6.10 DEVELOPMENT OF A REAL-TIME, AUTOMATED BOUNDARY LAYER HEIGHT DETECTION ALGORITHM USING RADAR WIND PROFILER DATA

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1. INTRODUCTION

Boundary layer depth is recognized as one of the key parameters for numerical models to simulate correctly for air quality and surface temperature prediction, but it is also a difficult measurement to accomplish. Wind profiling radars can provide an estimate of the mixing depth using the intensity of the backscatter signal, which is proportional to the refractive index structure function parameter C_n^2 (e.g. Ottersten, 1969). The procedure is based on the fact that, in the convective boundary layer, the refractive index structure parameter C_n^2 has a local maximum at the inversion due to small-scale buoyancy fluctuations associated with the entrainment process. C_n^2 in turn is directly proportional to the range-corrected Signal-to-Noise Ratio (SNR) of the backscattered power of wind profiling radars, thus allowing for continuous monitoring of the boundary layer's depth.

Although previous studies (White, 1993; Angevine et al., 1994; Wilczak et al., 1997) have shown that this method of maximum radar SNR has skill in estimating the convective boundary layer depth with wind profiling radars, it can fail for several reasons. Errors in the estimation of the SNR due to ground clutter, radio-frequency interference, or atmospheric point targets such as birds (Wilczak, et al., 1995) can produce erroneous mixed layer depths. Also, the algorithm can fail if there is an elevated layer of high refractivity associated with the residual inversion associated with the previous day's boundary layer. Finally, the algorithm can lead to significant errors in estimating the boundary layer depth during periods when the entrainment process is weak or when the entrainment zone is large, resulting in a deep layer with nearly uniform SNR. Because of these error sources, it has not been possible so far to apply the maximum SNR boundary layer depth algorithm as an automated wind profiler processing routine.

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To overcome some of these limitations, Bianco and Wilczak (2002) developed a new technique to measure the boundary-layer depth. This technique used fuzzy logic to reduce or eliminate contamination of the radar moments, and to also include the variance of vertical velocity, which is large within the convective boundary layer but smaller aloft. We present a further improvement of this technique, that relies on radar wind profiler observations of SNR, vertical velocity, and turbulence intensity (as expressed by the radar spectral width) to determine boundary layer depth automatically and in real-time.

Some of the NOAA/National Weather Service operational forecast models will soon have boundary layer depth as a predicted field available graphically for forecasters to utilize. However, very few measurements of boundary layer depth are routinely available for comparison to the models, and almost never in real-time. Real-time boundary layer depths calculated using the new fuzzy logic algorithm will be shown for a 915 MHz radar wind profiler located in New England that will be operating during the time of the conference.

2. WIND PROFILER OPERATION

In June-July 1995 a campaign of the Southern Oxidants Study (SOS 1995) took place in north central Tennessee in the vicinity of Nashville. During SOS 1995, NOAA/ETL deployed a 915 MHz wind profiler in Dupont, Tennessee (lat 36.28 N, lon 86.52 W, alt 155 m). This profiler was operated in an experimental mode to obtain high temporal resolution profile only using a vertical beam. Table 1 summarizes the settings of the instrument.

	DUPONT WP
Antenna aperture	2 m x 2 m
Pulse width (μs)	0.4
# of spectral averaging	25
# of spectral points	64
Dwell time (s)	13
# of vertical samples per hour	~240

Table 1. Parameter set for the 915-MHz Dupont, Inc. wind profiler.

The main differences between this and a standard deployment of a 915 MHz wind profiler is that it has a shorter dwell time and little spectral averaging. The smaller spectral averaging gives better defined spectral widths with less smearing, but also less sensitivity, so that most often above the Planetary Boundary Layer (PBL) there was no signal, only noise. Because the profiler was operated with a vertical beam only, one height mode, and a short dwell, there were on the order of 240 samples per hour. In contrast, a standard profiler operating in two-resolution mode will provide only 8 samples per hour.

Although many days of data from this profiler have been used to develop the new technique, only two of them (1 July and 3 July 1995) will be presented here in detail.

3. ANALYSIS METHOD

Figures 1 and 2 show radar time-height cross-sections for the two days analyzed, 1 July and 3 July, 1995. In both figures the first panel presents range-corrected SNR, the second panel the vertical velocity, and the third panel the radar spectral width.

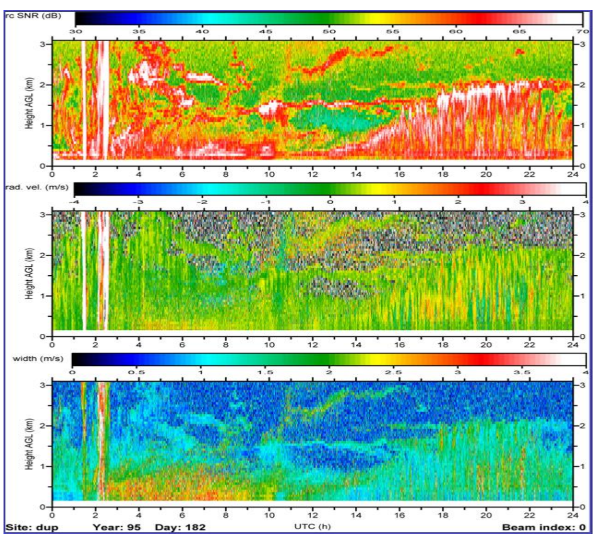

Fig. 1. First panel: time-height cross section of range-corrected SNR for 1 July 1995 at Dupont, Inc., Tennessee. Second panel: time-height cross section of the vertical velocity. Third panel: time-height cross section of the radar's spectral width. Time is UTC (local standard time = UTC – 6h).

In both cases the growth of the convective boundary layer is clearly visible in the SNR panel, and the vertical velocity shows a large variance within the convective boundary layer. In addition, the Doppler spectral width clearly contains additional useful information that could be used as a further input in the fuzzy logic algorithm for the estimation of the boundary layer depth height.

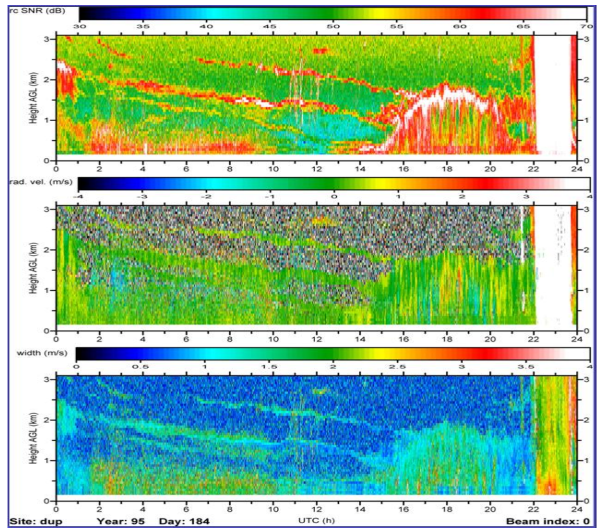

Fig. 2. As in Fig 1 but for 3 July 1995.

In particular, the spectral width profiles have large values within the convective boundary layer and small values above. Residual layers also have large values of spectral width, and the layer between the top of the convective boundary layer and any residual layer aloft has a minimum value of spectral width that approaches the noise level value.

In order to add spectral width as an input into the original fuzzy logic original algorithm of Bianco and Wilczak (2002, hereafter BW), new membership functions and rules had to be developed. The main difference with the previous approach was that the earlier algorithm used all of its inputs (C_n^2, its standard deviation over an hour period, its curvature, its gradient, and the variance of the vertical velocity, measured by the wind profiler's vertical antenna) at independent heights, giving for each height a "score". The computation of the score at each range gate height was independent of all of the gates above and below, and the depth of the convective boundary layer was taken as the range gate with the maximum score.

In contrast, to make the greatest use of the spectral width parameter it became clear that the entire profile needed to be considered simultaneously. This is because the PBL is a layer of continuous, enhanced turbulence that is connected to the surface. If the turbulence intensity becomes small at any height, then the top of the convective PBL must be below, even though the spectral width may become large again at a greater height. In comparison, Cn2 can become small within the convective PBL (Fig. 1) before reaching its maximum value at the inversion. These concepts have been incorporated through the addition of another fuzzy logic algorithm sequence to the one we have been using so far.

This new algorithm has two inputs:

1. vertical hourly profiles of the "scores" obtained from the 2002FL;
2. vertical hourly profiles of the spectral width on the vertical antenna.

The algorithm uses rules in combination with the two inputs, and the output from these rules gives a value of 0 to the heights that do not satisfy the condition of being within the convective boundary layer, and gives a value of 1 to the heights that do satisfy this condition. The algorithm then chooses the maximum value of the vertical profiles of the "scores" in the first, continuous, interval of "ones" (heights that were recognized as being in the convective zone).

4. RESULTS

As a first step we applied the BW fuzzy logic algorithm, without the use of the new input (figs. 3 and 4). The first panel is the time-height cross section of range-corrected SNR obtained, without using any fuzzy logic processing, by the standard procedure. The black circles denote the mixing depth estimates determined by the peak of the hourly median profiles of the standard radar SNR. The second panel is the time-height cross section of the vertical velocity computed using standard methods. The third panel is the time-height cross section of range-corrected SNR obtained by fuzzy logic for the same time period. In this panel the black circles denote the mixing-depth estimates determined by the BW fuzzy logic algorithm, while the red dots are mixing-depth estimates calculated using the new fuzzy logic algorithm that includes spectral width. The fourth panel is the time-height cross section of the vertical velocity computed by the fuzzy logic algorithm.

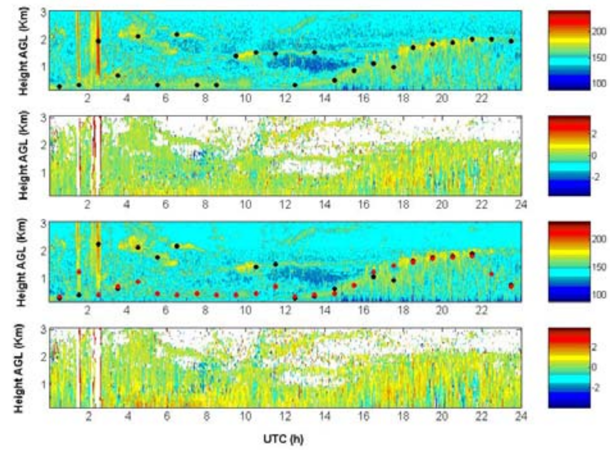

Fig. 3. First panel: time-height cross section of range-corrected SNR obtained by the standard procedure for 1 July 1995 at Dupont, Tennessee. The black circles denote the mixing depth estimates determined by the peak of the hourly median profiles of the standard radar SNR. Second panel: time-height cross section of the vertical velocity computed using standard methods. Third panel: time-height cross section of range-corrected SNR obtained by fuzzy logic for the same time period. Black circles denote mixing-depth estimates determined by the BW algorithm; red dots denote the boundary layer depth estimates obtained with the new fuzzy logic algorithm that includes radar spectral width. Fourth panel: time-height cross section of the vertical velocity computed by the fuzzy logic algorithm.

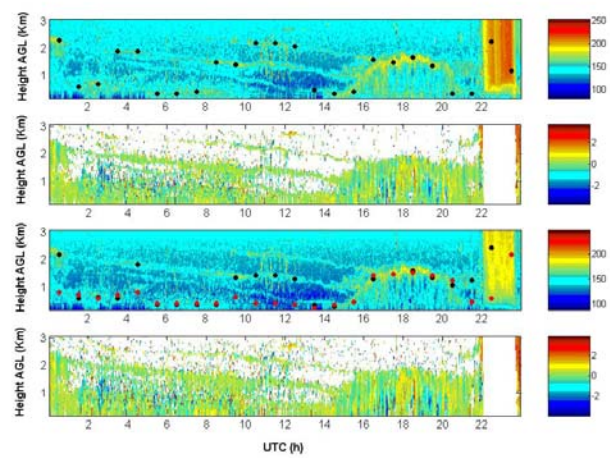

Fig. 4. As in Fig 3 but for 3 July 1995.

In Fig. 3 (1 July) both the BW and the new algorithm show their ability to detect not only the growing convective boundary layer, but also the collapse of the boundary layer during the evening transition. The new algorithm also shows a somewhat smoother hour-to-hour variation of the PBL depth.

In Figs. 2 and 4 (3 July) one can see the collapse of the convective boundary layer between

2000-2200 UTC probably due to the development of clouds that later led to the rain showers between 2200-2400 UTC. The BW algorithm (black dots in the third panel of Fig. 4) did not correctly follow the collapse the PBL at hour 21:30 UTC, but instead choose the residual layer associated with the capping inversion present several hours earlier (around 1300m). However, the new algorithm did properly follow the gradual collapse of the boundary layer prior to the development of the rain showers.

Another difference between the new algorithm and the BW and standard maximum SNR algorithms can be seen in figs. 3 and 4 for the nighttime hours. Whereas the simple maximum SNR and the BW algorithms both often detect large values of the boundary layer depth associated with residual layers aloft, the new algorithm chooses much smaller values that vary smoothly in time. Further research is needed to determine if the new algorithm is capable detecting either the depth of the nocturnal boundary layer or the depth of the nocturnal inversion.

5. SUMMARY AND CONCLUSIONS

A new technique has be described that relies on 915 MHz radar wind profiler observations of SNR, vertical velocity, and spectral width to determine boundary layer depth automatically and in real-time. This technique is based on a fuzzy logic algorithm developed previously by Bianco and Wilczak (2002), but has been expanded to also include information on turbulence intensity as expressed by the radar's spectral width parameter.

Examples of the new algorithm have be shown that demonstrate its ability to detect not only the growing convective boundary layer, but also the collapse of the boundary layer during the evening transition and the collapse of the boundary layer during periods of cloud layer advection aloft.

6. REFERENCES

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