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Improvement of VAD wind profile from Doppler lidar using accumulated spectra

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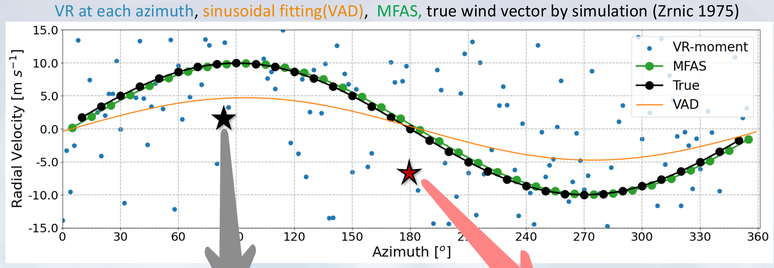
Introduction and Motivation

- The vertical wind profile is estimated using the velocity-azimuth-display (VAD) algorithm under the assumption of homogeneous wind field (Browning and Wexler 1968).
- The quality of the retrieved wind field is deteriorated at low signal-to-noise ratio (SNR).
- **This work focuses on improving the wind measurement at low SNR using accumulated spectra without compromising the spatiotemporal resolution.**

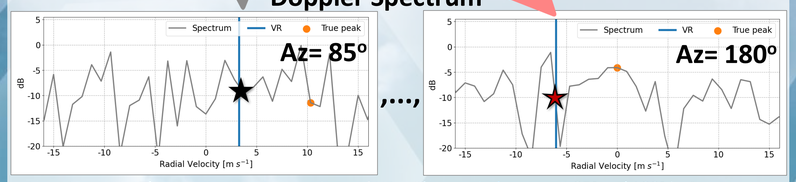
Methodology

Maximum of the function of accumulated spectra (MFAS) by Smalikho et. al. (2003)

VR at each azimuth, sinusoidal fitting(VAD), MFAS, true wind vector by simulation (Zrnic 1975)



Doppler Spectrum

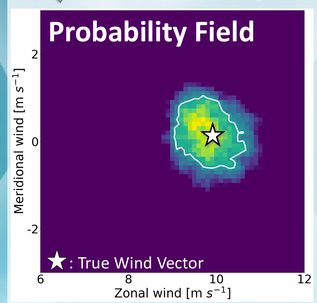


The power spectrum, estimated VR and true wind vector at 85° and 180° in Az

All Doppler spectrum mapping by

$$Vr_i = \boldsymbol{u} \cdot cos\beta cos\theta + \boldsymbol{v} \cdot sin\beta cos\theta + \boldsymbol{w} \cdot sin\beta$$

i = 1, 2, 3, . . . , N
N: the number of the Doppler velocity bins
θ, β: the elevation and azimuth angles of the lidar beam axis



- The MFAS is the technique of accumulating Doppler velocity bins from each spectrum in a probability field without estimating radial velocities at each azimuth angle, and then applying a sinusoidal fitting in the traditional VAD method.
- The horizontal wind is estimated by a weighting average of the probability field (enclosed by the white contour).

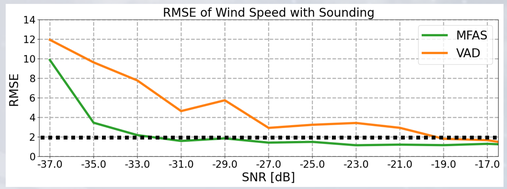
Metro Weather Coherent Doppler Lidar (CDL)



Parameter	Value
Wavelength	1.55 μm
Range Gate	75 m
Number of sampling (FFT Points)	125 (128)
Accumulative Pulses	1024
Pulse Width	0.5 μs
Pulse Repetition Frequency	5 kHz
Sampling Frequency (Nyquist Velocity)	250 MHz (~96.9 m s^{-1})

Scanning Strategies			
Temporal Resolution	2 mins	Elevation Angle	PPI with 60°, 90°
Angular Resolution	1.23°	Experiment Period	Sep. 21–Nov. 26, 2024 (67 days)

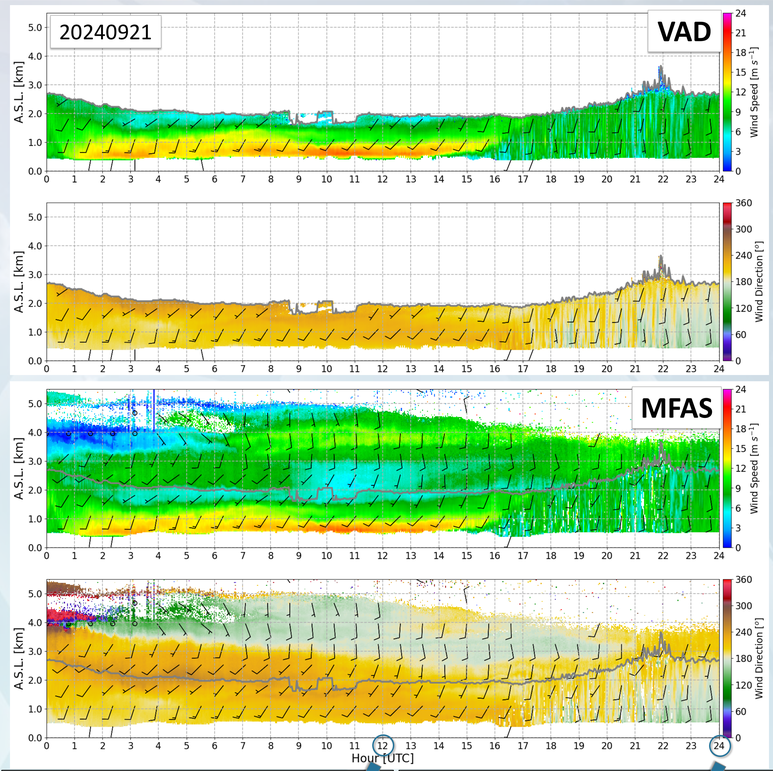
Quality control of retrieved wind → finding SNR threshold

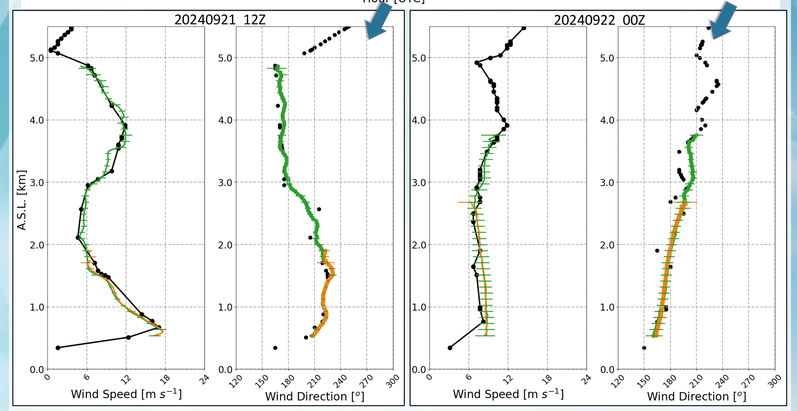


MFAS	SNR_{avg} < -33 dB
VAD	SNR_{avg} < -19 dB

SNR_{avg}: The SNR with azimuth average

Case Study

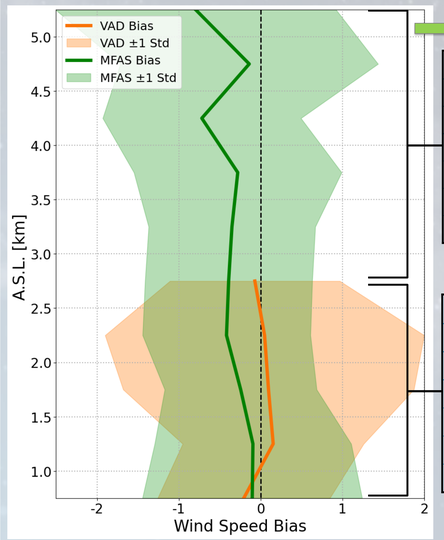




- The MFAS-derived wind vector extends up to 5 km during nighttime, exceeding the range achieved during daytime.
- Wind speed and wind direction exhibit the high similarity with sounding data at 00 and 12Z.

Statistical Analysis of Performance

	Number of Profile	Data Selection
CDL	Sep. 21–Nov. 26, 2024 (N= 131)	Within 50 m of the sounding and 45–15 mins before launch
Sounding(OUN)		A.S.L. > 0.6 km



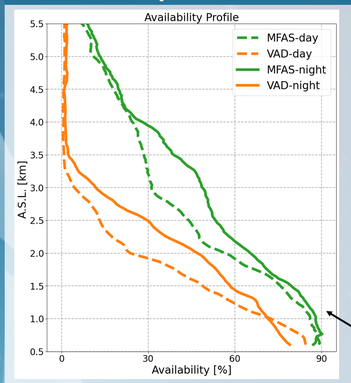
Extended range by 2.5 km

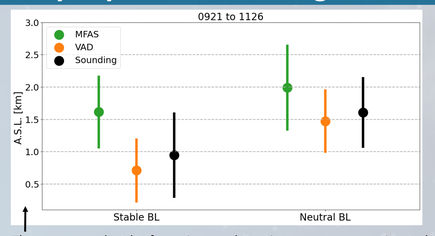
MFAS		
N	474	
	R	RMSE
U	0.98	1.32 m s^{-1}
V	0.99	1.17 m s^{-1}
WS	0.97	1.32 m s^{-1}
WD	0.99	7.99°

MFAS/VAD		
N	1116/740	
	R	RMSE
U	0.97/0.97	1.18/1.36 m s^{-1}
V	0.98/0.98	1.35/1.36 m s^{-1}
WS	0.92/0.95	1.16/1.45 m s^{-1}
WD	0.99/0.99	13.00/12.20°

- **Below the 2.75 km, the VAD- and MFAS-derived wind vectors are highly correlated with sounding.**
- **Above the 2.75 km, only MFAS-derived wind vector is reliable, whereas the VAD is not working due to the low SNR.**

Comparison of Boundary Layer Wind Coverage





The mean and std of maximum detection range are estimated using the MFAS and VAD before launch, respectively. The BL height is determined using the sounding by Liu and Liang (2010).

The availability of wind vector during daytime (12-24Z) and nighttime (0-12Z) by the MFAS and VAD, respectively.

- The wind vector within the boundary layer (BL) is fully measured using the MFAS.
- Above the 1 km, the availability is higher during the nighttime at Norman, OK in the fall.
- The availability of MFAS-retrieved wind vector during daytime is greater than it of the VAD-derived wind vector.

Conclusion

- Both VAD and MFAS provide reliable wind estimates to the height of 2.75 km.
- The MFAS extends the observation height to approximately of 5.5 km where the SNR is as low as -33 dB.
- For both stable and neutral conditions, only MFAS can provide wind estimates to the top of boundary layer.
- The availability of MFAS wind estimates during nighttime can reach 90% below 1 km.

References:

Browning, K. A., and R. Wexler, 1968: The determination of kinematic properties of a wind field using Doppler radar. *J. Appl. Meteor.,* **8**, 105-113.
Liu, S., and X.-Z. Liang, 2010: Observed diurnal cycle climatology of planetary boundary layer height. *J. Climate*, **23**, 5790–5809.
Smalikho, I., 2003: Techniques of wind vector estimation from data measured with a scanning coherent doppler lidar. *J. Atmos. Oceanic Technol.*, **20**, 276-291.
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