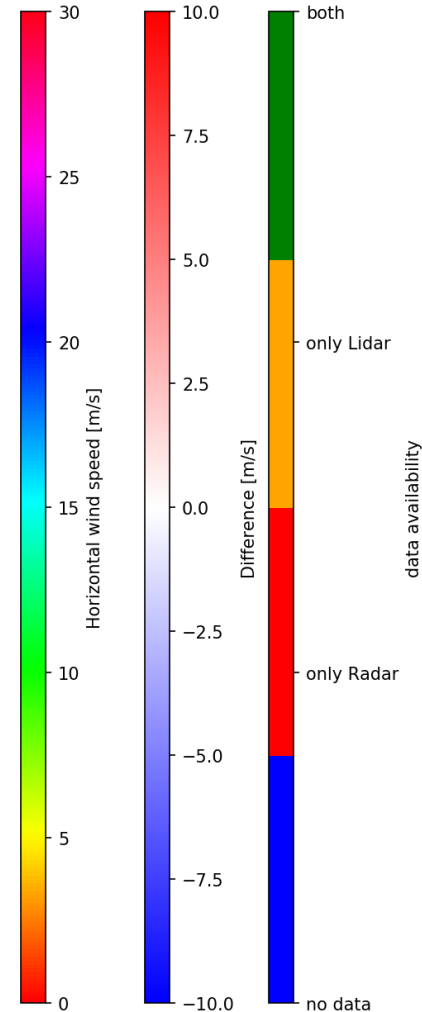
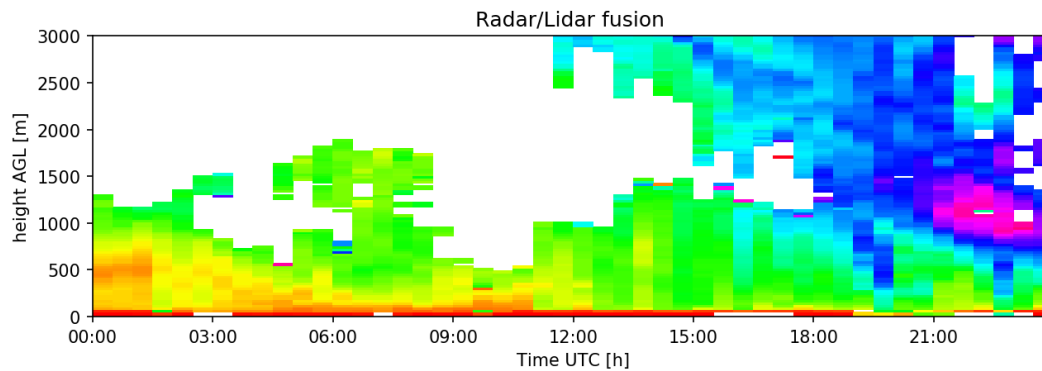
availability



difference
radar-lidar



fusion



Potential for wind forecasting

- Study on future, potential network configurations
- How many DWL do I need to improve the short-term wind forecast?
- Use of existing ACTRIS and E-Profile networks



Benefits of Doppler wind lidars to improve short-term low-level wind forecasts

Nomokonova et al.,
2022

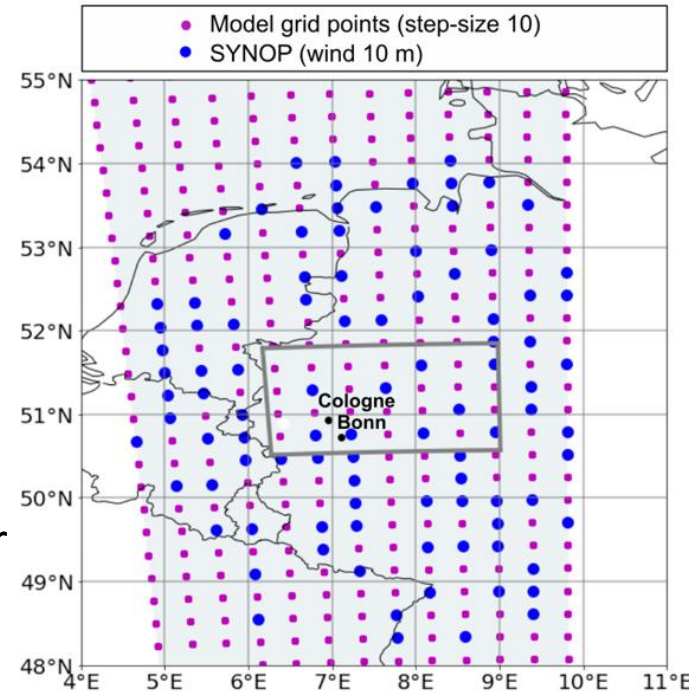


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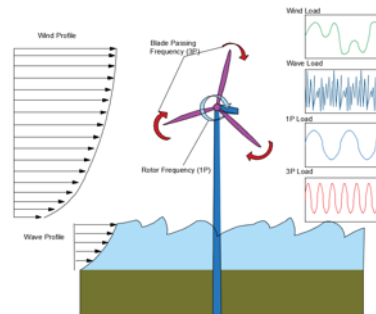
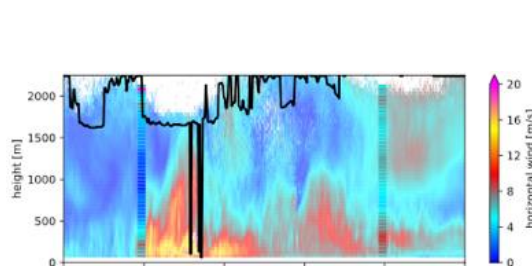
Methodology: Ensemble Sensitivity Analysis (Ansell and Hakim (2007)) to estimate relative variance change.

1. **SCALE-RM 1000-member ensemble** (Necker et al., 2020) over Germany (**3 km**)
2. 16 initial times covering 8 days in May/June 2016
3. Target: **domain averaged 80 m wind** component over Rhein-Ruhr-Metropolitan Area (*typical hub-height of wind turbines*)



4) Incorporated observations:

- **wind at 10 m** (SYNOP stations)
- **wind profiles: 1 to 5 levels** included: 80, 429, 1062, 1853, 2845 m



Results: Variance reduction

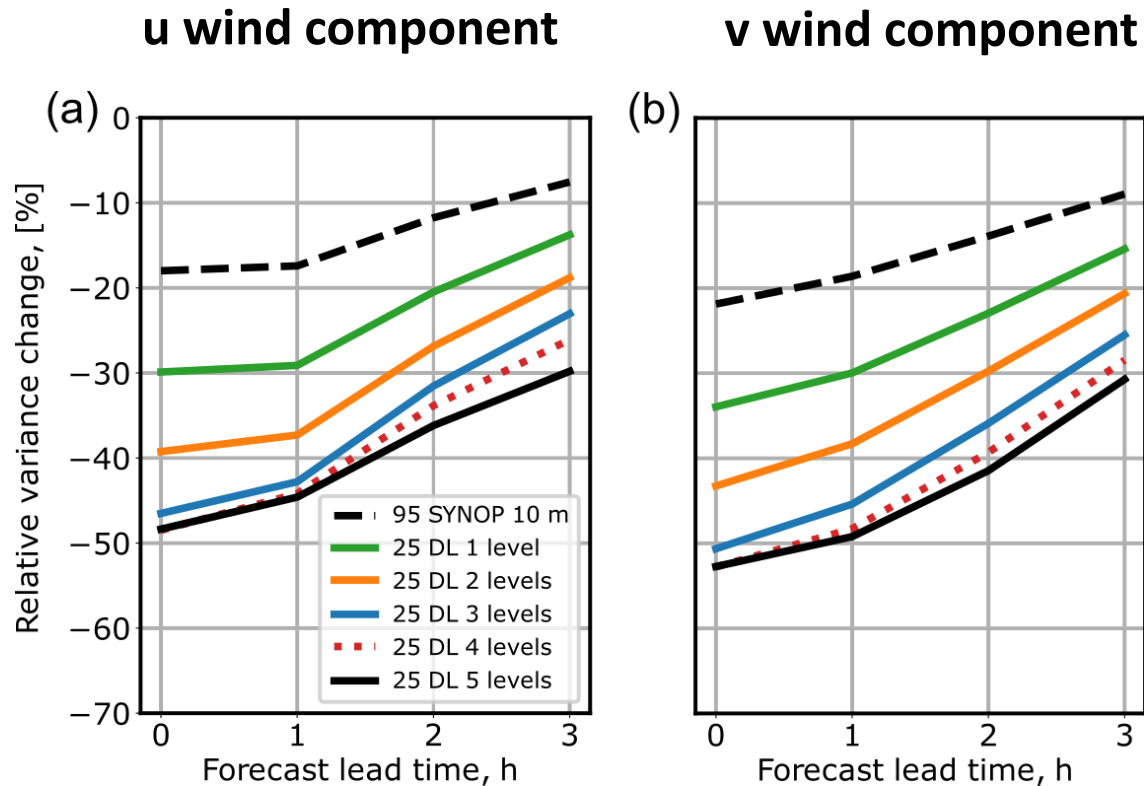


Figure adopted from Nomokonova et al., 2022

- DL network beneficial for short-term forecast of low-level wind (80m): up to **3 times more valuable** than SYNOP observations
- **Most cost-efficient improvement with 25 DWL: corresponds to an installation of 1 DWL at every 4th SYNOP site > 40-50 DWLs over Germany**
- Impact of DL network strongly depends on vertical ABL penetration depth, **best results if lidar can penetrate lowest 1 km.**

Summary

- Novel methods for retrieving wind profiles from ground-based remote sensing networks
- Observation of wind gusts possible with rapid scanning
- Combination of DWL with MWR to improve PBL observations
- Synergy of DWL+DCR for wind profiles
- All methods are being applied to operational networks
- Potential of DWL networks for data assimilation



Thank you !

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<http://joyce.cloud>