7.8 BOUNDARY LAYER MEASUREMENTS WITH A 3GHZ FMCW ATMOSPHERIC PROFILER

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1. INTRODUCTION

For highest sensitivity in boundary layer measurements, one usually uses a low frequency radar system with a probing frequency around 1 GHz. Although higher frequencies can be used, the usable frequency limit is at approximately 7.5 GHz. For the smaller scale lengths corresponding to higher frequencies, all turbulent energy is dissipated and no clear air reflections are detected anymore. For cloud and precipitation research, higher frequencies are used as the radar cross section of small particles increase with frequency (as long as the wavelength is larger than the particle size). A high sensitivity radar with a transmit frequency of 3 GHz, like the Transportable Atmospheric Radar TARA, can be used for both turbulence studies as well as for cloud and precipitation studies. Designed for use in experimental atmospheric research, the TARA system is based on the FM-CW radar principle such that system specifications like sensitivity and resolution, both in space and in time, can be changed independently of each other, Heijnen (1999).

This paper will address the sensitivity of TARA for boundary layer measurements and show some high-resolution measurements.

2. THE TARA SYSTEM

The TARA system is a fully polarimetric atmospheric profiler. Small feed arrays are used to generate beams at an angle of 15° offset from the axis of symmetry in two orthogonal directions, Moumen (2001). The off axis beams are used for wind profiling, Heijnen (2001). The polarimetric capability is used for target classification and Doppler spectrum de-alliasing, Unal 2002. A carrier frequency of 3.3 GHz combined with a high sensitivity and high resolution in space and time makes the system usable for all kinds of studies of atmospheric phenomena like cloud processes, drizzle formation, turbulence studies and 3-D wind profiling.

Figure 1: The TARA system. Clearly visible are the multiple feed systems to generate off-axis beams.

A spatial resolution of 3 m combined with a temporal resolution of 0.5 s makes it possible to study the boundary layer with unprecedented detail. Recently, the system has been extended with the possibility of logging raw data. This opens a completely new level of detail at which atmospheric processes can be studied.

The sensitivity of the system for clear-air reflections is derived from the radar equation for Bragg scattering, valid for the inertial sub range of the turbulent spectrum:

$$P_r = \frac{0.38 G^2 \theta^2 \lambda^{5/3} 2\Delta r}{512(2\ln 2)\pi^2 r^2} C_n^2 P_t \qquad (1)$$

The TARA system has an antenna gain G of 38.5 dBi and a beam width θ of 2.2°. The actual transmitted power is 36 W. With a

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receiver noise figure of 1 dB and an antenna temperature of 50 K, the minimum detectable structure constant becomes $6.2 \cdot 10^{-14}\, m^{-2/3}$. This is calculated for a signal to noise ratio of one, a 1 ms sweep time, a resolution of 6 m and a range of 1 km. Doppler processing can improve the sensitivity with 10 dB depending on the actual circumstances. It is implicitly assumed that the turbulence fills the antenna beam completely. From Eq. (1) it follows that the sensitivity for clear-air reflections increases for increasing wavelength. This is if all other radar parameters, like antenna gain and sensitivity, remain constant.

3. MEASUREMENTS

A typical example of boundary layer reflections in a broken cloud cover stuation is shown in Fig.2. The avaraged hight of the cloud base is at an altitude of 5 km. When the cloud blocks the sun-radiation, reflections from the boundary layer can be seen up to an altitud of 1 km. When no cloud is over the radar, the intensity of reflections from the boudary layer increases and after a delay also the hight of the boundary layer increases. Horizontal lines in the picture are system artifacts and do not represent reflections from atmospheric objects.

This measurement was done with a range resolution of 20 m and a time resolution of 0.5 s.

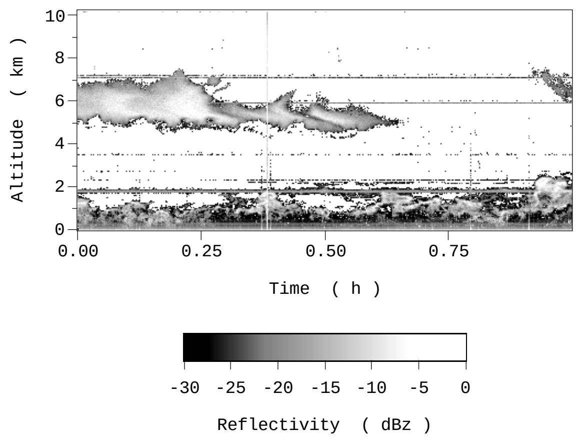

Figure 2: Measurements of a cloud over the inversion layer.

A second example is measured around ten o'clock in the morning on the 30th of august 2001. This was a very sunny day. The measurement was done with a sweep time of 1 ms and a spatial resolution of 6 m. Fig 3. clearly shows a thin boundary layer extending to an altitude of 250 m. Measured reflectivities reach a value of -20 dBz at an altitude of 200 m. This corresponds to a structure constant of $C_n^2 = 5 \cdot 10^{-14}\ m^{-2/3}$.

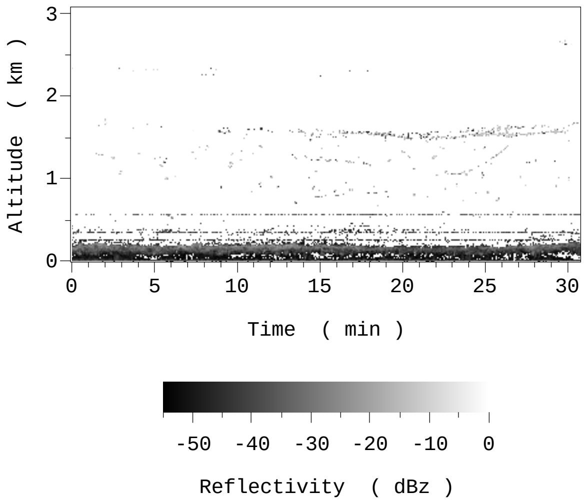

Figure 3: Boundary layer measured with a 6 m resolution.

As the TARA system is a fully coherent system also the Doppler velocity and the Doppler spectral width can be calculated, see Fig. 4 and 5. The vertical velocities are limited within -2 till +2 m/s. In this case, negative velocities are in the direction of the radar.

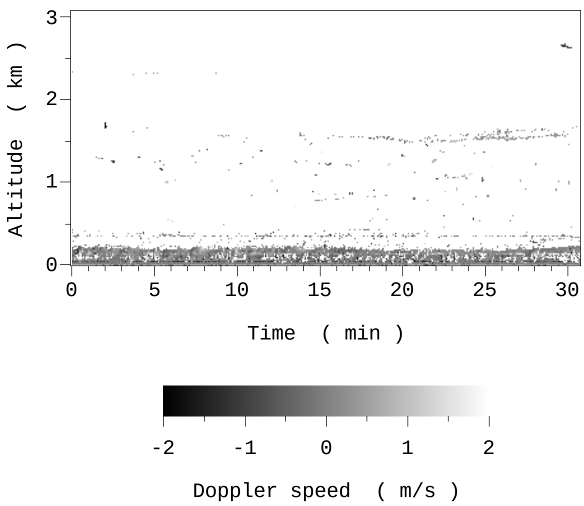

Figure 4: Doppler measurement for the same event as shown in Fig 3.

The spectral width is shown as a histogram. Spectral widths above 1.5 m/s are 100 times less occurring than the maximum occurrence.

An exponential decay of the occurrence is seen for increasing spectral widths.

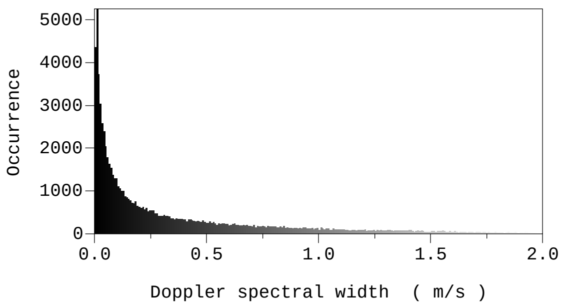

Figure 5: Histogram of the Doppler spectral width.

The high resolution of the TARA system becomes obvious when looking at same detailes in the measurements of Fig. 3 and 4. First a detailed look is taken at the boundary layer, see Fig. 6 and 7. Small wavelike structures with periodes less than a minute are superimposed on a wave with a much longer period of 15 min. The layer has a thickness less than 100 m but structures much smaller than that are resolved. The antenna beam overlap becomes increasingly small for range bins below 100 m. Therefore, the boundary layer base heigth is somewhat artificial.

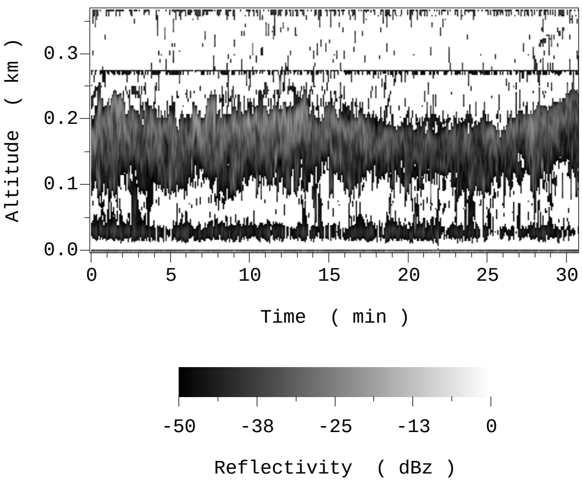

Figure 6: Detailed view of the top boundary layer. Clearly visible are wavelike structures with different oscillation periods.

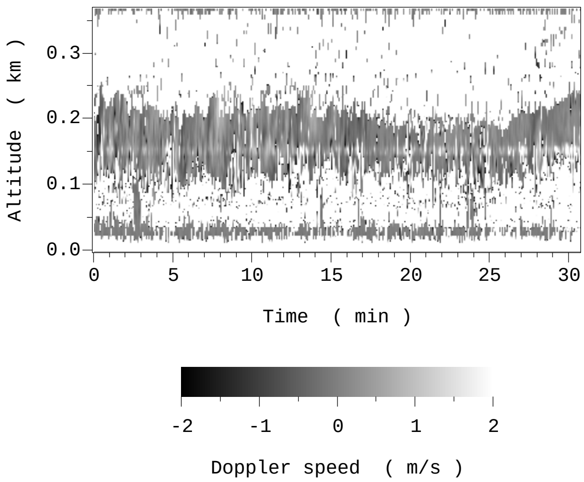

Figure 7: Corresponding Doppler velocity.

Small point reflections are detected on many occasions. These are also vissible in Fig. 3 up to an altitude of approximately 2 km. An example of a spot reflection is shown in figures 8 and 9 where the reflectivity and the Doppler velocity are shown. For this measurent, the processing was changed to give a time resolution of 32 ms. Detailed analysis revealed a high polarisation dependency of these targets with no prefered direction of polarization. The phase information in the detected signal showed interference like behaviour pointing towards small asymetric hard targets. The intensity of the reflected signal corresponds to a radar cross section of $1.5 \cdot 10^{-5} m^2$. Therefore, it is concluded that these point reflections originate from insects.

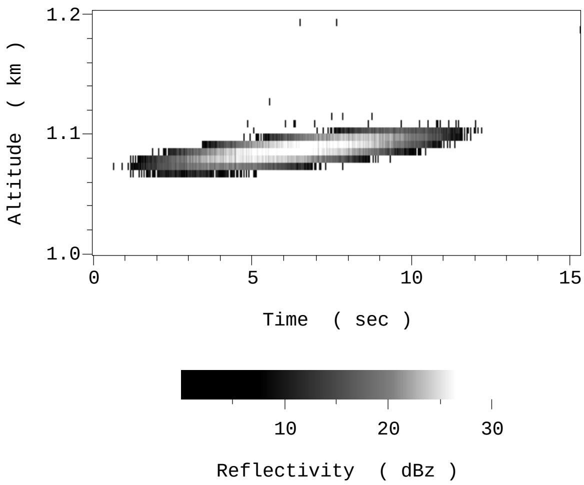

Figure 8: Example of a spot reflection. The maximum intensity of 28 dBz corresponds to a radar cross section of $1.5 \cdot 10^{-5} m^2$.

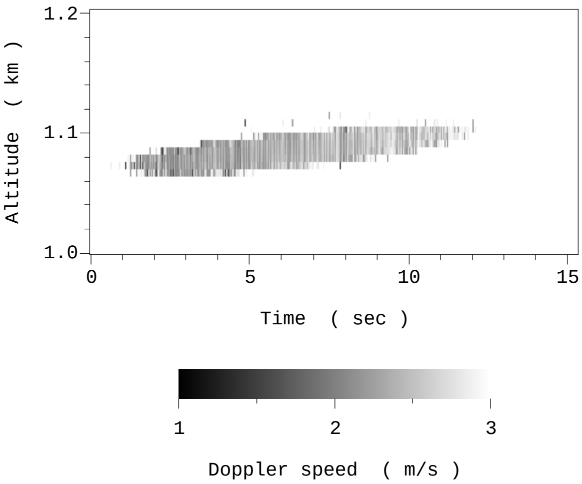

Figure 9: Doppler speed of the spot reflection shown in Fig 8.

4. CONCLUSIONS

Some examples of high-resolution measurements of the boundary layer are shown. High temporal and spatial resolution of the radar system was illustrated by the detection of atmospheric waves and insects.

5. ACKNOWLEDGEMENT

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6. REFERENCES

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