P13B.13 OPERATIONAL CONFIGURATION AND SOFTWARE EVALUATION OF THE RNDSUP DOPPLER RADARS FOR THE AUSTRALIAN WEATHER RADAR NETWORK

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1. INTRODUCTION

Finding an appropriate balance between unambiguous range and Nyquist velocity (the so-called Doppler “dilemma”), between clear-air detection and volume scan update period, and being able to supply both legacy and new products, are issues to be addressed when specifying a scanning configuration for an operational radar network. Dynamically varying or interactively user-controlled configurations are possible but have been considered impractical, at least initially, for the Australian weather radar network. In the past Australian radars have been individually configured to suit local terrain conditions. These configurations have changed over time as service requirements and radar capabilities have evolved. With more and more products and services now being generated automatically from radar data, and with the radar network growing in size and complexity, a standard configuration has become desirable to ensure product quality and to aid network manageability.

This paper provides a description of the issues considered when specifying the operational scanning configuration for the Gematronik Meteor 1500S 1° S-band Doppler radars (hereon “S1” radars) acquired for the Australian weather radar network through the Radar Network and Doppler Services Upgrade Project (RNDSUP) (Canterford, 2007). This paper also gives an overview of signal processing software evaluation activities.

2. VOLUME SCANNING CONFIGURATION

The main objectives considered when designing the volume scan configuration were to i) monitor deep convection, ii) allow quantitative precipitation estimation, iii) complete in a 5-6 minute update cycle, iv) maintain reasonable clear-air detection, and v) have a minimal “cone of silence”. The final set of 14 tilt angles chosen were 0.5, 0.9, 1.3, 1.8, 2.4, 3.1, 4.2, 5.6, 7.4, 10.0, 13.3, 17.9, 23.9 and 32.0 . These tilts were based on the lowest 5 tilts of VCP12 (Volume Coverage Pattern 12, as used in the USA WSR-88D network, and referred to as VCP Gamma in Scott, 2002), and combined with a geometric sequence of 9 tilt angles from 3.1° to a maximum tilt elevation of 32°. The resulting set of tilts is very similar to VCP12 except that its highest elevation tilt is 32° as opposed to VCP12’s 19.5°. The 32° highest elevation tilt in the volume scan was chosen mainly for historical reasons associated with “cone-of-silence” concerns at airport-sited radars.

VCP12 is a scan configuration designed for deep convection which is of prime concern in Australia. Importantly the lowest 5 tilts were assessed to also provide a vertical resolution suitable for quantitative precipitation estimation within the target range of 150km.

VCP12 involves 17 rotations of the antenna as the lowest 3 tilts are repeated at different pulse repetition frequencies to enable range folded echo identification. As the S1 radars employ phase coding techniques in the signal processing, the repeated low elevation tilts are unnecessary giving extra time available in the volume update cycle for slower antenna rotation rates and thus better clear-air echo detection. A single configuration for the Bureau S1 radars was sought that also provided adequate clear-air echo detection. VCP12 completes in 4.1 minutes on the WSR88-D, and despite the time savings mentioned above, this was considered too short an update cycle to satisfy all the considerations. At the present time it is planned that the S1 radars will eventually operate with a 6 minute update cycle.

The first S1 radar was delivered and installed in Adelaide in early 2005 with a DRX signal processor without phase coding capabilities (though it has been since upgraded with a GDRX in April 2007). Based on prior experience with C-band radars in Sydney and Darwin operating with dual pulse repetition frequencies (1000:666Hz), initial expectations were that a pulse repetition frequency of 1000Hz (range 150km) would be employed on the S1 radars. However forecasters at the Bureau of Meteorology were unaccustomed to recognising range folded echoes associated with klystron based radars as all the radars in the existing network were magnetron based. Subsequently dual pulse repetition frequencies of 750:500Hz were initially employed. Due to the 200km unambiguous range, combined with judicious choice of signal quality index (SQI) thresholds, and “adaptive” mode velocity de-aliasing (equal numbers of low and high prf pulses in each azimuth interval), the occurrence of range folded echoes was minimised in both reflectivity and velocity imagery while still retaining reasonable clear air performance and clutter filtering. However the mere possibility of range folded echoes was considered unacceptable for legacy pseudo-cappi “CompPPI” reflectivity products for display to the public on the internet. Hence an additional 2 tilts at low prf (400Hz) were also required to ensure this legacy product was free of range folded echoes. Another implication of these additional tilts was that the implementation of a 5-6 minute update cycle had to be deferred, and the legacy standard 10 minute cycle temporarily retained.

3. SOFTWARE EVALUATION

3.1. DUAL PRF DE-ALIASING

Experience over many years has been gained with dual prf de-aliasing techniques on Bureau designed Rapic signal processors on C-band radars. The standard method employed on Australian radars is currently that of Joe and May, 2003.

GDRX phase coding software on the second S1 radar (Brisbane, delivered in late 2005) was capable of second trip echo suppression, with second trip echo recovery capability to be delivered at a later date (currently under evaluation the third (Melbourne) S1 radar).

For the Brisbane S1 radar no changes were made to the volume scan configuration as adopted for the Adelaide S1, except that "fixed" mode velocity de-aliasing (high and low prf on alternating 1° azimuth intervals, and de-aliasing as in Joe and May, 2003) and DFT clutter filtering was used. A 10 minute update cycle was also retained. The Brisbane S1 radar was brought into operational service in August 2006. However the shortcomings of fixed mode dual prf velocity de-aliasing in the chosen volume scan configuration, particularly in highly sheared environments, soon became evident as warm season convective activity increased in the months following commissioning. In an attempt to evaluate the relative performance of other configuration options, two experimental single tilt elevations scans, both at 0.5°, were inserted into the update cycle such that they occurred immediately after the two low prf tilts (used to produce the operational Rapic "CompPPI" pseudo-cappi product) and before the operational dual prf (750:500Hz) volume scan. In this way there was a low prf reflectivity product free of second trip echoes immediately followed by 3 consecutive tilts at 0.5° with varying prf configurations, all occurring within the first 2 minutes of each 10 minute operational update cycle. The products are summarised in Table 1.

Product	**PRF**	**Nyquist Velocity**	**Unambiguous Range**
CompPPI	400Hz	-	375km
Volume 1	1000Hz	26.5m/s	150km
Volume 2	1000:666Hz	53m/s	150km
Volume 0	750:500Hz	40m/s	200km

Table 1: Radar products produced in the evaluation of various prf options

An example of the results observed can be seen in Figure 1 and Figures 2a-2f. In Figure 1 the CompPPI long range reflectivity product shows active convection to the north-west of the radar, moving toward the northeast. Figure 2 shows a zoomed in view of the convective cell arrowed in Figure 1.

Note that second trip suppression is enabled in the reflectivity image for Volume 0 (Fig 2a), and in all velocity images (Figs 2b, 2d and 2f), but not in the reflectivity images for Volume 1 (Fig2c) and Volume 2 (Fig 2e). This allows one to easily see the amount of second trip echoes present in the reflectivity images and the effect of their removal on the velocity images. See para 3.2 for discussion of the second trip echo suppression.

Dual prf velocity de-aliasing errors (particularly in Fig 2b (750:500Hz)) are evident in the mesocyclone to northwest of the radar. Figures 2c and 2d (single prf 1000Hz) confirm that the increased inbound velocities in Fig 2b are erroneous. Though there are de-aliasing errors apparent in Fig 2f (1000:666Hz) they are not as frequent and, in this case, not associated with the mesocyclone couplet. The de-aliasing errors seen if Fig 2b have been seen to be somewhat typical in super-cellular convection and have served to impede forecaster confidence in interpretation of velocity imagery. This has important implications when introducing Doppler velocity data to forecasters for the first time. Also of note is the single pixel of velocity aliasing in the Fig 2d (1000Hz) outbound flow which, though undesirable, is somewhat easier to interpret with confidence.

3.2. SECOND TRIP ECHO SUPPRESSION

With the addition of phase coding capabilities to the GDRX signal processor, suppression of second trip echoes was made possible. This feature has been subjectively observed to perform acceptably. In Figs 2c and 2e (suppression not enabled) second trip reflectivity from the cell to the distant north-northwest (see Fig 1) can be seen to contaminate the data to the north-east of the main convective cell discussed above. In Fig 2a the second trip reflectivity echoes have been successfully suppressed without loss of first trip information. "Holes" in the velocity images in Figs 2d and 2f generally correspond to the locations where second trip echoes have been suppressed, while in Fig 2b no such areas of missing data are evident, as would be expected from the 200km unambiguous range for the Volume 0 product..

3.3. SECOND TRIP ECHO RECOVERY AND IQ REPLAY MODE

Second trip echo recovery software for the GDRX signal processor was delivered in early 2007 and was in the process of being evaluated on the third (Melbourne) S1 radar at the time of writing. Eventual retrofit to existing S1 radars at Adelaide and Brisbane is envisaged.

Another feature of the Gematronik GDRX software suite is the "replay mode". Raw IQ data was also stored for the event of 16th December

2006 from the Brisbane S1 radar on hard disk, and was replayed at a later date through a stand-alone GDRX system off-site from the radar. Unfortunately the dual prf data collected for the 16th December 2006 was in an incompatible format for the later version of GDRX software that was eventually delivered with second trip recovery capability. Nevertheless the single prf Volume 1 data that was collected was in a compatible format and has been replayed through the IQManager software (Wielant 2007) supplied by Gematronik.

Figure 3 shows a 3D-Rapic (Purdam 2007) display of Volume 1 data as collected in real-time from the Brisbane S1 radar for 04:41UTC on the 16th December 2006. Figure 4 shows the same data displayed post-event after being reprocessed from stored raw IQ with IQManager. Note that the colour palettes used by the two display packages are different, but general consistency between the two images is apparent.

Figure 5 shows 3D-Rapic displays of velocity data as collected in real-time for velocity data for Volume 0 (left) and Volume 1 (right). Both the Volume 0 and Volume 1 velocity data had second trip echo suppression enabled at the time of collection and are generally similar. Figure 6 shows the IQManager display of the Volume 1 velocity data after being reprocessed from stored raw IQ data with second trip data recovered. Figure 7 shows the unambiguous CompPPI reflectivity product data and Figure 8 shows the IQManager display of second trip recovered reflectivity data for Volume 1.

The data after second trip recovery (Figures 6 and 8) subjectively appears to be generally similar to that collected for Volume 1 in both reflectivity and velocity when compared to the Volume 0 velocity data (Fig 5) beyond 150km range, and the CompPPI reflectivity data (unambiguous range 375km) (Fig 7), though of lesser quality where the second trip has been recovered from an area with overlaid first trip echoes (e.g. Fig 8 reflectivity echoes to the northwest of the radar between 200 and 300km distance).

4. FUTURE PLANS

It is planned to undertake more objective evaluations of the second trip recovery capabilities before operational implementation on the S1 radars. Until a satisfactory evaluation is completed it will be necessary to continue to combine at least one low prf tilt scan with those obtained from a high prf volumetric scan to satisfy all Bureau of Meteorology service requirements.

It is envisaged that the current ‘fixed’ mode dual prf mode of operation will continue in the short term, though it is noted that progress is being made in other countries with staggered prt schemes such as those implemented on the WSR-88D network in the USA (Sachidananda 2002, Torres 2004, Zrnic 2005, NSSL 2006) and triple prf techniques in use in the French radar network (Tabary 2006). It is also noted that alternative techniques, such as that proposed in Pirttila 2004 may be worth consideration, where the Doppler dilemma is solved but with reduced quality data instead of data ambiguity (Ruzanski 2007).

5. ACKNOWLEDGEMENTS

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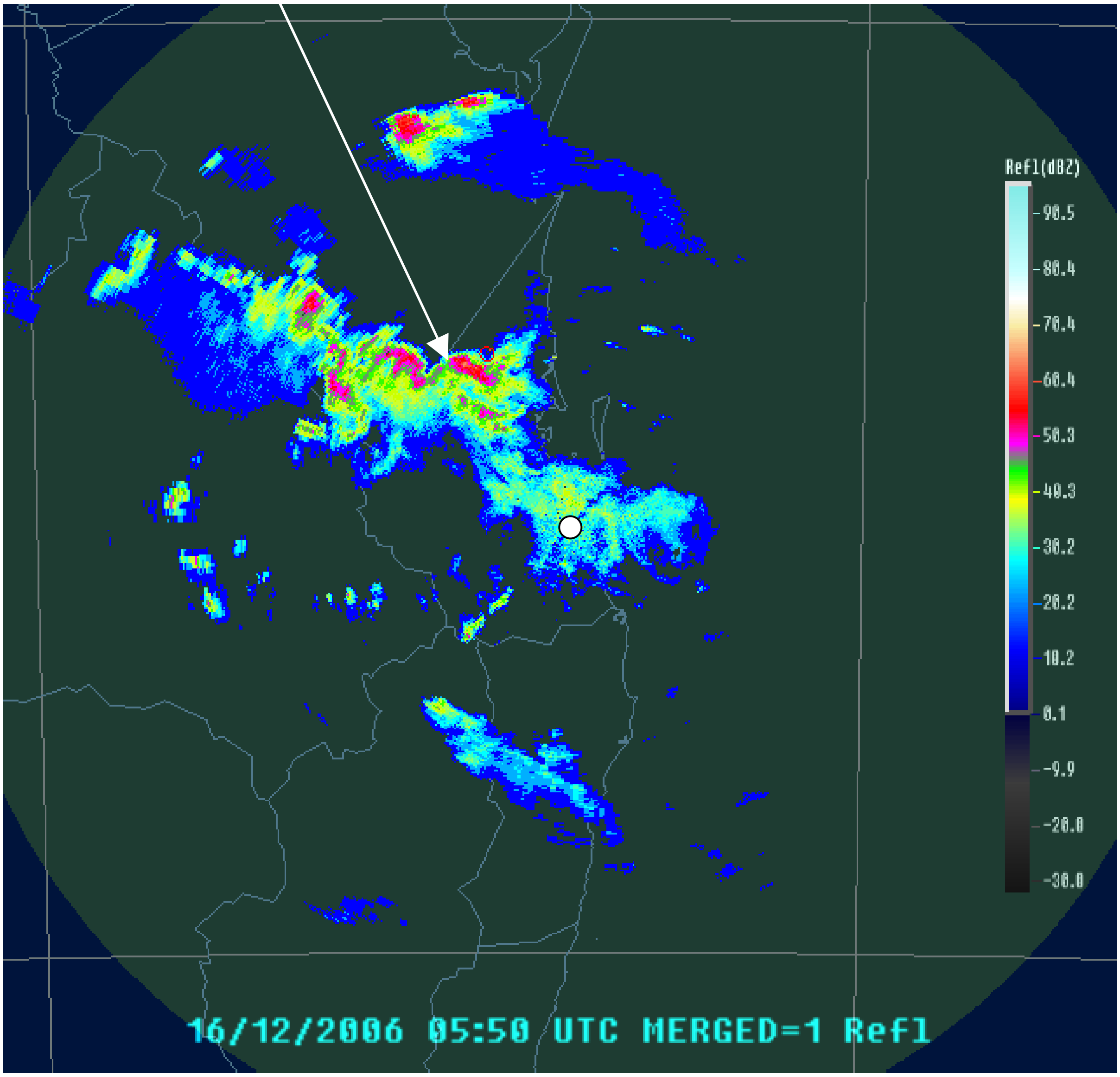

Figure 1: CompPPI (400Hz) reflectivity product from the Brisbane S1 radar at 05:50UTC on 16 December 2006. Note the convective cell indicated by the white arrow, and the radar location indicated by the white filled circle.

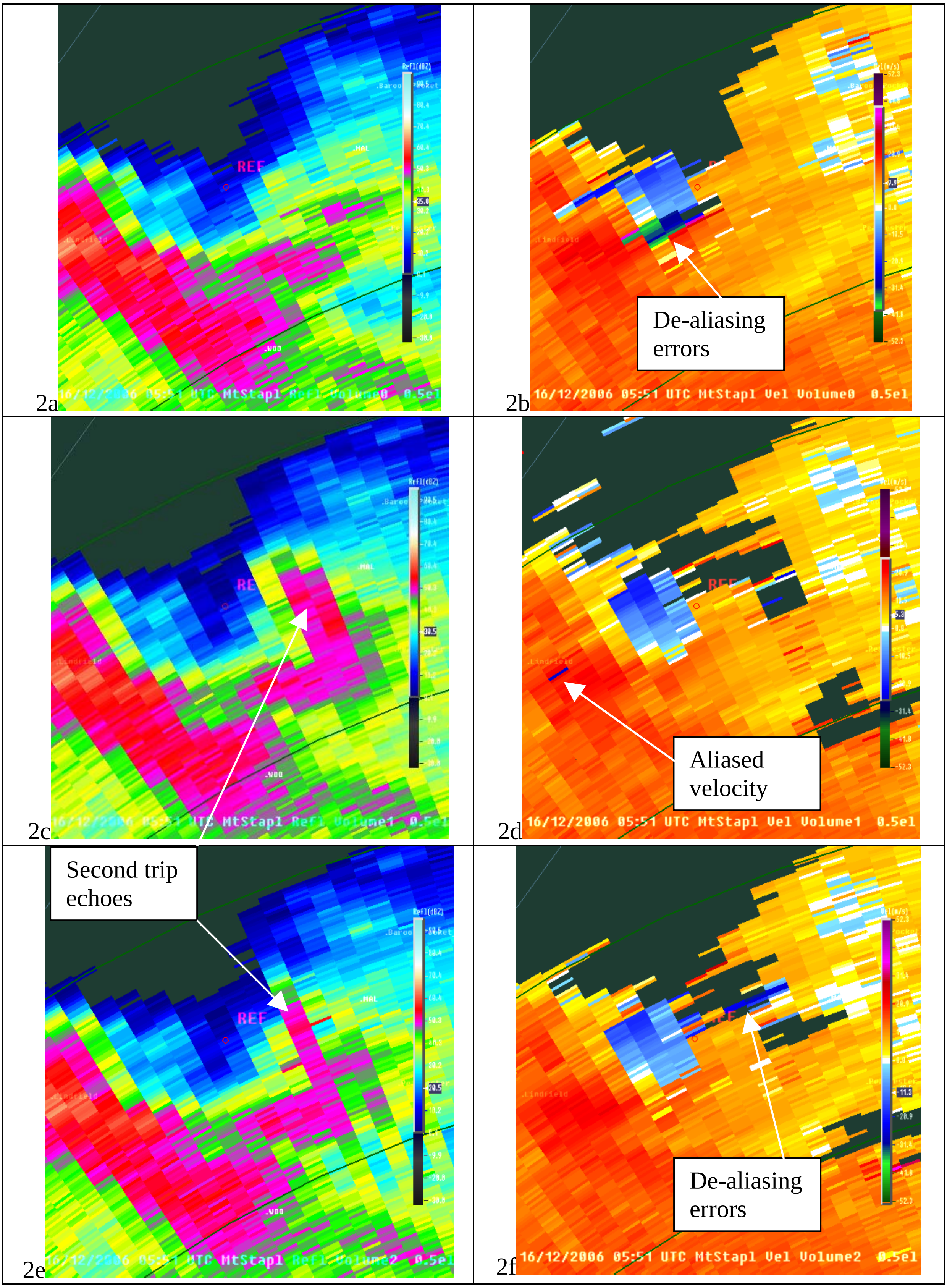

Figure 2: Reflectivity (left) and Velocity (right) images for 05:51UTC on 16 December 2006, for 750:500Hz (2a,2b), 1000Hz (2c,2d) and 1000:666Hz (2e,2f). Note the small red reference empty circle.

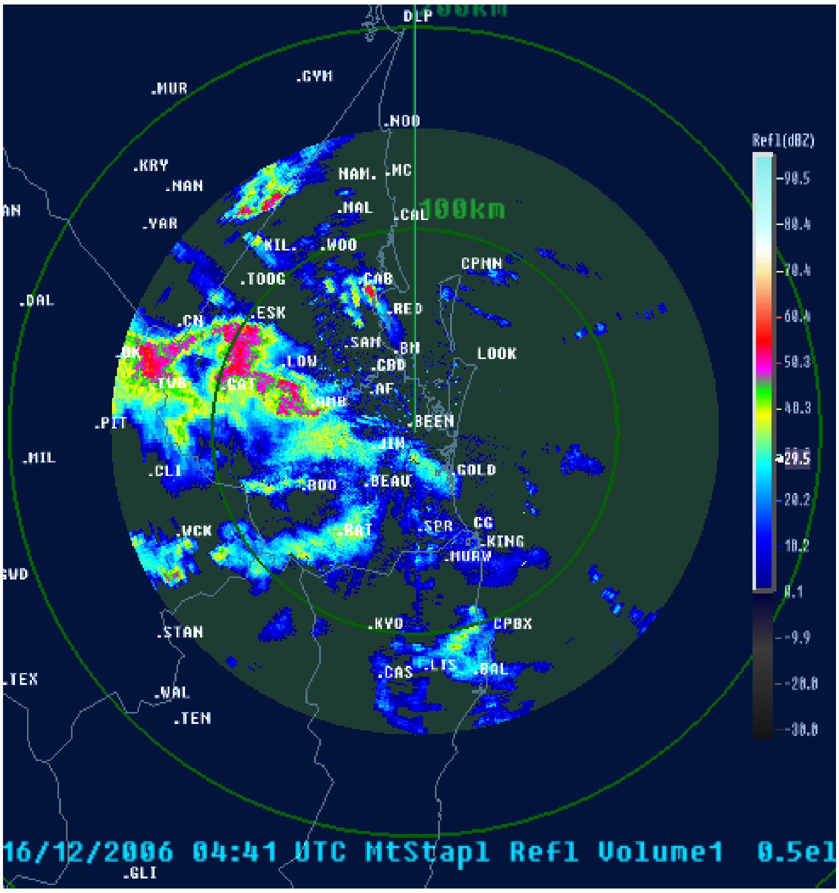

Figure 3: 3D-Rapic display of Volume 1 (1000Hz) product, second trip suppression and recovery is not enabled.

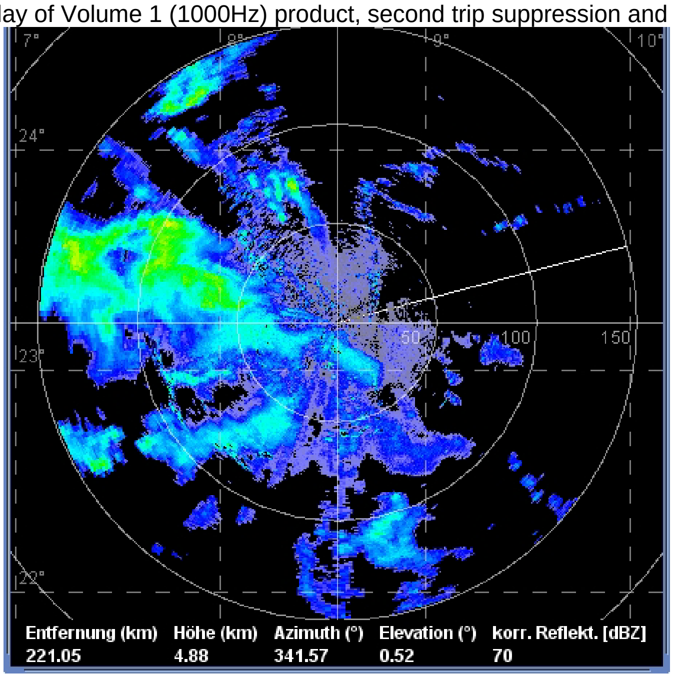

Figure 4: IQ Manager display of the same data in Fig 3 (note different colour palette used).

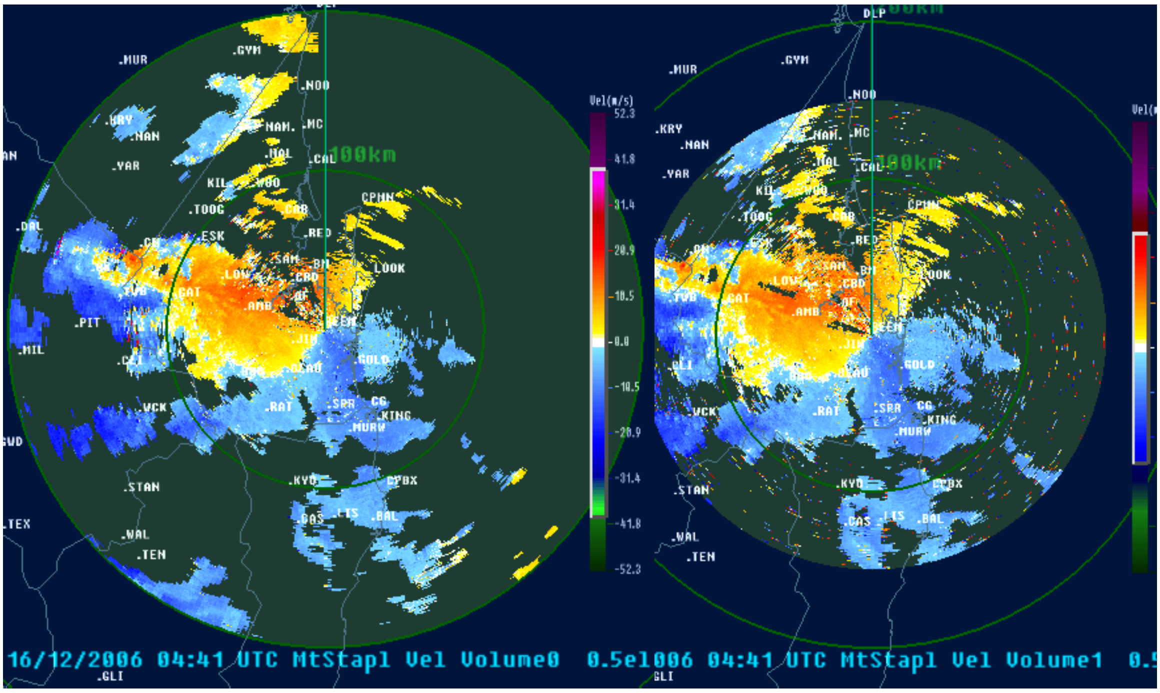

Figure 5: 3D-Rapic display of Volume 0 (left) and Volume 1 (right) velocity, with second trip suppression enabled

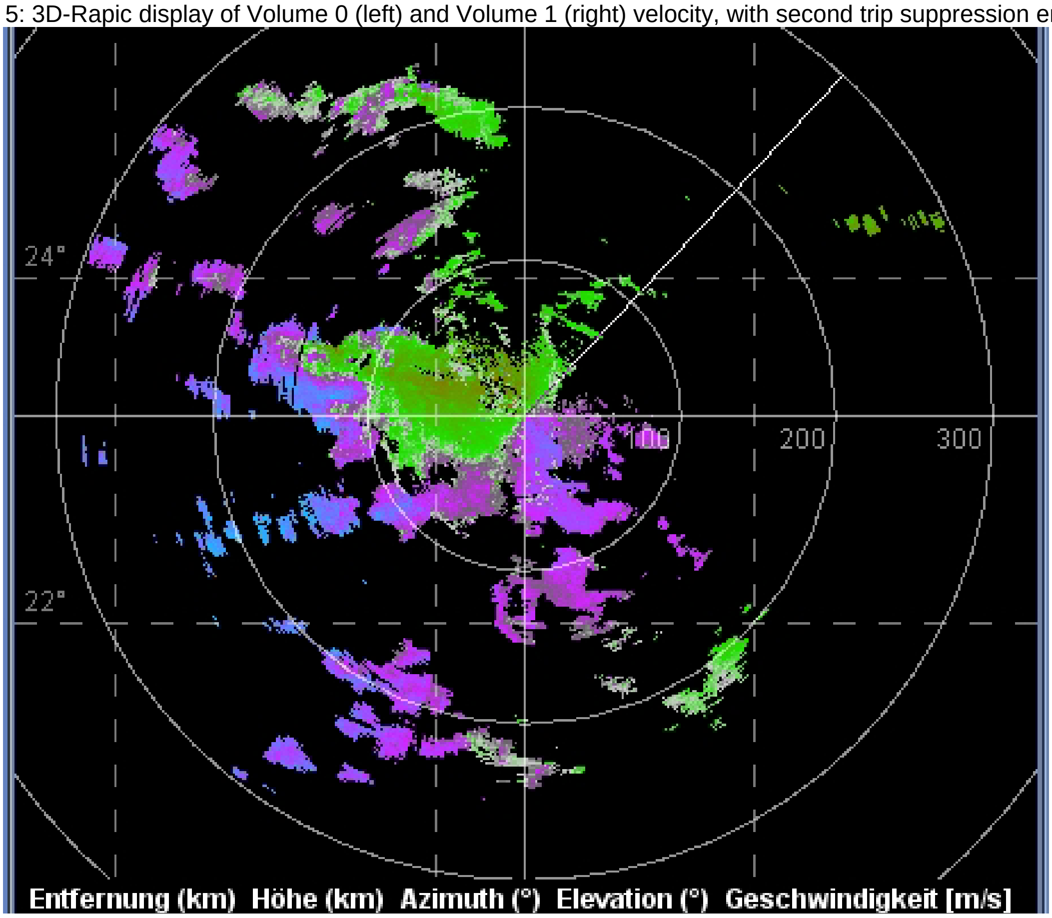

Figure 6: IQ Manager display Volume 1 velocity data with second trip recovery enabled (note different colour palette used) . The recovered data (range >150km) is generally similar to that collected for Volume 1. (Trip SQI threshold of 0.4 and a notch width of 0.3).

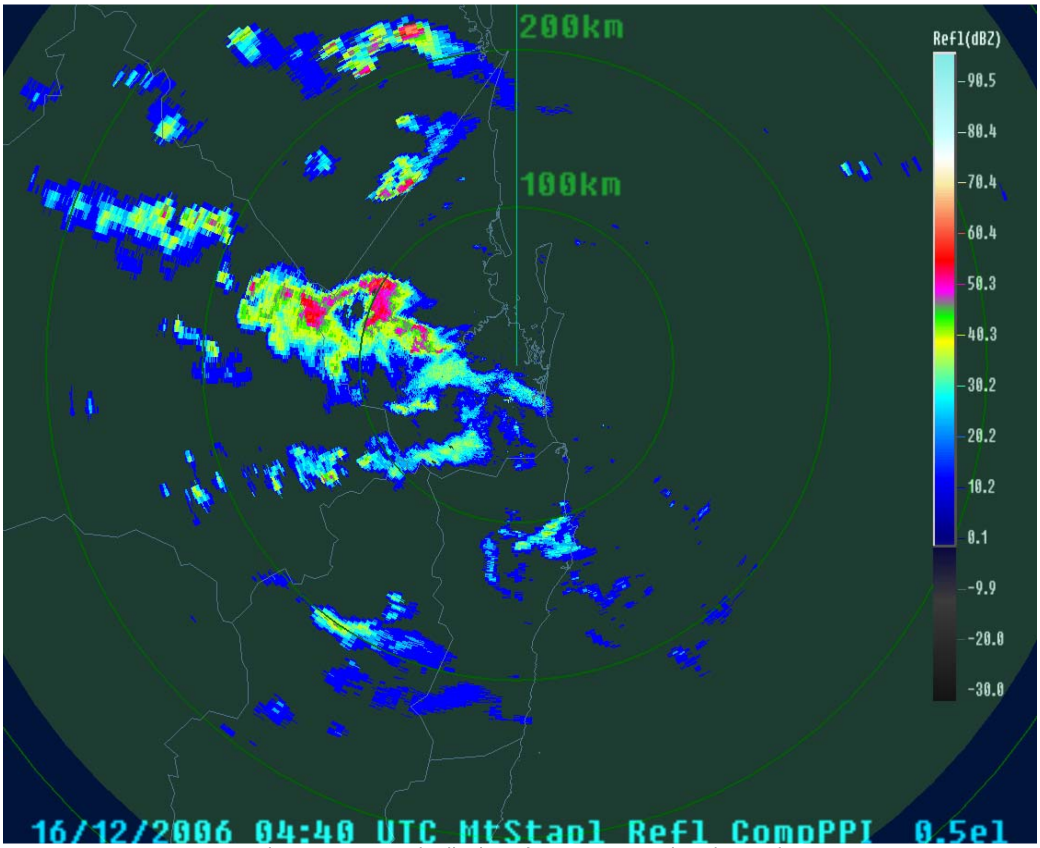

Figure 7: 3D-Rapic display of CompPPI product (400Hz)

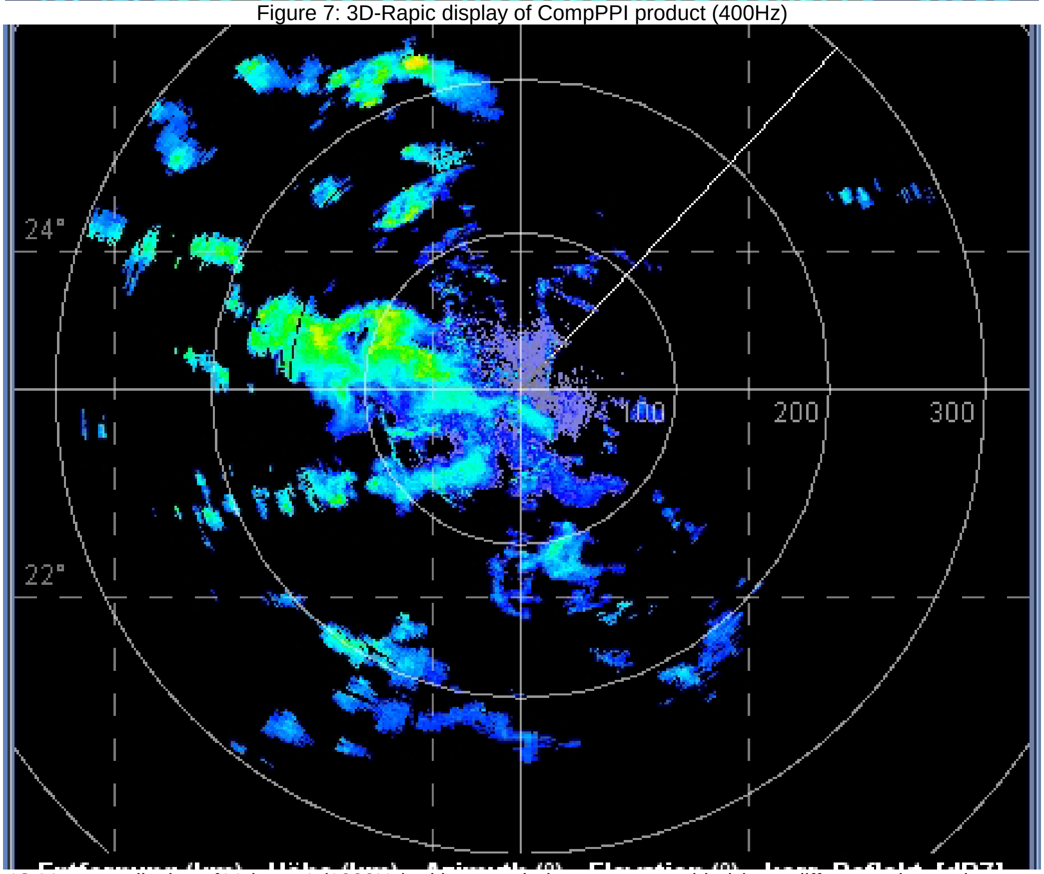

Figure 8: IQ Manager display of Volume 1 (1000Hz) with second trip recovery enabled (note different colour palette used).