PO.182

Reducing Lidar Sensitivity to Atmospheric Conditions with Hybrid Wind Field Reconstruction

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Summary

Wind Field Reconstruction

Wind Field Reconstruction is a class of algorithms used to convert raw line-of-sight (LOS) lidar data into 10-minute average Cartesian wind components: horizontal wind speed, wind direction, vertical wind speed, and turbulence intensity. Generally, they include geometric translations, and averaging.

Scalar Averaging

Scalar averaging generates a new wind speed every second, using the last four line-of-sight (LOS) measurements. These 1 Hz wind speeds are averaged at the end of the 10-minute period to generate the average wind speed. This technique is used in WindCube v2.0, ZX300, and many other remote sensing devices

Vector Averaging

Using the same LOS data, vector averaging generates just one wind speed for each period using the 10-minute LOS averages. This technique is used in the Triton sodar and was initially the WFR chosen for WindCube v2.1.

Sensitivities to Turbulence

In an ideal case, with no turbulence, these two WFR equations are exactly equivalent. However, there is always some turbulencehe turbulence has different effects on the scalar and vector averages.

Scalar Averaging: Effects of Turbulence

The equation for the wind speed scalar average, when expressed as a Reynolds' decomposition (average + turbulent component) follows a Rice Distribution.

The Rice Distribution

Rice distributions are found in a variety of applications, including radio wave propagation (Rician fading) and synthetic aperture radar (SAR) imaging. Rice distributed-noise does not cancel out: it causes a positive bias that depends on the square of the turbulence. This turbulence-dependent bias is observed in scalar averaged WindCube data.

Vector Averaging: Effects of Turbulence

Summing vectors together includes both the wind speed and wind direction. If the direction of the wind is fluctuating, an key phenomenon of turbulence, the summation is affected by the turbulence. As the turbulence grows, the vector average gets shorter. Vector averaging creates a negative bias dependent on the square of the turbulence, observed in WindCube data.

Hybrid Averaging

These two turbulence sensitivities have opposite signs. Blending them via weighted linear combination mathematically eliminates the sensitivity to turbulence.

Field Campaigns

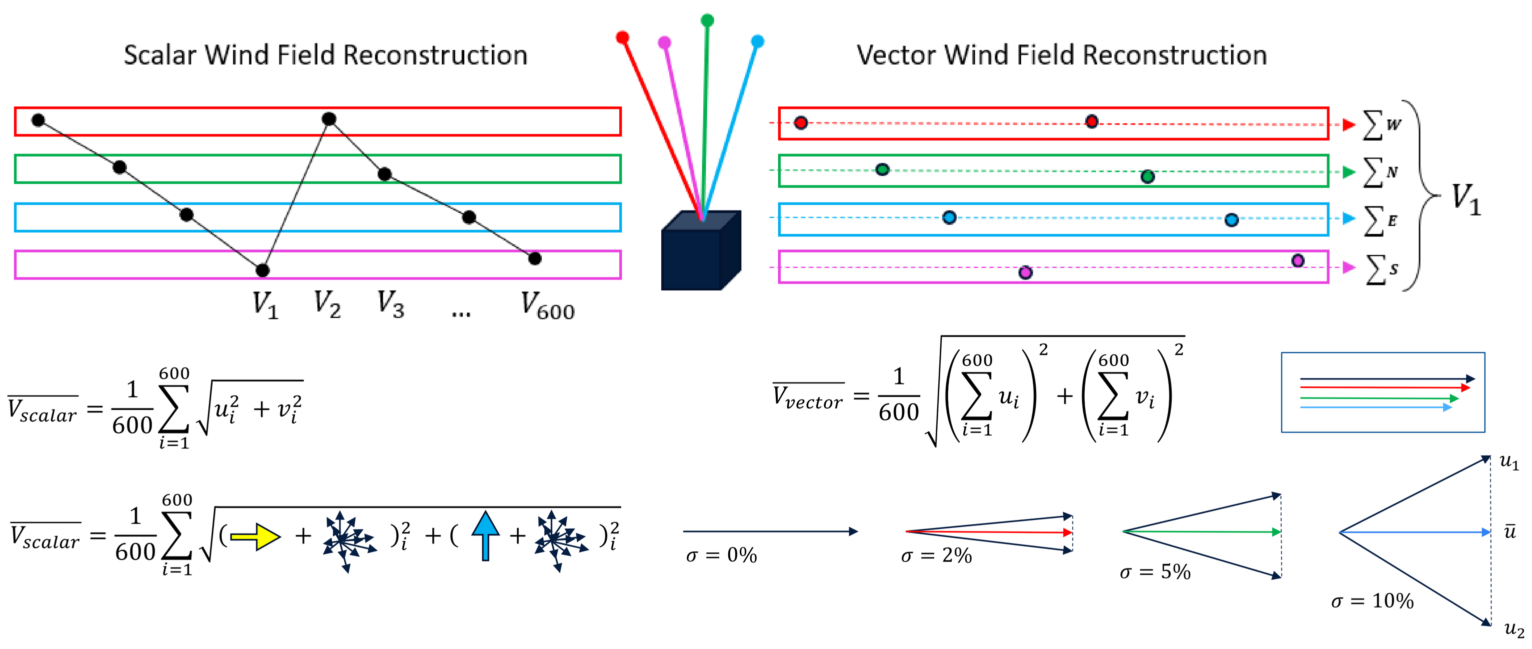
Following the IEC 61400-12-1 RSD Classification process, three WindCube v2.1s were tested for atmospheric sensitivities at two different sites. Hybrid averaging was found to reduce the sensitivity to turbulence, resulting in a reduction of 120m IEC Final Accuracy Class from 3.8% to 1.1%.

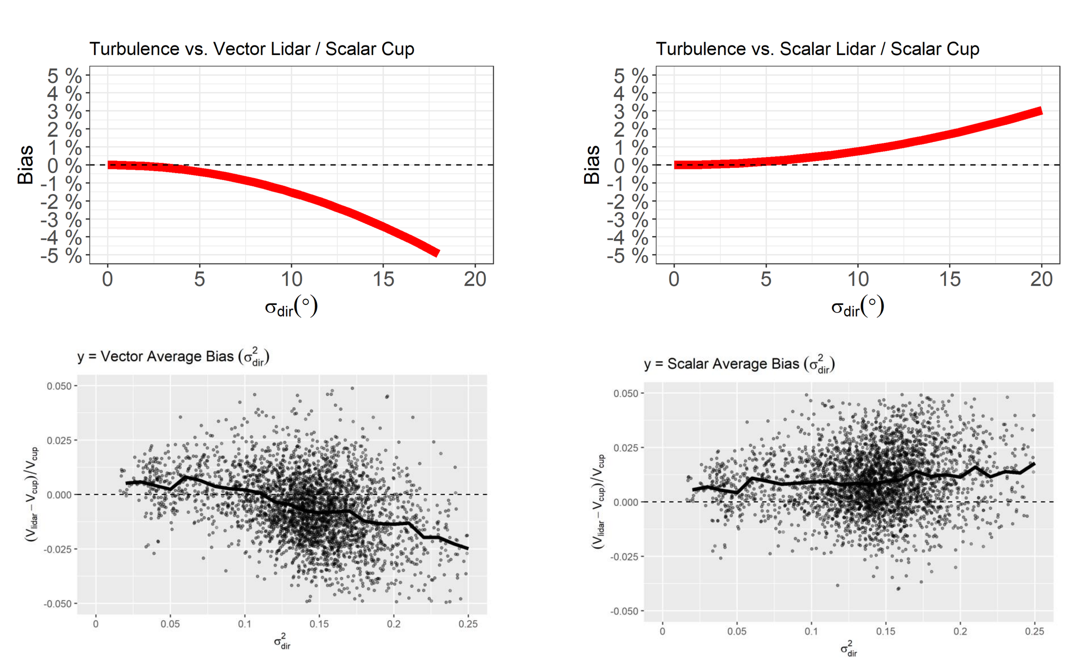
Conclusion

The theory of Hybrid WFR is confirmed in field campaigns and shown to significantly improve wind speed accuracy in WindCube v2.1 lidars.

By combining vector and scalar averaging, lidar wind speed sensitivity to turbulence is eliminated, leading to more accurate wind speed measurements

Additional Graphs and Tables





$$\overline{V_{vector,lidar}}\left(1 + \frac{1}{2}\sigma_{dir}^2\right) = \overline{V_{scalar,cup}}$$

$$V_{scalar,lidar} \sim V_{scalar,cup}\left(1 + \frac{1}{4}\sigma_{dir,cup}^2\right)$$

$$\begin{aligned} V_{Hybrid}^{lidar} &= \frac{2}{3}V_{scalar}^{lidar} + \frac{1}{3}V_{vector}^{lidar} \\ &= \frac{2}{3}V_{scalar}^{cup} + \frac{1}{3}V_{scalar}^{cup} + \frac{1}{6}\tilde{\sigma}^2 - \frac{1}{6}\tilde{\sigma}^2 \\ &= V_{scalar}^{cup} \end{aligned}$$

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