

# INITIAL TESTS OF A SMALL SCALE VHF BOUNDARY LAYER RADAR

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## ABSTRACT

This paper describes a small scale VHF Spaced Antenna Boundary Layer Radar which has been developed using only three antennas. This radar was deployed at Buckland Park, Adelaide Australia for five days in October 2003. Comparisons with a 27 antenna VHF Boundary Layer Radar installed at the same site show excellent agreement with comparable coverage.

## INTRODUCTION

Until the late 1990's wind profiling of the atmosphere by Very High Frequency (VHF) radars was typically restricted to heights above 1.5 km. In recent years, through advances in technology and the use of smaller antenna arrays, observations as low as 300 m have been obtained at VHF [1] [2]. Wind profiles of the boundary layer (BL) had previously been obtained using UHF profilers typically operating at ~915 MHz [3] or ~404 MHz.

UHF radars are extremely sensitive to Rayleigh scattering from birds, insects and precipitation, while VHF radars are not. The echoes from these scatterers can overwhelm clear air returns at UHF such that determination of the wind velocity is not possible. This has led to the development of VHF boundary layer radars (BLR) [1, 2, 4], which are able to determine the motion of the air in the presence of precipitation, while being insensitive to birds and insects. The two techniques currently employed by VHF BLR are Doppler Beam Steering (DBS) [2] and Spaced Antenna (SA) [1]. This paper describes a small scale VHF SA BLR (Mini-BLR) based upon larger VHF Boundary Layer radars (BLR) which have been successfully operated in Adelaide [1], Alice Springs [5], Sydney [6], Melbourne and Tiwi Islands [7] in Australia as well as in Auckland, New Zealand and Cabauw, Netherlands [8].

The Mini-BLR has been developed to address the desirability for a small portable system which can be quickly installed. Ideally such a system could be stored in a truck or trailer and rapidly deployed, enabling observations of localized phenomena with high temporal variation (i.e. tornados). Conversely the simplicity and size means the system would be ideal as an educational or research tool.

## THE MINI-BLR RADAR

The mini-BLR was installed and tested at the Buckland Park field station, located 35 km North of Adelaide (34° 38' S, 138° 29' E). Transmission, reception and data acquisition is performed using a commercial radar system, the STX, manufactured by Atmospheric Radar Systems (ATRAD, [www.atrad.com.au](http://www.atrad.com.au)). The STX is a portable radar system capable of operation at frequencies between 30 and 60 MHz with only minor hardware adjustments. These radars have been used for boundary layer [1], meteor [9], and ionospheric radar [10] observations. The observations described in this paper were made at 42.5 MHz.

The specifications of the mini-BLR are shown in Table 1. The transmitting system consists of three solid state modules capable of producing single or coded Gaussian shaped pulses with a wide range of peak powers and pulse lengths. The radar data acquisition system (RDAS) consists of 3 receiving channels, and allows a wide range of receiver bandwidths and range and time sampling parameters. Radar control and data acquisition is performed by a Windows-NT "acquisition" PC fitted with data acquisition hardware and software acquiring data with 12-bit resolution. This resolution is increased to 16-bit upon coherent integration. The control program provides considerable flexibility in experimental sequencing and scheduling. Data acquired by the acquisition PC is transferred to a Linux "analysis" PC providing user interface to the radar, including analysis, display, and all radar system configuration. The analysis PC is accessible through the Internet, allowing interaction with the radar from a remote site. The antenna array consists of three three-element gamma-matched Yagi antennas arranged in an equilateral triangle. Each individual antenna is connected to a transmitter module and a separate receiver via a passive transmit/receiver (T/R) switch. A gamma-match provides a cheap, purely mechanical method of feeding the antenna while having high power handling capability. Gamma-matched antennas do have limitations, having narrow bandwidths, and due

Parameter	Value	Parameter	Value
Maximum Power	7.5 kW	Maximum PRF	20000 Hz
Maximum Duty cycle	5%	Transmit Pulse length	100 m to 4000 m
Frequency	42.5 MHz	Receiver bandwidth	18 kHz to 808 kHz

Table 1: Mini-BLR radar specifications.

to their mechanical design can be difficult to tune while also being susceptible to environmental effects which can require subsequent re-tuning. Both these effects can cause ringing in the system which will restrict the low height coverage obtained. Future designs will utilize more robust, wide-bandwidth feeding mechanisms for the antennas (i.e. toroid Baluns).

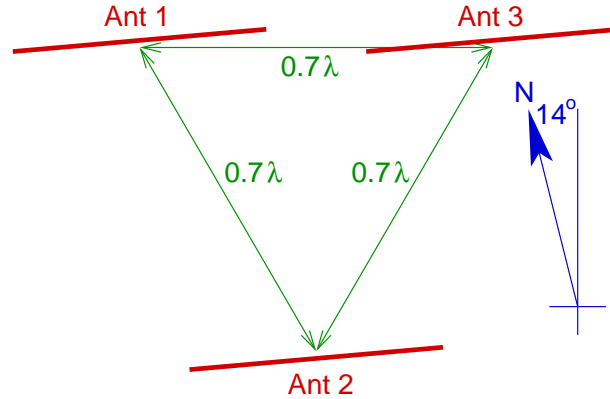


Figure 1: Layout of Mini-BLR at Buckland Park during October 2003 trials.

To achieve optimal wind measurements with a spaced antenna technique the average spatial cross correlation between pairs of receivers ( $\rho_{ij}(0)$ ) should be 0.5 [11], the distance corresponding to this is known as the “pattern scale”. The pattern scale is primarily dependent upon two parameters, namely the beam-widths of the antennas and the polar diagram of the scatterer (which is a function of the anisotropy). Below the Boundary Layer (BL) the atmosphere is typically well mixed with isotropic scattering being dominant, thus resulting in the pattern scale being a minimum which is only dependent upon the antenna beamwidths. For this initial deployment the spacing between the antennas was initially set at  $0.7\lambda$ . If  $\rho_{ij}(0)$  was found to be less than 0.5 then this spacing would have been reduced, while if  $\rho_{ij}(0)$  was found to be greater than 0.5 then the spacing would need have been increased. During this trial  $\rho_{ij}(0)$  was found to be  $\sim 0.5$  over a range of heights and times, hence the antennas spacing was kept at  $0.7\lambda$ .

Figure 2 shows the Polar diagrams of the transmit array and individual receive antennas calculated using Numerical Electromagnetics Code (NEC2). The transmitting array has a half-power full width (HPFW) of  $44^\circ$ , while the receiving antennas HPFW is  $24^\circ$ . The gain of the transmitting array and a receiving antenna is 12.3 dBi and 7.35 dBi, respectively. The expected pattern scale for isotropic scattering was thus determined to be less than  $0.83 \lambda$  [12].

The parameters used for observations are shown in Table 2. Two modes of operation, high and low were implemented. The low mode was optimized for lower height coverage, with a 100 m transmitted pulse used to minimize the effects of T/R switch recovery, thus enabling measurements to occur from lower heights while obtaining high resolution measurements. The high mode used a longer transmitted pulse of 450 m which increased the power in a single pulse thus increasing the maximum height coverage, however the effective height resolution is reduced with an effective height smearing of any measurements.

The raw data is analysed online using Full Correlation Analysis (FCA) [11], providing estimates of the dynamics and the spatial and temporal properties of the radio-wave scatterers. The FCA is part of the “Analysis and Display suite” written in Interactive Data Language (IDL). The analysis module allows each raw data record to be analysed using a number of different techniques, and also to be saved as raw time-series, spectra and correlation functions. The display module allows the analysed and raw data records to be viewed in a number of different forms. The analysis products can be used for post-analysis, such as hourly averaging, and incoherent averaging of spectra and correlation functions for further analysis.

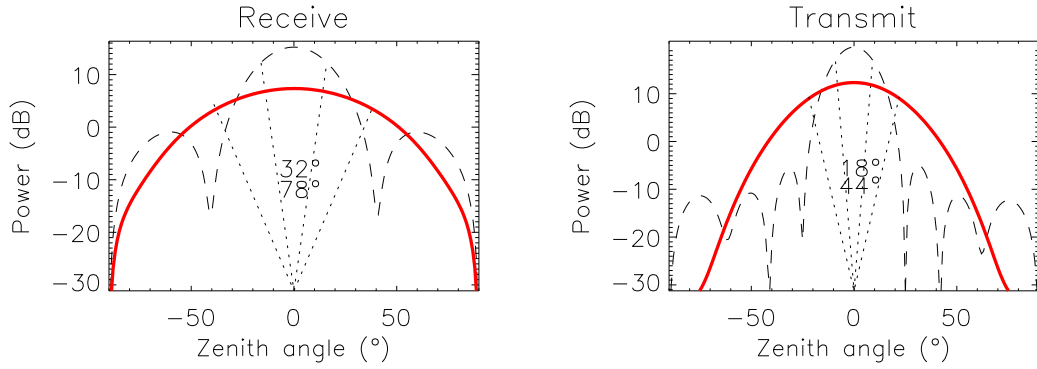


Figure 2: Antenna polar diagrams. The solid lines are for the Mini-BLR, while the dashed are for the present Buckland Park BLR. The half-power-full-widths (3 dB) for Mini-BLR are shown (dashed lines).

Parameter	Value	Parameter	Value
Pulse half power full-width	100 m (450 m)*	Coherent Integrations	500
Height range (min)	300 m (1000 m)*	Effective sampling time	0.05 s
Height range (max)	3800 m (9800 m)*	Number of samples	1100
Height sampling resolution	100 m (300 m)*	Acquisition length	55 s
Pulse Repetition Frequency	10000 Hz	Dead time	5 s

Table 2: Buckland Park Mini-BLR operating parameters. (\*High mode parameters are shown in brackets).

## RESULTS

For validation of observations the following comparisons used measurements obtained from a 1 kW 54.1 MHz BLR co-located at Buckland Park. The 54.1 MHz BLR is a refinement of the radar described in [1] with an increase in the number of antennas in the entire array from 12 to 27 [5]. Direct comparisons between the two radars are complicated by the different operating frequencies, different transmitting power (1 kW for BLR compared with 7.5 kW for Mini-BLR) and differing beam-patterns and gains (see Figure 2). Hence the power, signal to noise ratio (SNR) and pattern scales will differ. However, the measured wind velocities should be directly comparable. It should be noted that the larger beam-width of the Mini-BLR will result in additional height smearing of measurements compared with the BLR (see Figure 3).

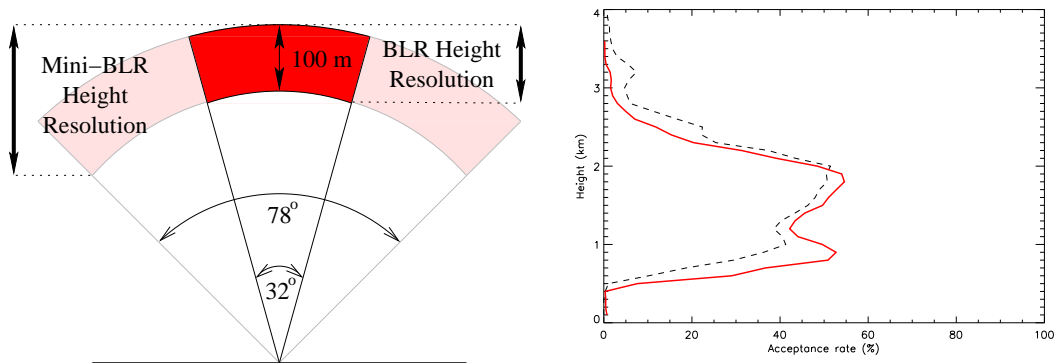


Figure 3: Illustration of effective height resolution obtain from Mini-BLR and BLR radars considering receiving arrays/antennas only using a 100 m tx pulse (left). Coverage rates for low-mode operation of the Mini-BLR (thick red) and BLR (dashed) from 9 to 13 October, 2003 (right)

The performance of the Mini-BLR is comparable to that obtained with the BLR radar (see Figure 3). Below 2 km the

performance of the Mini-BLR is superior, while above 2 km the coverage rate drops off more rapidly than the BLR radar. The overall performance of both radars was also limited by two effects. Firstly, both radars were in close proximity (i.e. < 50 m) to four 30 m masts which are potential sources of interference and clutter at the lower heights. Previous campaigns with the BLR at other locations (Alice Spring, Sydney) showed a superior low height coverage, thus implying the location of the radar at the Buckland Park field site is less than ideal [5]. Secondly, the performance of the BLR was lower than that observed previous to and following the trial, thus implying background atmospheric conditions were less than ideal.

The reduced coverage of the Mini-BLR, compared with the BLR, above 2 km is due to the different antenna gains, cable attenuation and differing peak transmitted powers. The antenna gain differences between the Mini-BLR and BLR during transmission and reception are 7.4 dB (i.e. 19.7 dB - 12.3 dB) and 7.8 dB (i.e. 15.2 dB - 7.4 dB) respectively. Due to time constraints and limited options for the location of the Mini-BLR antennas, substantially long feeder cables were required. The long length of the feeder cables added an additional 3 dB loss during both transmission and reception. Hence the total gain difference due to the antennas and feeder cables would  $\sim 21$  dB, which negated any advantage provide by the more powerful 7.5 kW Mini-BLR transmitter compared with the 1 kW BLR transmitter.

The lower height coverage of the Mini-BLR even though superior to the BLR was additionally limited by two things. Firstly the longer feeder cables used were not an  $\frac{1}{2}\lambda$  multiple thus being a potential source of mismatching and subsequent ringing. Secondly the use of the gamma match as detailed previously may not be the best feeding mechanism for optimal lower height coverage. With the use of shorter  $\frac{1}{2}\lambda$  multiple cables and finely-tunable wide-bandwidth baluns in place of the gamma matches the lower height coverage would be substantially improved.

The use of a high mode (longer transmit pulse) should improve the performance of the system at the higher heights. However, this was not obvious with the Mini-BLR (not shown). At the time of the trial it was believed that the two radars operating at 42.5 MHz and 54.1 MHz should not interfere, however following the trial it was determined that the crude square transmitted pulse of the 54.1 MHz BLR radar was interfering with the Mini-BLR, albeit only being apparent when the SNR was low. The converse, however, was not observed as the Mini-BLR has a Gaussian shaped pulse which is substantially spectrally cleaner.

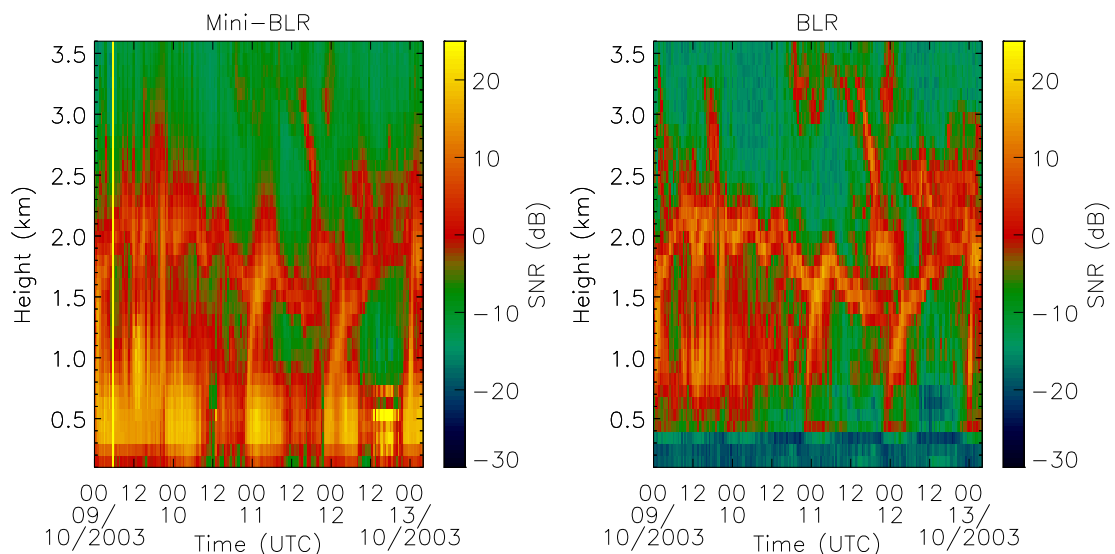


Figure 4: SNR (30 min. averages) obtained from the Mini-BLR (left) and BLR (right) from 9 to 13 October, 2003

Figure 4 shows 30 minute averaged SNR values obtained during the trial from 100 metres to 3600 metres for the Mini-BLR and the BLR. Extremely strong correlation can be seen in the two plots. The presence of an inversion can be easily observed between 1.5 km and 2.2 km throughout the period. However only the Mini-BLR is able to clearly detect the diurnal growth of Boundary-Layer below 600 m following sunrise. This can be clearly seen in the left plot where strong SNR levels can be seen just before 00 UTC (i.e. 0930 LT), especially on the 11th and 12th of October. On these days the growth of the BL is followed by the development of a well mixed layer with a subsequent reduction in SNR below the capping inversion (or entrainment zone). The success of the Mini-BLR system at detecting these low height features is primarily due to superior

T/R switching and receiver recovery compared with the BLR. The height smearing effect due to the wider beamwidth of the Mini-BLR compared with the BLR can be observed by the reduction of the fine detail of the inversion around 2.0 km.

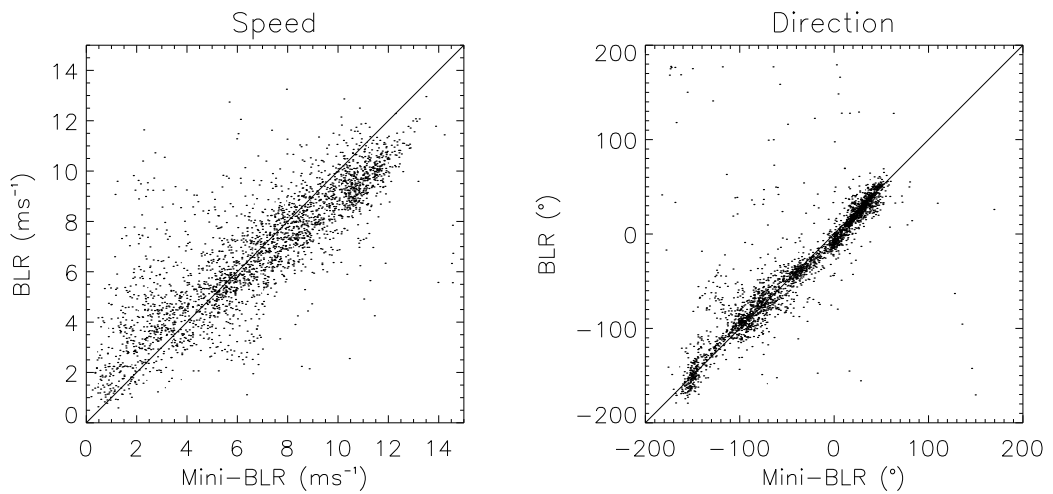


Figure 5: Scatter-plot of wind speed (left) and direction (right) measured by Mini-BLR and BLR. Lines of unit slope are shown.

A scatter-plot comparison of winds obtained with the Mini-BLR and the BLR radars is shown in Figure 5. There is excellent agreement in both speed and direction of the winds. Mini-BLR wind speeds appear to be 5-10 % greater than the BLR derived winds. This effect warrants further investigation as previous comparisons between the BLR and radiosonde observations have sometimes shown a 5-10% underestimation [1]. This suggest the Mini-BLR derived winds would be closer to measurements obtained from radiosondes.

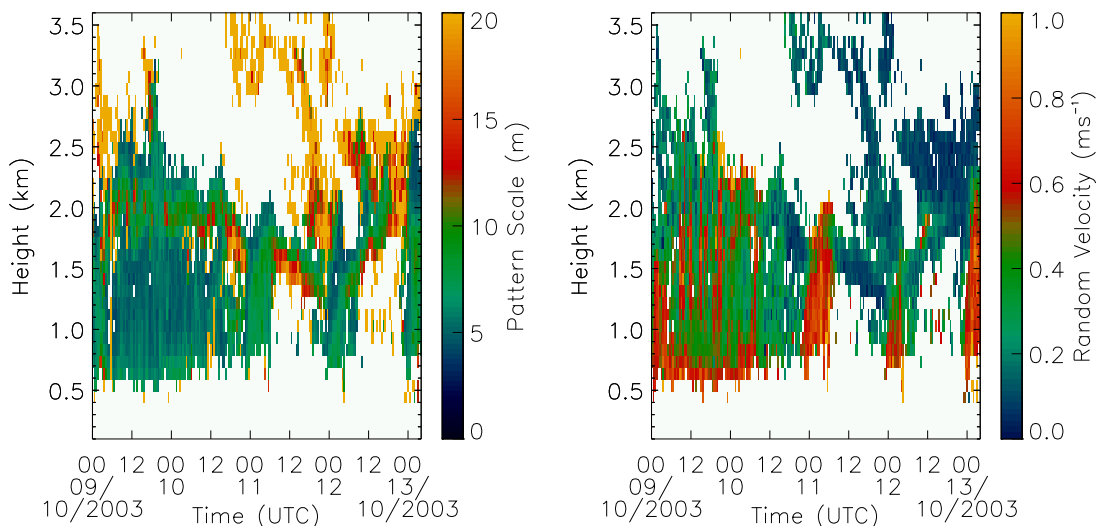


Figure 6: Pattern scale (left) and random velocity ( $V_{rms}$ ) (right) obtained for the Mini-BLR, 9th to 13th October 2003 (30 min. averages).

In Figure 6 the pattern scale and random velocity ( $V_{rms}$ ) obtained for the Mini-BLR are shown. As previously discussed the pattern scale is directly related to the anisotropy of the scatterer. In the left plot of Figure 6 below the inversion layer

the value of pattern scales are less than 10 m implying that isotropic scatter is dominant. Pattern scales of greater than 15 m indicate regions of high anisotropy. From the right plot of Figure 6 the random velocities ( $V_{rms}$ ) are greater below the inversion layer than above, which is consistent with the occurrence of convective mixing. The strong region of  $V_{rms}$  at 00 UTC on 11th October from 0.6 to 1.8 km coincides with the enhanced region of SNR shown in the left plot of Figure 4, thus being an active region associated with the growth of the BL during the morning. Another point of interest is following the development of the well mixed layer (0600 UTC) on 11th October, where a region of high anisotropy (pattern scale  $> 15$  m) and small values of  $V_{rms}$  can be seen at the bottom of the inversion layer, implying this is a stable specular region.

## SUMMARY

We have detailed a Mini-BLR radar developed by ATRAD and deployed for a 5 day trial in October 2003 at the Buckland Park field site. Comparisons with a co-located BLR radar are excellent, despite interference and site-specific limitations. The Mini-BLR is able to determine a number of atmospheric characteristics including wind velocity, reflected power, anisotropy and random velocity from 500 m up to 3.5 km (depending on background conditions). Further testing of the system at a range of sites will include improvements to antennas and cabling, thus improving both the lower and higher height coverage. With each antenna supported by a basic stand which is placed upon the ground the entire system is highly portable and can be setup in less than 15 minutes.

## ACKNOWLEDGMENTS

Thanks to Prof. Bob Vincent of the University of Adelaide for providing the Buckland Park BLR data used for the comparisons.

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