Operation of a Mobile Wind Profiler In Severe Clutter Environments

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1. Introduction

Wind profiling radars have been in use since the 1970s (Green et al. 1979). They are now being used with increasing frequency in operational meteorology under a wide range of conditions. One limitation to operation at many sites is contamination from ground and intermittent clutter and radio frequency interference (RFI). Currently, wind profiler radars must be deployed at locations with a minimum of clutter contamination to produce accurate winds, especially at lower altitudes required for boundary layer applications. Recent advancements in both radar hardware and signal processing allow wind profilers to operate in severe clutter environments.

A mobile wind profiler capable of operation in nearly any clutter environment would be useful for many applications. Examples include local weather forecasts during forest fires and dispersion prediction in case of a toxic substance release. In addition, a rapid deployment capability is required for these real world applications. NOAA's Environmental Technology Laboratory has developed a prototype mobile wind profiler and demonstrated its feasibility. This paper describes the changes to a standard wind profiler that are necessary to operate in severe clutter conditions and shows some early results from the mobile profiler.

Figure 1 Photograph of the mobile wind profiler deployed in a severe clutter environment.

2. Profiler Improvements

The prototype mobile wind profiler has been redesigned for operation in severe clutter environments. To operate in these environments, radars must have a large linear dynamic range, the ability to separate large clutter signals from the desired small atmospheric signals, and the intelligence to select the atmospheric component from among the many other interfering signals. The prototype profiler has been designed with a 105 dB linear dynamic range and wavelet filtering to reduce clutter contamination. When used in conjunction with an intelligent peak picking algorithm, these developments make mobile wind profiling possible.

a. Dynamic Range

Ground clutter is radar return from more or less stationary targets, such as trees, buildings, and power lines, that produces contamination of the Doppler spectrum near zero Doppler shift. Intermittent clutter is radar return from moving targets such as cars, airplanes, and birds. Radar return from water waves, called sea clutter, can also contaminate wind measurements. Power scattered from these clutter sources can be over 60 dB larger than that scattered from clear-air turbulence. Radar parameters are usually expressed using a logarithmic scale with every 10 dB change representing an order of magnitude. In addition, RFI can be a source of contamination. Wind profilers must be capable of measuring very small signals scattered from clear-air turbulence in the presence of very large contaminating signals, which requires a large dynamic range.

Dynamic range is defined as the difference between the smallest and largest signal that the profiler can detect and is usually measured in dB. In addition, the dynamic range must be linear. Linear response allows large signals and small signals to be summed together in the receiver. A non-linear response creates the product of received signals, which makes it virtually impossible to separate them later. The prototype mobile profiler has been designed with a linear dynamic range of 105 dB, corresponding to over 10 orders of magnitude. This allows the mobile profiler to operate in severe clutter environments without a clutter fence and still recover the clear-air signal.

b. Wavelet Filtering

Peaks in the Doppler spectrum from contamination can occur at nearly the same velocity as the desired atmospheric peak. Often the atmospheric signal is completely masked by contamination (i.e., when the atmospheric peak cannot be distinguished from the clutter peak). In this case, windowing of the infinite sinusoids used in Fourier analysis leads to a significant spectral leakage of low-frequency clutter energy into the higher-frequency atmospheric portion of the Doppler spectrum. This leakage makes it difficult, if not impossible, to extract the atmospheric signal. Wavelet filtering (Jordan et al., 1997) is used to reduce the amplitude of the contaminating signal which nearly eliminates spectral leakage in the Doppler spectrum. The compact nature of wavelet basis functions greatly reduces the amount of spectral leakage in the wavelet transform, which makes it easier to extract the atmospheric signal.

Three wavelet filters have been developed of the mobile profiler. Each filter is designed for contamination from a different source. The first filter removes RFI from cell phones, the second reduces ground clutter contamination, and the third is for intermittent clutter. Sea clutter is not addressed here. RFI from cell phones generates spikes in the time series data of I and Q collected by a 915-MHz profiler. The Harr wavelet is used to isolate these spikes in the wavelet domain and eliminate them. Spikes in the time series cause the noise level in the Doppler spectrum to increase, which ultimately masks the desired atmospheric signal. Ground clutter produces smooth, slowly varying signals in the time domain. These signals are a good match to the Daubechies 20 wavelet and can be reduced by clipping the clutter coefficients in the wavelet domain. Finally, the harmonic wavelet is used to detect intermittent clutter targets and remove their wavelet coefficients. In all three cases, the modified wavelet coefficients are transformed back to the time domain before the Doppler spectrum is computed.

c. Intelligent Peak-Picking

Currently, wind profilers assume that there is only one peak in the Doppler spectrum, due to the atmospheric signal. A consensus routine (Strauch et al., 1984) is then used to reject any outliers and the remaining peaks are assumed to be the result of atmospheric backscatter. If this assumption is valid, profilers produce good estimates of the horizontal wind speed and direction. However, there are many times when there is more that one peak in the spectrum and profilers report erroneous winds. This can happen with clutter contamination, bird migrations, intermittent precipitation, and non-linear effects as the receiver recovers from the transmitter pulse. Errors can be large and obvious or subtle and difficult to detect without some other supporting measurement, such as rawinsondes. There are several intelligent peak-picking algorithms that have been developed to separate the clear-air peaks from any contaminating peaks. The three most popular algorithms are examined here. They are NOAA Advanced Signal Processing (Wolfe et al., 2001), Greisser (Greisser and Richner, 1998), and NCAR's Improved Moments Algorithm (NIMA) (Morse et al., 2002).

NOAA has developed an intelligent peak-picking algorithm that can be integrated with existing radar wind profilers. This algorithm first selects signals in the Doppler spectrum using multiple-peak picking techniques, calculates moments for all these spectral peaks, then uses temporal, spatial and cross-antenna beam consistency to identify the atmospheric signal. The identified atmospheric signals are combined to produce wind speed and direction estimates including confidence indicators.

Another technique to identify the atmospheric peak was developed by Greisser. This method identifies peaks in the Doppler spectrum and forms chains of peaks across range gates by connecting the peaks that satisfy continuity constraints. A neural network is used to classify chains of spectral peaks according to time and height continuity and spectral characteristics. The most likely atmospheric profile is then selected from these chains.

NIMA separates the atmospheric peak in the Doppler spectrum from peaks generated by contaminating signals using fuzzy logic. Doppler spectra from each dwell are processed together as an image. Each spectral point in this image is assigned a score based on different characteristics, such as signal-to-noise, height continuity, etc. This score is a weighted sum of values derived from fuzzy interest maps for each characteristic. The region in the Doppler velocity image with the highest score is accepted as the atmospheric signal.

ETL has begun a validation project to compare these three intelligent peak picking algorithms to determine how successful they are under a variety of clutter conditions. The project is presently in the data collection phase, therefore, all three techniques are described here as possible candidates for use with a mobile profiler.

3. Results

A prototype mobile profiler has been constructed by ETL to evaluate these signal processing algorithms. It was designed to be deployed on a trailer without a clutter fence for rapid deployment. The profiler only requires 15 min. to be setup. Figure 1 shows a photograph of the prototype profiler deployed in a severe clutter environment. The profiler is at an urban location with ground clutter from houses and trees and RFI from wireless and cellular phones. An example of twelve hours of wind data from the profiler is shown in Fig. 2. The data is collected with half hour averages with 100m resolution. NOAA's Advanced Signal Processing was selected for peak picking for this example, other peak picking algorithms will be evaluated in the future.

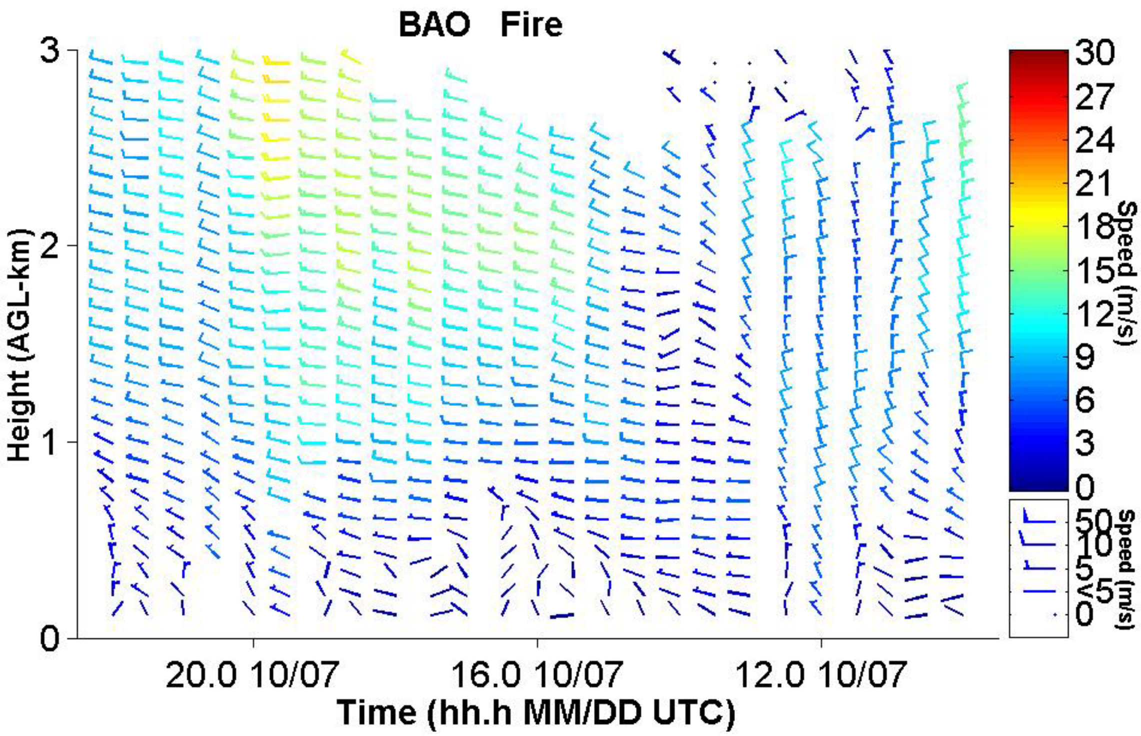

Figure 2 An example of wind profiler data collected at the location shown in Fig. 1. The first sample is at 70m with 100m resolution and half hour averages.

4. Conclusions

Recent improvements in profiler technology have made it possible to measure horizontal wind profiles in severe clutter environments. The new digital radar receiver resulted in 105 dB of linear dynamic range. This allows the profiler to operate in high clutter locations without the use of a clutter fence. Wavelet filtering removes much of the clutter contamination, thereby reducing the effects of spectral leakage in the Doppler spectrum. Reduced spectral leakage allows overlapping Doppler peaks to be identified. Three possible intelligent peak picking algorithms are available to identify the atmospheric signal from clutter contamination. Validation work is continuing on the available intelligent peak picking algorithms to determine the best technique for mobile profiling. Early success with the prototype profiler demonstrates that accurate wind profiles can be measured in severe clutter environments.

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6. References

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