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Doppler Lidar Motion-Correction Wind Profiles (DLMCPROF-WIND) Value-Added Product Report

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Acronyms and Abbreviations

ARM	Atmospheric Radiation Measurement
ASCII	American Standard Code for Information Interchange
DBS	Doppler beam-swing
DL	Doppler lidar
DLMCPROF-WIND	Doppler Lidar Motion-Correction Wind Profiles Value-Added Product
DLPROF-WIND	Doppler Lidar Horizontal Wind Profiles Value-Added Product
DOE	U.S. Department of Energy
IR	infrared
MOSAiC	Multidisciplinary drifting Observatory for the Study of Arctic Climate
netCDF	Network Common Data Form
PPI	plan position indicator
QC	quality control
SNR	signal-to-noise ratio
UTC	Coordinated Universal Time
VAP	value-added product

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1.0 Introduction

Wind speed and direction, together with pressure, temperature, and relative humidity, are the most fundamental atmospheric state parameters. Accurate measurement of these parameters is crucial for numerical weather prediction. Vertically resolved wind measurements in the atmospheric boundary layer are particularly important for modeling pollutant and aerosol transport. The U.S. Department of Energy (DOE) Atmospheric Radiation Measurement (ARM) user facility currently operates several scanning coherent Doppler lidar (DL) systems that provide accurate height-resolved measurements of wind speed and direction.

These instruments operate in the near infrared (IR;1.5 microns) and provide range-resolved measurements of radial velocity, attenuated aerosol backscatter, and signal-to-noise ratio (SNR). The systems are operated using a fixed scan schedule consisting of plan position indicator (PPI) or Doppler Beam-Swing (DBS) scans. PPI scans are performed by scanning the beam in azimuth while maintaining a fixed elevation angle, and DBS scans are similar but typically also include a vertical beam. Radial velocity data from these scans are processed to yield profiles of wind speed direction.

For stationary ground-based deployments, the Doppler Lidar Horizontal Wind Profiles (DLPROF-WIND) Value-Added-Product (VAP) provides height- and time-resolved measurements of the winds (Newsom and Krishnamurthy 2022). For operation on a moving platform, modifications to the existing DLPROF-WIND VAP are required to compensate for the effects of the platform motion. This report describes a parallel VAP, DLMCPROF-WIND, that was developed for computing motion-compensated wind profiles from ARM Doppler lidar data acquired during the Multidisciplinary drifting Observatory for the Study of Arctic Climate (MOSAiC) campaign, when the lidar was deployed on the German icebreaker *Polarstern*.

2.0 Input Data

During MOSAiC, the ARM Doppler lidar was set up to perform DBS scans throughout the campaign. Each DBS scan consisted of six slant-path beams with an elevation angle of 73°, and one vertical beam. The motion-corrected data from these scans are stored in the mosdlmcusrM1.b1 datastream. The data are organized such that each mosdlmcusrM1.b1 file contains 16 DBS scans. The total elapse time for each mosdlmcusrM1.b1 file is just over 6 minutes.

The DLMCPROF-WIND algorithm reads in data from the <*site*>dlmcusr<*facility*>.b1 datastream and parameters from one ASCII configuration file. The configuration file contains parameters used in generating quicklook plots, and a threshold value for the signal-to-noise ratio. Radial velocity estimates corresponding to SNR values below this threshold are not used in the computation of the wind profiles. We find that a threshold value of about 0.008 works well in rejecting most of the poor-quality radial velocity data.

In contrast to DLPROF-WIND, the DLMCPROF-WIND VAP uses only data from the lidar and does not require data from other datastreams. Specific variables required from <*site*>dlmcusr<*facility*>.b1 are listed in Table 1.

Table 1. Variables and global attributes from the <*site*>dlmcusr<*facility*>.b1 datastream used by the DLMCPROF-WIND VAP.

Variable Name	Description	Units
base_time	seconds since 1970-1-1 0:00:00 0:00	sec
time_offset	Time offset from base_time	sec
Range	Distance from lidar to center of range gate	M
Azimuth	Beam azimuth relative to true north	deg
elevation	Beam elevation relative to local horizon	deg
radial_velocity	Radial velocity (motion corrected)	ms^{-1}
attenuated_backscatter	Attenuate backscatter	$m^{-1}sr^{-1}$
intensity	Intensity (signal-to-noise ratio + 1)	unitless
Alt	Altitude above mean sea level	m
lat	Lidar latitude	deg
lon	Lidar longitude	deg

3.0 Algorithm and Methodology

The wind retrieval technique was adapted from the least-squares technique that ARM uses for processing its ground-based Doppler lidars (Newsom et al. 2017, 2022). When operating on a moving platform, wind profile scans will in general be tilted, as illustrated in Figure 1. To retrieve the winds at a given height, the DLMCPROF-WIND VAP first interpolates the radial velocities from each beam in the scan to a predefined uniform vertical grid. This step represents the only significant difference between the DLMCPROF-WIND and DLPROF-WIND VAPs. Computation of the wind vector at each vertical level then proceeds as in the DLPROF-WIND VAP. Assuming horizontal homogeneity, the wind vector at a given height is obtained by solving the following linear system:

$$\begin{pmatrix} \sum_i x_i^2 & \sum_i x_i y_i & \sum_i z_i x_i \\ \sum_i x_i y_i & \sum_i y_i^2 & \sum_i y_i z_i \\ \sum_i z_i x_i & \sum_i y_i z_i & \sum_i z_i^2 \end{pmatrix} \begin{pmatrix} u \\ v \\ w \end{pmatrix} = \begin{pmatrix} \sum_i u_{ri} \hat{x}_i \\ \sum_i u_{ri} \hat{y}_i \\ \sum_i u_{ri} \hat{z}_i \end{pmatrix}$$

where $x_i = cos\,\theta_i\, sin\,\phi_i$, $y_i = cos\,\theta_i\, cos\,\phi_i$, u_{ri} is the interpolated motion-corrected radial velocity, ϕ_i is the true azimuth angle, θ_i is the true elevation angle, and the summation is performed over all beams in the scan.

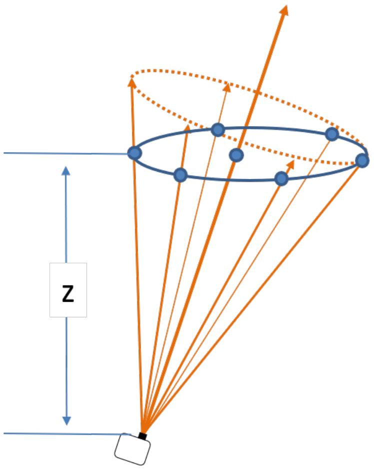

Figure 1. An example of a wind profile scan on a tilted surface. Winds are retrieved at height *z* by interpolating the radial velocities in each beam and then applying the least-squares retrieval technique on the interpolated data.

4.0 Output Data

During MOSAiC, the ARM Doppler lidar was operated with 30-m range gates, so the nominal height resolution for the derived wind profiles was 30sin(73°) = 28.7m. The DLMCPROF-WIND VAP was configured to process data from 100m up to a maximum height of 3 km, with grid spacing of 28.7m.

The DLMCPROF-WIND VAP produces a single netCDF file per day, and the output datastream name is <*site*>dlmcprofwind<*facility*>.c1. Fields contained in this datastream include the eastward and northward wind components (*u* and *v*, respectively), vertical velocity, and corresponding uncertainty fields. Also included are several fields useful for quality control, such as the mean signal-to-noise ratio (SNR), fit residuals, and linear correlations. Metadata fields include the total elapse time for all scans used in the result, and the number of beams used in the result.

Primary variables in the output datastream include the three wind components (*u*, *v,* and *w*), wind speed, wind direction, and corresponding uncertainty estimates. Other important variables in the output include the fit residual, the linear correlation coefficient, and the mean SNR. Variables are listed in Table 2.

Table 2. DLMCPROF-WIND output variable names, descriptions, and units.

Variable Name	Description	Units
base_time	seconds since 1970-1-1 0:00:00 0:00	s
time_offset	seconds since 00 UTC	s
height(	Height above ground level	m
scan_duration	time period for one profile	s
nbeams	number of PPI scans used in average	-
u	Eastward component of wind vector	m s-1

Variable Name	Description	Units
u_error	Estimated uncertainty in eastward wind component	m s-1
v	Northward component of wind vector	m s-1
v_error	Estimated uncertainty in northward wind component	m s-1
w	vertical component of wind vector	m s-1
w_error	Estimated uncertainty in vertical wind component	m s-1
wind_speed	Wind speed	m s-1
wind_speed_error	Wind speed uncertainty	m s-1
wind_direction	Wind direction	deg
wind_direction_error	Wind direction uncertainty	deg
residual	Fit residual	m s-1
correlation	Fit correlation coefficient	-
chisq	Fit chi squared	-
mean_snr	Signal-to-noise ratio averaged over nbeams	-
lat	North Latitude	deg
lon	East Longitude	deg
alt	Altitude above mean sea level	m

The primary variables contain missing values in regions where the SNR is below threshold. Users can apply additional quality control (QC) by filtering out wind estimates corresponding to large fit residuals and/or small linear correlation coefficients. QC can also be performed based on the relative wind speed uncertainty, i.e., wspd_error/wspd. Additionally, users can apply a higher SNR threshold than was used in the original processing.

5.0 Summary

The DLMCPROF-WIND VAP uses the output from the DLMC VAP to compute profiles of wind speed and direction. Both VAPs were developed specifically for processing raw DL data acquired during the MOSAiC campaign, when the ARM DL was deployed on the *Polarstern*. The VAPs are general enough to be used for most ship-based deployments.

The DLMCPROF-WIND VAP was developed by modifying the algorithm used by the existing DLPROF-WIND VAP. The primary modification involves the addition of a “preprocessing” step in which the beams in a given scan are interpolated to a predefined vertical grid. After that, the method of computing the winds at each level is the same as in the DLPROF-WIND VAP (Newsom and Krishnamurthy 2022).

The DLMCPROF-WIND VAP algorithm produces a single netCDF file per day. Primary variables include the three wind components (*u*, *v,* and *w*), wind speed, wind direction and corresponding uncertainty estimates.

6.0 Example Plots

Figure 2 shows wind speed and SNR from the DLMCPROF-WIND output for March and April of 2020, and Figures 3 and 4 show the results of a preliminary comparison with radiosonde observations. Figure 3 presents a comparison between the DLMCPROF-WIND and radiosonde wind speed and direction for 11 March 2020 at 16:47 UTC, while Figure 4 shows distributions of the wind speed and wind direction difference for the period from 8 October 2019 to 20 September 2020. The Doppler lidar indicates a slight slow bias of 39 cm s-1 relative to the radiosonde, while the wind direction is essentially unbiased.

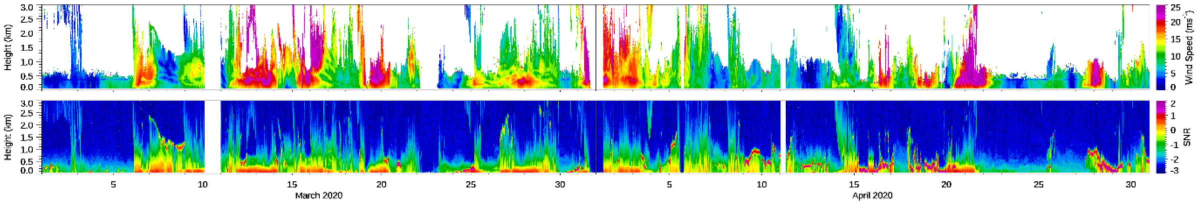

Figure 2. Wind speed (top) and SNR (bottom) for March and April of 2020. Regions of missing wind speed data are those regions for which SNR<0.008.

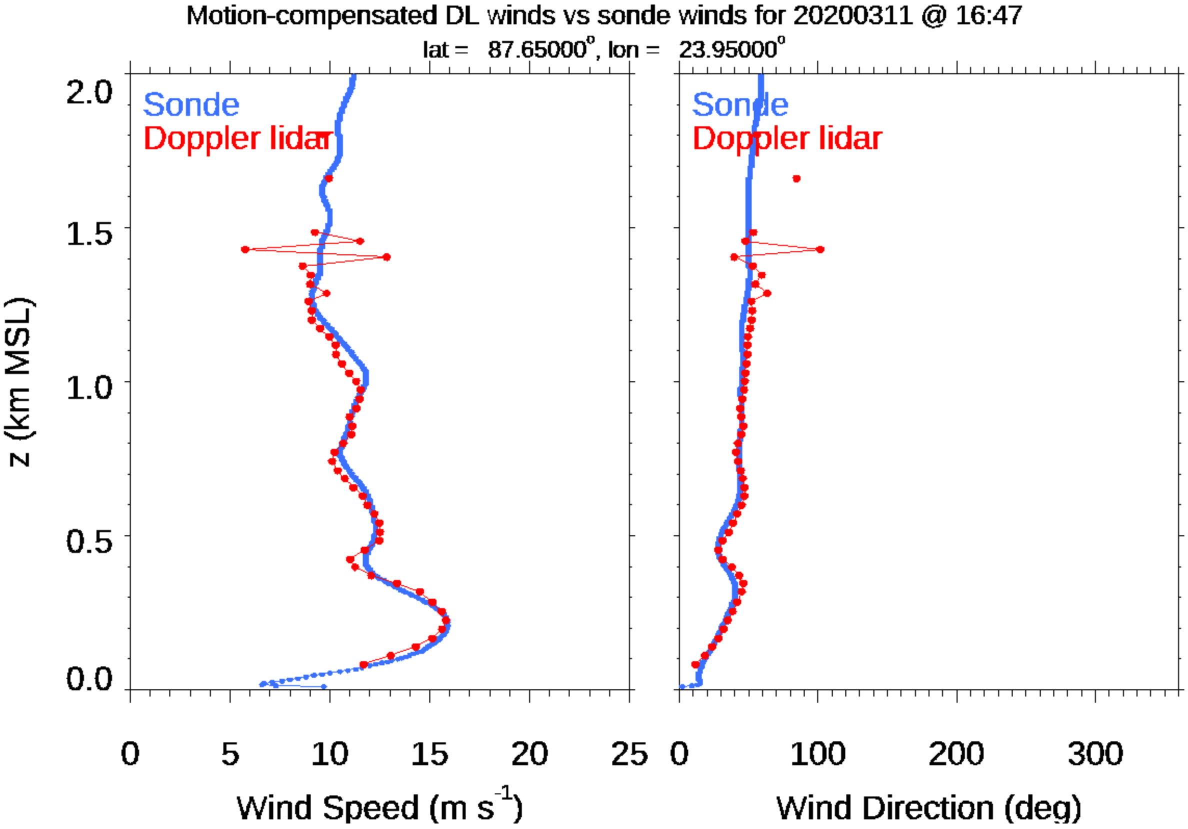

Figure 3. Comparisons between the radiosonde and the ARM Doppler lidar showing a) wind speed and b) wind direction profiles on 11 March 2020 at 16:47 UTC. The blue and red profiles correspond to the radiosonde and the Doppler lidar, respectively.

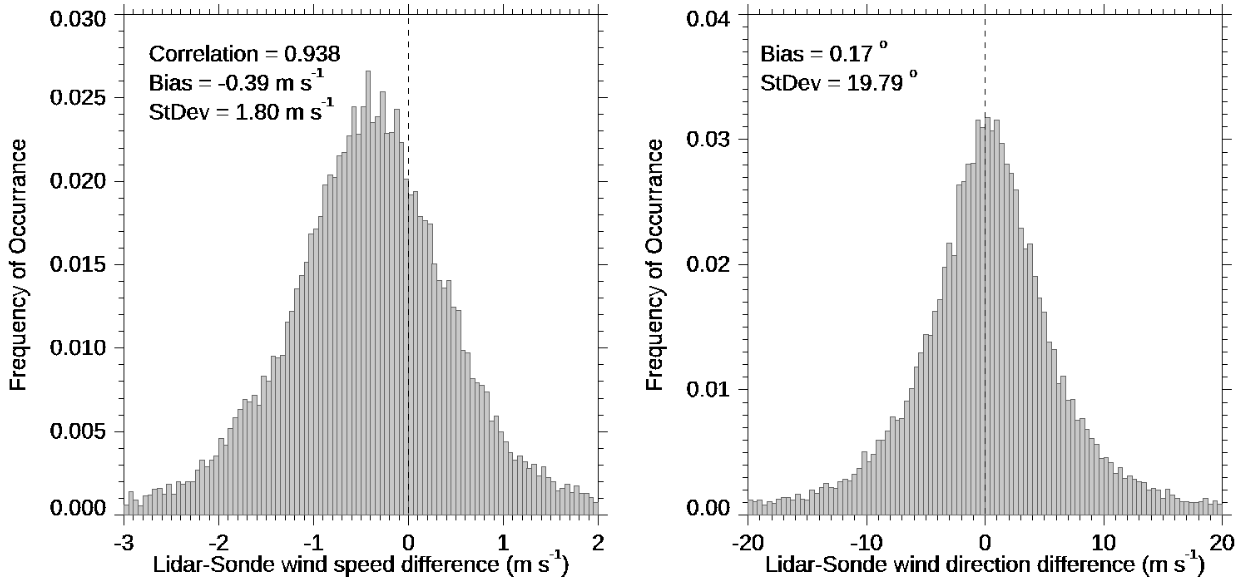

Figure 4. Distribution of the a) wind speed and b) wind direction difference between the Doppler lidar and the radiosonde for the period from 8 October 2019 to 20 September 2020.

7.0 References

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