EMS Annual Meeting
Corvinus University of Budapest, Hungary
03 – 07 September 2018

Deutscher Wetterdienst
Wetter und Klima aus einer Hand

An attempt to synthesize tower, sodar, lidar and radar wind measurements into a composite wind profile

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The Lindenberg Meteorological Observatory – Richard-Aßmann-Observatory (German Meteorological Service, DWD) has been performing operational wind measurements from the surface layer up to the lower stratosphere using different in-situ and remote sensing techniques over almost two decades. Sensors and systems employed cover cup anemometers mounted on masts up to a height of 99 m, Doppler sodar, Doppler lidar (since 2014), and radar wind profiler. The single records of wind data from these systems at different heights are typically used independently of each other for a variety of applications, including data assimilation, validation and verification in numerical weather prediction and the analyses of wind power conditions.
These systems fundamentally differ in the measurement physics, height range covered, height and time resolution of derived mean wind vector, and data availability. This may result in different wind values at a given height where data from several systems are available.
To further support the use of the wind profile data for model validation a project has been defined aimed at the development of a robust method that provides consistent composite wind profiles across the troposphere (from 50 cm above ground up to a maximum height of 16 km) based on the measurements with different systems. These profiles are finally averaged over 30 minutes and affiliated to a model grid point close to the Lindenberg site (WMO-ID 10393, Germany). An important objective was the estimation of uncertainties for each individual wind vector value representing both the instrumental uncertainty and the uncertainty due to spatial and temporal variations of the wind field. Composite wind profiles have been created over a period of more than four years.

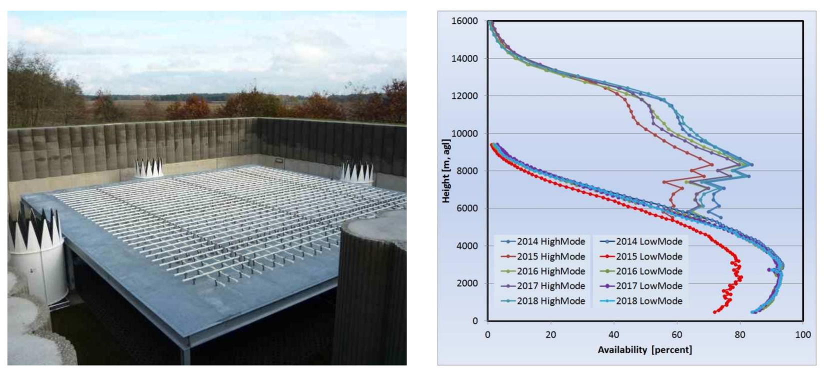

Figure 1: 482-MHz Windprofiler Radar (WPR) completed with sound sources to a Radio-Acoustic Sounding System (RASS) operates with different height resolutions (vertical resolution in the so-called Low Mode: 94 m, in the High Mode: 314 m). The wind data availability reaches 90 % at heights from 2000 m to 3000 m (right panel).

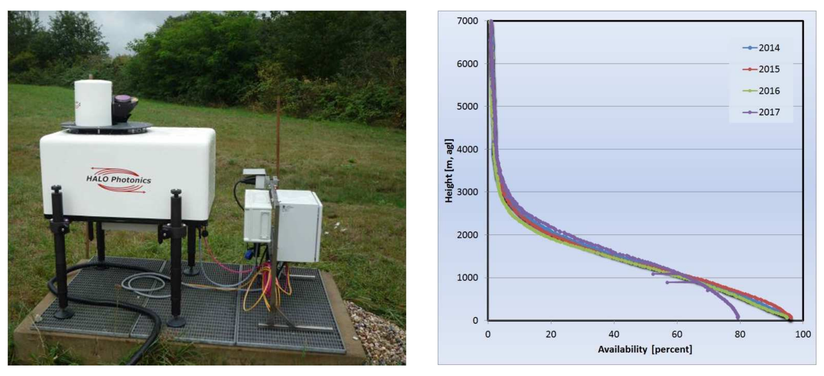

Figure 2: The IR Doppler lidar "Streamline" from HALO Photonics (λ = 1,5 µm) is most sensitive to aerosol particles (100 nm to 10 µm in diameter). Therefore wind data availability decreases quickly with height (right panel).

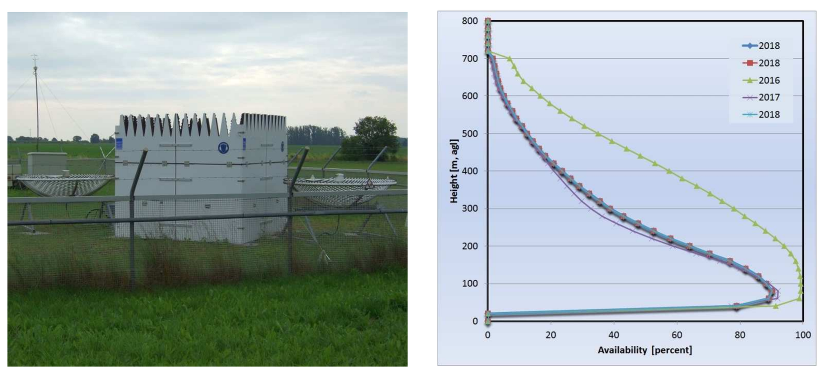

Figure 3: Sodar measurements at MOL-RAO are usually limited to the lowest 200 m to 300 m (right panel).

Figure 4: A 10-m mast (left) and a 99-m tower (right) deliver wind data with over 98% availability.

First steps

The project started with statistical investigations of the measuring differences between the individual devices (or measuring methods) for comparable heights. In addition, it was determined how different surface characteristics over a distance of 5 km affect the wind profile (see Fig. 5).
With the experience of these comparisons performed for a dataset of 4 years, measurement uncertainties could be assigned to each system. Data quality information for the single systems is considered in the uncertainty estimation. For Doppler lidar measurements, an additional error is considered that depends on signal strength and on the quality of the sine-wave model fit (*Päschke et al., 2015).*

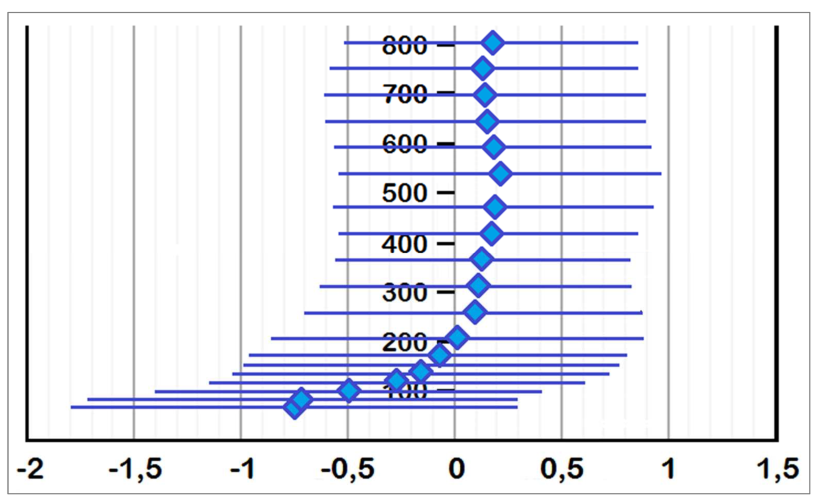

Figure 5: Profiles of mean wind speed differences and their standard deviations between two different sites (open meadow in an agrarian landscape vs. wooded hilly landscape with some buildings) measured by two Doppler lidars in winter 2016/17.

Vectorial averaging

Remote sensing winds are a-priori vectorially averaged. Also, as far as possible, the 30-min-mean for the tower data has been calculated from the 10 min cup anemometer and vane data vectorially.

Uncertainty of single measurement values of wind speed and direction

All measured values and uncertainties are converted to a uniform height grid. This must also be done vectorially. The uncertainties of the wind components u and v are composed of uncertainties of the wind speed <u>and</u> wind direction.

Weighting

For each height, a weighted average and a mean error of the weighted average are calculated from the available data, following the concept of Gränicher (1996), who distinguishes between internal and external consistency and assigns the maximum value of both errors (Equation 1 and 2) as uncertainty of the weighted mean

$$s^2_{m,int} = \frac{1}{\sum_i 1/s_i^2} \qquad (1)$$

$$s^2_{m,ext} = \frac{[p(x-\bar{x})^2]}{(N-1)[p]} \qquad (2)$$

with $p_i = 1 / s_i^2$.

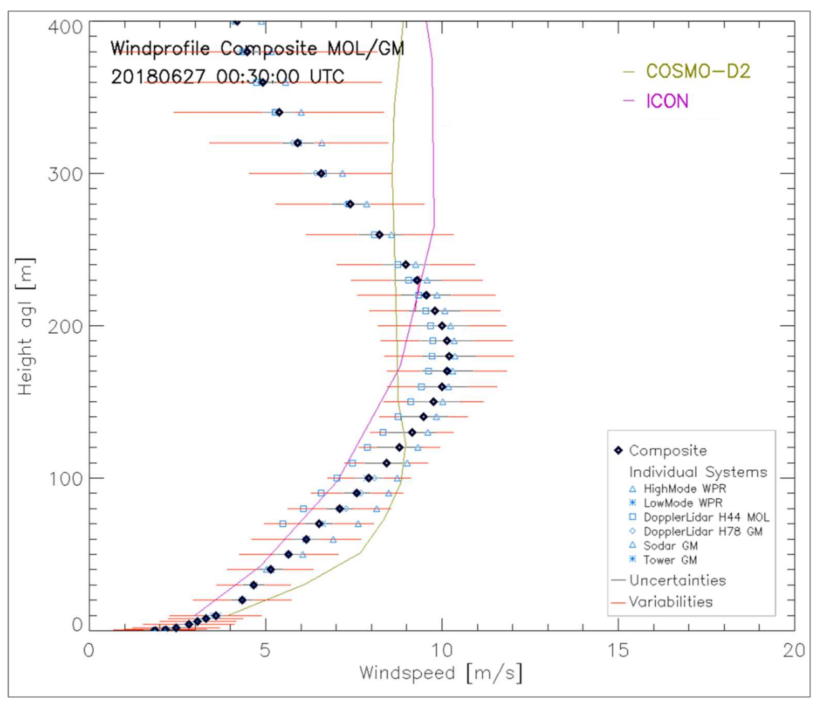

Figure 6: Example of a composite wind speed profile derived from different instruments compared to model data up to 400 m.

From the weighted uncertainties for the wind components u and v uncertainties for speed and direction are derived by means of an iterative method. This can lead to larger uncertainties in wind direction at low wind speeds. In synthesizing the data, gap filling is performed with application of strict rules concerning the maximum number of time steps and height levels to be filled.

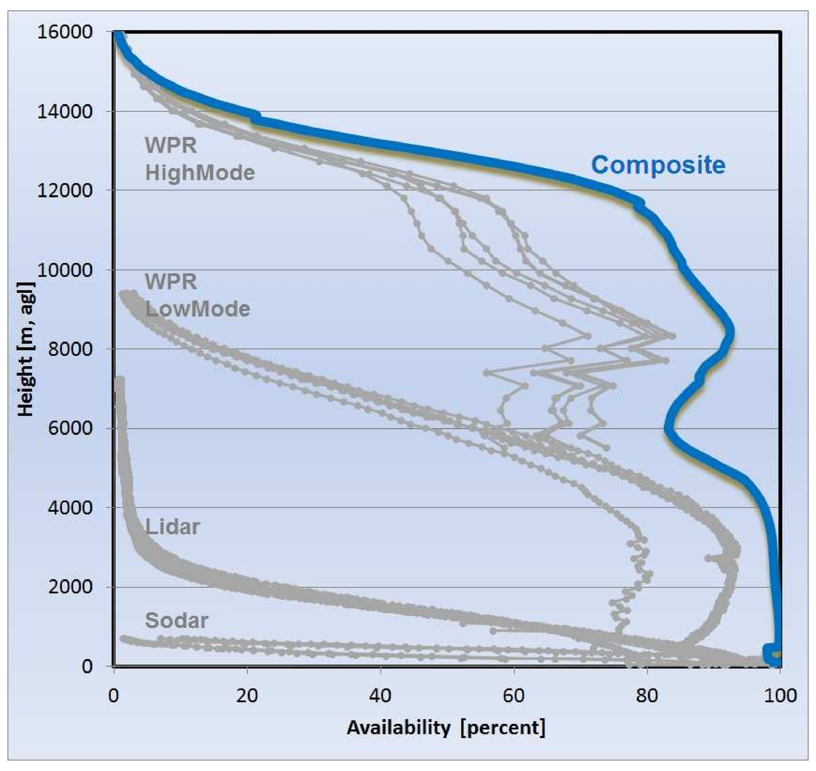

Figure 7: Composite data availability with height over the period January 2014 to August 2018.

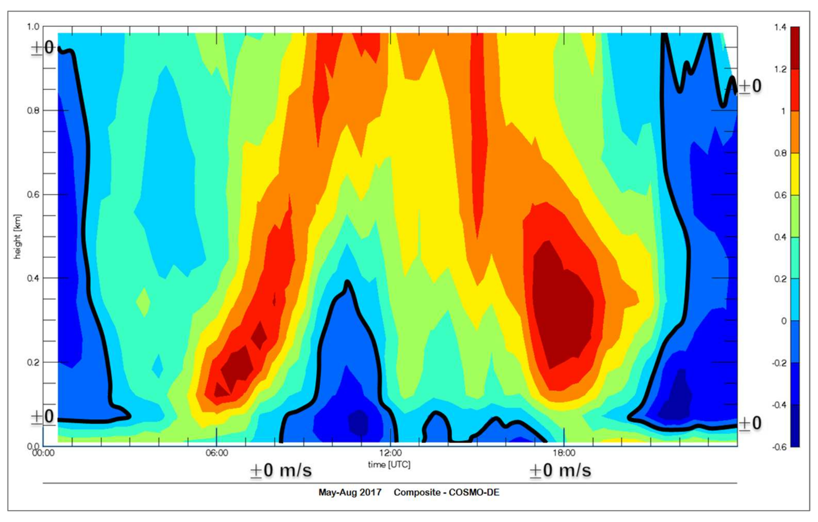

Figure 8: Composite wind speed minus model prediction (COSMO-DE, 12 to 24 hours forecast), the mean difference in summer 2017 shows an underestimation of wind speed in the region of convective boundary layer top and an overestimation near ground during the day.

In any case gap filling increases the uncertainty of the composite value.

Model comparisons and mean wind profiles

The composite wind data support both the verification of wind forecasts by the different Numerical Weather Prediction models of DWD (Fig. 8) and the derivation of wind-climate products (Fig. 9).

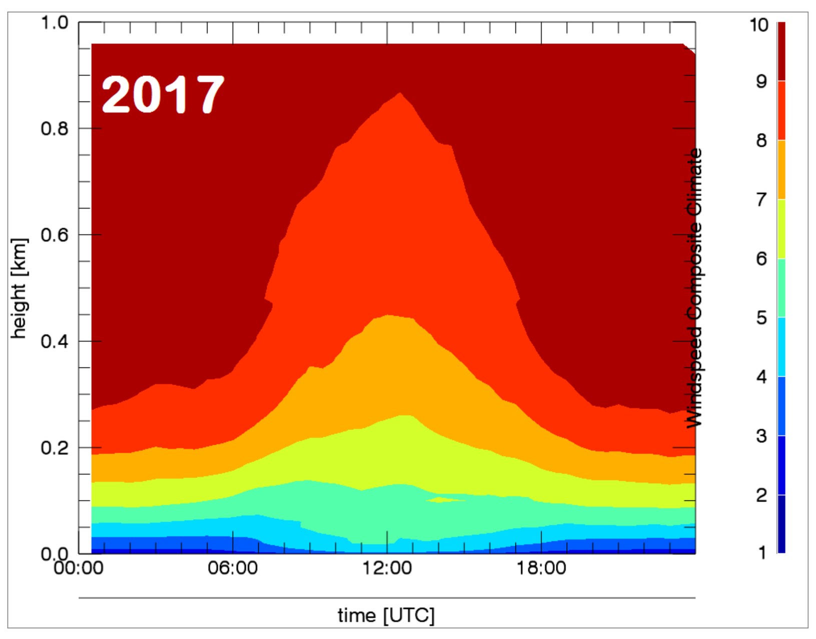

Figure 9: Daily circle of composite wind speed as annual average (2017) up to the height of 1 km.

References:

Päschke, E., Leinweber, R., and Lehmann, V. (2015): An assessment of the performance of a 1.5 µm Doppler lidar for operational vertical wind profiling based on a 1-year trial, Atmos. Meas. Tech., 8, 2251-2266, doi:10.5194/amt-8-2251-2015.

Gränicher, W. H. (1996): Messung beendet, was nun? Einführung und Nachschlagewerk für die Planung und Auswertung von Messungen. ETH Zürich; Stuttgart: Teubner

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