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Sodar Measurements During Periods of Precipitation: Results of New Rain Rejection Algorithm

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Abstract summary

A spectral decomposition is developed to identify the signature of rain in the Doppler shifted frequency spectra obtained by SoDAR equipment to measure the wind. The spectral decomposition is further processed to obtain simple rain metrics to be saved with the wind data at the end of each 10-minute data interval. When rain is detected, the method also provides a measure of rain intensity and estimates the degree to which the rain has degraded accuracy of the wind measurements. For light rain, wind measurement accuracy is shown to be improved using spectral cutoff frequencies shown in the decomposition.

Objectives

As the size and hub height of modern wind turbines increase, the need for valid data across the entire swept area becomes vital. SoDARs are being considered as an alternative to meteorological towers since SoDAR technology offers wind data up to heights of 200 m. One concern that has been raised with respect to SoDAR data, however, is its ability to measure accurate wind data during periods of precipitation.

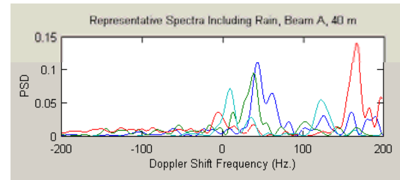
Errors in SoDAR measurements during precipitation arise from the Doppler shifted frequency component of falling precipitation particles. The magnitudes of the wind and rain spectral components vary randomly, so some particulate Doppler shift frequencies are averaged with those of the wind, yielding incorrect wind averages. Because the echo from the particles is, at times, quite strong, the SoDAR may report high data quality even though the measured wind speeds are wrong.

The filtering method presented detects the spectral signature of rain and provides the following indicators to be stored with each 10-minute, average wind reading:

•*Rain Confidence* - indicates the percent certainty that rain is present.

•*Wind Confidence* - indicates certainty that the wind readings are valid.

In addition, the filter provides improved wind measurement accuracy, for periods of light rain, by optimizing the spectral cutoff frequency for each SoDAR beam.



Reflections from the wind and the rain result in two spectral peaks.

Methods

Capture the spectral statistics from each SoDAR beam over a 10-minute sampling interval:

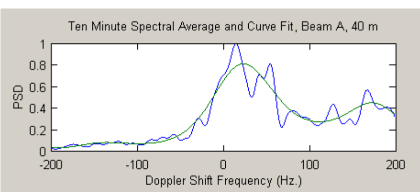
•Discard spectra with high noise level.

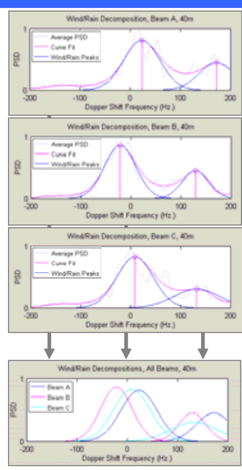
•Discard outlying spectra with very high peaks.

•Average power spectral densities over 10-minute interval.

•Fit a smooth polynomial curve to the logarithm of the average spectrum.

•A different curve is obtained for each SoDAR beam.

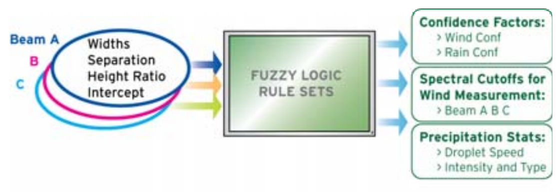




To decompose the spectrum into wind and rain components, wind and rain peaks are identified on the fit curve with a fuzzy rule set. A quadratic function is matched to the fit curve at each of the two peaks.

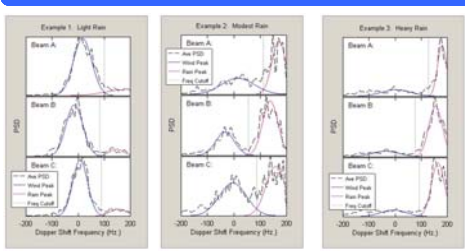
The exponential (inverse logarithm) of each quadratic yields the Gaussian shape of a normal distribution. The Gaussians capture the statistics of the wind/rain spectral components, and the intercept of the two Gaussian peaks divides the spectrum.

Spectral decomposition shows several distinctive characteristics during times of rain: First, the width of the wind peaks relates to turbulence intensity. Also, the height ratio between rain and wind peaks relates to rain intensity.The frequency separation between peaks relates to droplet terminal velocity. Finally, the intercept frequency provides a per-beam spectral cutoff for improved wind measurement.



Fuzzy logic rules are used to evaluate decompositions from all beams and at multiple heights. Commonality in two-peak decompositions gives confidence that rain is present. Separation between peaks gives confidence that wind measurements are valid. Spectral cutoffs are only used when wind peak is clear and separation is good.

Results

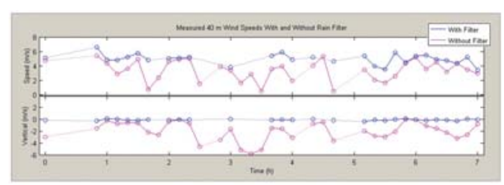


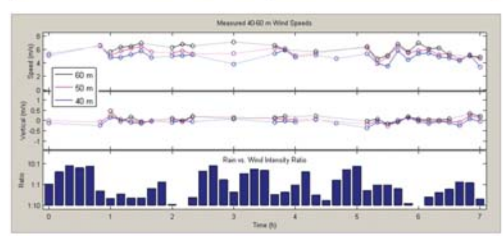
Example:	Confidence Factors: Precip (%)	Wind (%)	Rain/Wind Ratio (dB)	Rainfall Velocity (m/s)
1 Light Rain	15.7	100	-9.1	6.3
2 Modest Rain	100	86.2	3.1	6.4
3 Heavy Rain	100	10.4	9.2	7.0

The spectral decomposition is computed at 10-minute intervals and shows a large variation in relative intensity over the course of a rainy day. The three example plots show the differences between light, modest, and heavy rain. In light rain, the rain peak is slight but clearly distinguishable above the noise floor. In modest rain, both peaks are clear, and spectral interference from the rain degrades the wind measurement accuracy to a degree. In the heavy rain case, the wind peak is barely distinguishable, so the data quality is decidedly poor.

The comparative plot shows how the rain filter improves measured wind speeds over the course of a seven hour period of varying rain intensity. At times, the filter provides a more accurate reading of wind speed, through the use of spectral cutoffs. When rain is heavy, the filter marks the data bad, indicated by dotted lines over missing points on the plot.

The final plot shows the wind speed profile at 40, 50, and 60 meter elevations for the same rainy interval. The rain vs. wind intensity ratio shows how conditions vary from interval to interval. Periods of reduced rain intensity allow accurate wind speed measurement, while periods of more heavy rain are correctly marked as such.





Conclusions

The presented rain filter method provides a key feature for autonomous SoDAR operation in wind resource assessment. It removes uncertainty in a data set by identifying periods of rain and estimating the extent to which wind measurements have been degraded. The spectral cutoff frequencies given in the spectral decomposition also allow improved accuracy in times of light and moderate rain. The summary statistics generated by the rain filter are stored with the data allowing further analysis and data filtering in post processing for site analysis.

While the rain filter method provides dramatic improvement in periods of rain and hail, further work is required to deal with the snow. Snowfall is slower than rain, and the smaller Doppler shift gives less frequency separation in the spectral decomposition.

References

1. Journal Article, *Name of Journal*
2. Journal Article, *Name of Journal*
3. Journal Article, *Name of Journal*
4. Journal Article, *Name of Journal*