P5.10 **THE IMPACT OF RNDSUP DOPPLER RADARS ON FORECAST OPERATIONS IN ADELAIDE AND BRISBANE**

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1. INTRODUCTION

As part of the Australian Bureau of Meteorology's Radar Network and Doppler Services Upgrade Project (RNDSUP), four high resolution, one degree beam-width S-band (S1) Doppler radars are being installed in major population centres, which historically, have experienced significant losses from severe weather damage, particularly severe thunderstorm damage.

The first two of these radars were installed in Adelaide, South Australia and Brisbane, Queensland, in mid and late 2005 respectively. The third has been built recently in Melbourne, Victoria. The fourth, in Sydney, New South Wales, is expected to come on line early in 2008. These locations are shown in Figure 1 of Bally et al (2007).

As a result, operational forecasters in Adelaide and Brisbane have been exposed to "clear-air" reflectivity data and Doppler velocity data for the first time. A significant training program, described in Deslandes et al (2007), has been undertaken to facilitate the integration of these new data types into the forecast and warning process, but it is too soon to be able to quantify the impact on operations from changes in the Bureau's standard forecast and warning performance measures.

However, feedback from forecasters working in the Adelaide and Brisbane Regional Forecasting Centres (RFC) indicates that the new data has impacted positively on the quality of service they provide. This paper describes several specific examples covering a range of services.

2. SEVERE THUNDERSTORM WARNING SERVICE

The Bureau of Meteorology provides a severe thunderstorm warning service, where warnings are issued if thunderstorms are expected to produce:

- Tornadoes
- Wind gusts of 90 km/h (25 m/s) or more
- Hailstones 20 mm or more in diameter
- Flash flooding, and/or rainfall exceeding certain annual recurrence interval (ARI) thresholds

Supercell thunderstorms receive a lot of attention, because of their high-end damage potential. However, in the long run, improvements in the warning service are expected to come through improved probability of detection, increased warning lead-time and fewer false alarms for a wide spectrum of severe thunderstorm types. The example described here is a case where velocity data from the Brisbane S1 radar was important in correctly discriminating between a non severe and a low-end severe thunderstorm.

2.1 Brisbane - 25 January 2007

Severe thunderstorms are a frequent spring and summertime forecasting challenge in southeast Queensland. Typically, storms develop over the elevated terrain of the Great Dividing Range before being steered eastward towards the highly populated coastal plain.

Assessment of storm severity in this region is predominantly radar based, with little ground truth information available prior to the impact of storms on major population centres, including the city of Brisbane. Traditionally, this assessment used reflectivity-based techniques, such as Treloar (1996) and analysis of storm structure. However the S1 Doppler velocity data has provided forecasters with a useful extra source of information.

On the afternoon of 25 January 2007, a line of thunderstorms developed southwest of the greater Brisbane area. The storms were steered northeast and ultimately moved through the southern parts of Brisbane. Figure 1 shows the major storm tracks, as depicted by the GPATS lightning detection network.

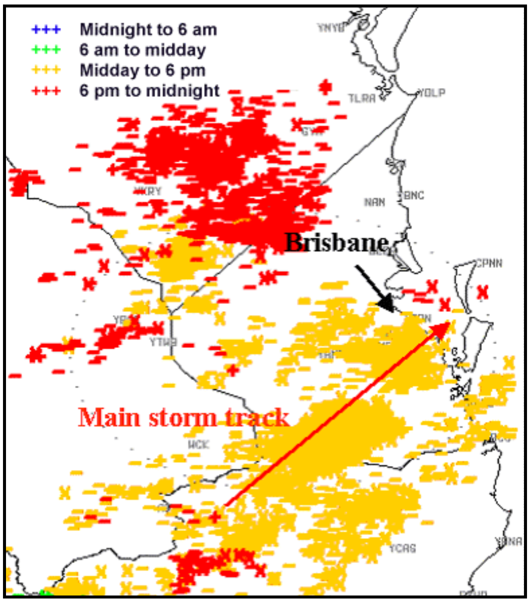

Fig 1: *Storm tracks on 25 January 2007, as depicted by GPATS lightning data.*

From the forecaster's analysis of the reflectivity data only from the Brisbane S1 Doppler radar, located 35 km south southeast of Brisbane City, it was not obvious that the thunderstorms were severe. However, Figure 2 shows consecutive 10 minute Plan Position Indicator (PPI) images of the storms with both reflectivity and velocity data depicted.

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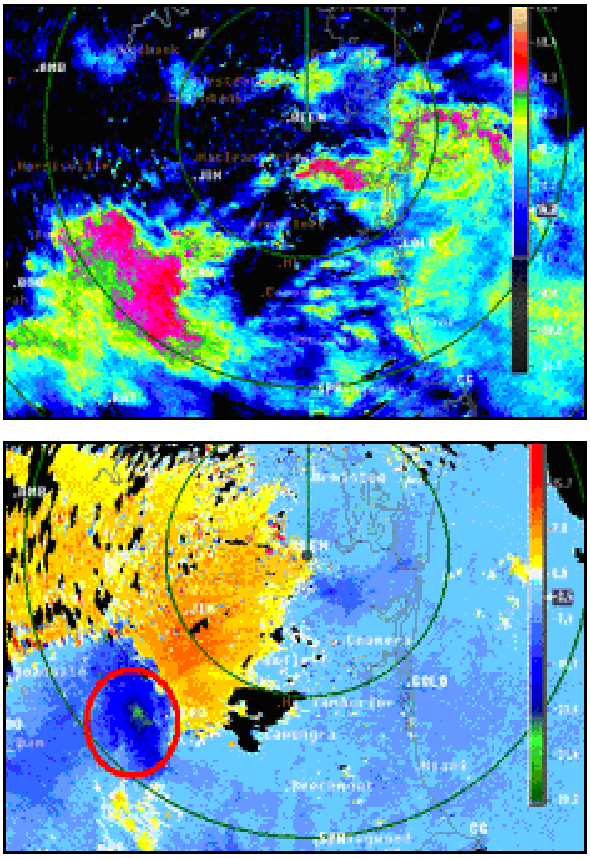


Fig 2a: *PPI reflectivity (top) and velocity images (below) at 0.5° elevation from the Brisbane S1 radar at 0620 UTC Range rings are at 25 km intervals. Height of the radar beam in circle is about 500 m. Nyquist velocity is 40 m/s.*

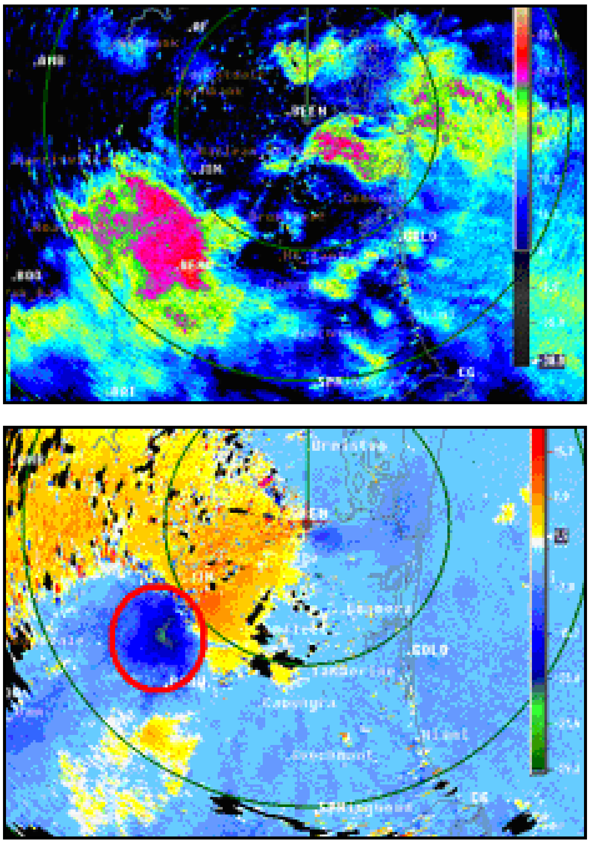


Fig 2b: *As for Fig 2a, but at 0630 UTC (4:30 pm local).*

The velocity data depicts a small area of "green" inbound velocities in excess of 25 m/s (90 km/h) in the outflow area of one of the thunderstorms (circled). The height of the radar beam at this location is about 500 metres AGL.

Forecasters considered this to be sufficient evidence that the thunderstorm was capable of producing severe (> 90 km/h) wind gusts at the surface, and a severe thunderstorm warning was issued based largely on this velocity data. The warning was issued for damaging winds and flash flooding, as the storm environment was also considered to be favourable for intense rainfall rates (not discussed here).

Both phenomena were later verified by ground reports. Trees and power lines were brought down by the wind and roads were flooded by rain in areas affected by the storm. Although not an extremely damaging event, it was notable for the fact that the Doppler velocity data had a direct and favourable impact on the warning decision.

3. MARINE SERVICES

Subtropical or “hybrid” maritime low pressure systems are significant meteorological events for the southeast Queensland region. These systems can be hazardous to mariners as they can produce 10 minute mean surface winds of storm force (> 48 knots or 24 m/s) over the ocean and exposed coasts.

3.1 Brisbane - 3 March 2006

One such event occurred in early March 2006. The mean sea level pressure (MSLP) analysis in Figure 3 shows the low pressure system off the southern Queensland coast at 2000 UTC, 2 March 2006 (6:00 am, 3 March, local time). The wind barbs depict the wind in knots (conventional symbols) as observed by ship or land station (dot at base) or derived from scatterometry (no dot). A ship observation of a 50 knot (25 m/s) south southeast wind can be seen on the western flank of the low.

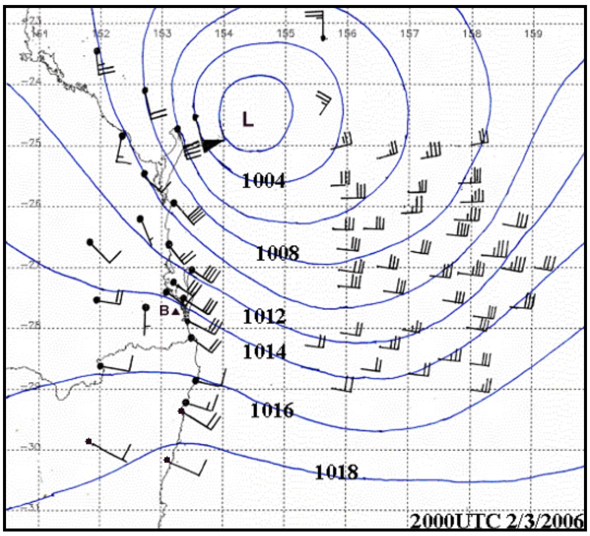


Fig 3: *MSLP analysis of subtropical low at 2000 UTC, 2 March 2006 (6:00 am, 3 March, local time). Wind barbs in knots (1 m/s = 2 knots). Isobars annotated in hPa.*

During the next six hours, a new low centre developed roughly 200 km due south of the original low, in an area near the edge of the 200 km maximum unambiguous range of the Brisbane S1 Doppler radar.

The new low centre then tracked slowly eastward away from the Queensland coast, so that by 2000 UTC, 3 March (6:00 am, 4 March, local time), it was located as in the MSLP analysis, in Figure 4.

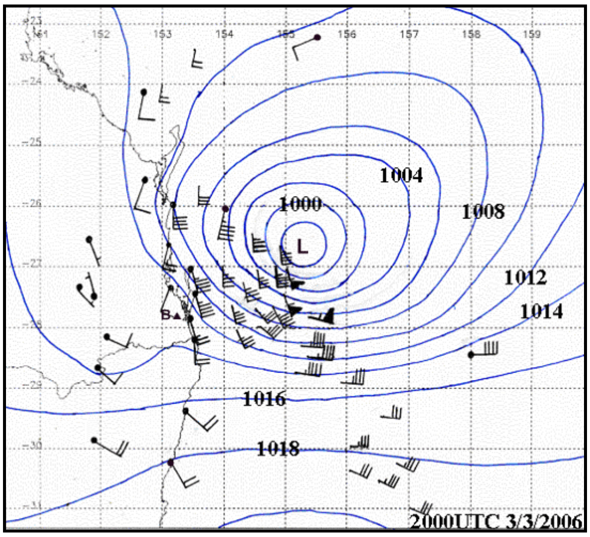
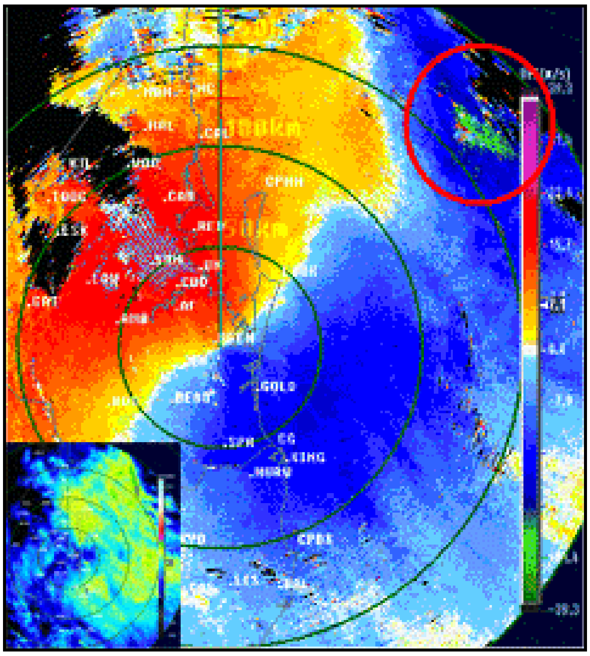


Fig 4: *MSLP analysis of subtropical low at 2000 UTC, 3 March 2006 (6:00 am, 4 March, local time). Wind barbs in knots (1 m/s = 2 knots). Brisbane S1 radar is marked by a triangle, about 220 km southwest of the low centre. Isobars annotated in hPa.*

During the early morning of 3 March, prior to the development of the second low centre, velocity PPI images (not shown) indicated a broad area of heavy rain and strong southeast flow on the southwest flank of the original low. But around midday, a significant change became evident. Figure 5 below shows two consecutive 10-minute velocity PPI images, with the first at 0210 UTC (12:10 pm local time).



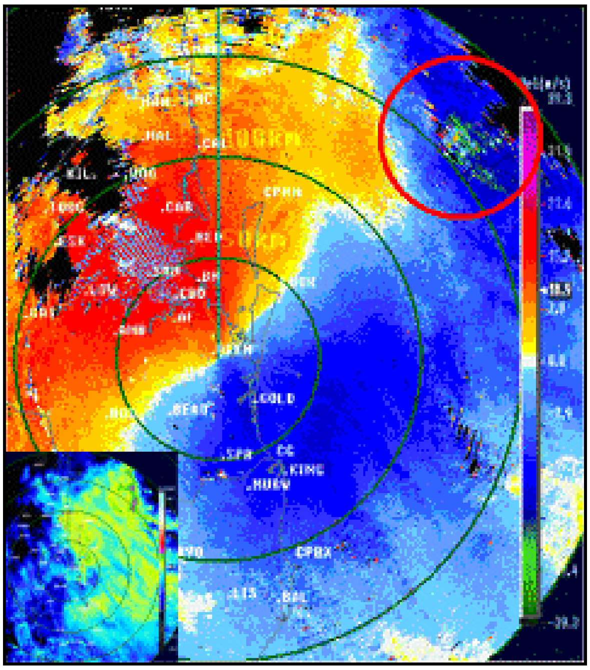


Fig 5: *Velocity PPI images at 0.5°* *(main) and reflectivity (inset) from the Brisbane S1 Doppler radar at 0200 UTC (bottom of previous column) and 0220 UTC (above), on 3 March 2006. Range rings are at 50 km intervals. Nyquist velocity is 40 m/s.*

Circled in the northeast quadrant of the velocity displays in Figure 5 is a small area of "green" inbound velocities greater than 25 m/s (above the storm force threshold).

This feature is associated with a general increase in convection in the same area. Although at this range (150-180 km), the radar observed winds were well above the surface (height of the radar beam at the circled locations is 3000-3200 metres), this data was instrumental in alerting forecasters to the development of the second southern low pressure centre. This enabled marine warnings for gale and storm force winds to be adjusted appropriately and in a timely manner.

4. AVIATION SERVICES

Aviation services comprise a substantial component of the weather services output from the Adelaide and Brisbane RFCs. As well as state-wide services for regular passenger transport (RPT) and general aviation, targeted services are provided 24 hours a day for Adelaide and Brisbane International Airports.

Of all the weather services, the Adelaide S1 Doppler radar has probably had most impact on aviation services, simply because of the number of occasions when the new data has played an important part in forecast decisions. Three examples are described here.

4.1 Adelaide - 22 September 2006

Adelaide Airport is a major capital city airport, which operates 24 hours a day. At similar airports on the east coast of Australia, aircraft measurements of wind and temperature (AMDAR data) provide wind profile observations at high temporal resolution, but at Adelaide Airport, upper wind data has been limited to four balloon flight observations per day. However, the velocity data from the Adelaide S1 radar, located about 40 km north of the Airport, now provides forecasters with a valuable additional source of vertical wind profile information.

In this example, a front was forecast to move through Adelaide Airport at about 2130 UTC, 21 September 2006 (7:00 am, 22 September, local time). Pre-frontal northerly winds were expected to strengthen during the overnight period ahead of the front.

The upper wind observation at 1100 UTC (8:30 pm local time), 21 September confirmed that above the surface northerly wind of 5-10 m/s, north northwest winds had already increased to 20 m/s at 300-600 metres AGL, with some indications of a low level wind speed maximum developing.

The reflectivity PPI images for the same time had sufficient clear air signal, to enable usable velocity data to be obtained up to about 1800 metres AGL. A Doppler velocity PPI image for 1100 UTC is shown in Figure 6. It indicates surface northerly winds, backing to a fairly uniform north northwest flow of around 20 m/s above 200 metres, consistent with the 1100 UTC upper wind observation.

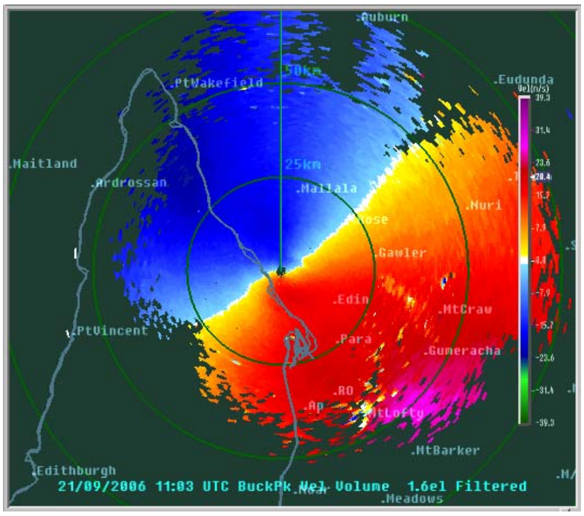


Fig 6: *Velocity PPI image at 1.6° from the Adelaide S1 Doppler radar at 1100 UTC, 22 September 2006. Range rings are at 25 km intervals. Nyquist velocity is 40 m/s.*

After 1100 UTC, the radar velocity data showed further strengthening of the winds in the 200-1800 metre layer, which presented the potential to cause a hazard to aircraft, especially on approach to landing and take-off. At 1400 UTC (11:30 pm local time), a warning for severe turbulence was issued for the area around and to the south of the Airport. A velocity PPI image for 1400 UTC, the time the warning was issued, is shown in Figure 7.

The low level winds continued to increase in strength after 1400 UTC, until about 1600 UTC and the Doppler velocity PPI image for this time is also shown in Figure 7. The "dark green" inbound and "dark purple" outbound velocities 15-25 km from the radar on the PPI at 1600 UTC, indicate north northwest winds of 35 m/s (70 knots) at 400-800 metres AGL.

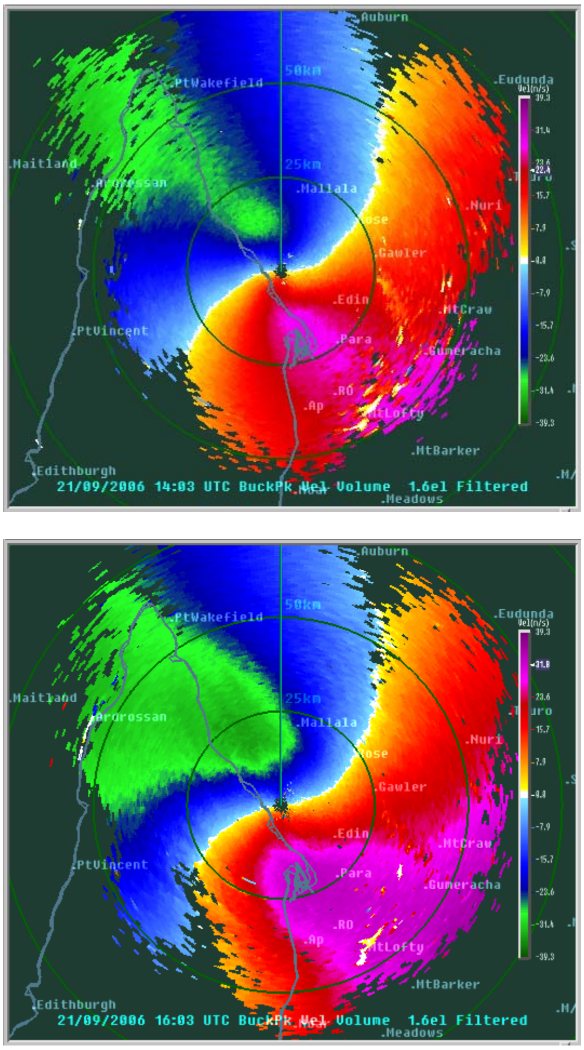


Fig 7: *Velocity PPI images at 1.6° from the Adelaide S1 radar at 1400 UTC (top) and at 1600 UTC (below), on 22 September 2006. Range rings are at 25 km intervals. Nyquist velocity is 40 m/s.*

With no other upper wind data available, the decision to warn was based almost totally on the Doppler velocity data. As a result, the warning was issued prior to the 1700 UTC upper wind observation and before the morning peak in aircraft traffic, thereby maximising the warning's effectiveness.

4.2 Adelaide - 23 March 2007

A significant front was forecast to move through the Adelaide area about 0200 UTC, 23 March 2007 (11:30 am, local time), bringing rain showers and thunderstorms. The pre-frontal northerly winds were quite strong, with north northwest winds of 20-22 m/s at 300 metres AGL and 25 m/s at 1000 metres AGL.

Forecasts were, justifiably, focussed on the frontal passage and the accompanying potential for thunderstorms, as the period most likely to cause hazardous conditions for aviation. However, in the early morning, at about 2030 UTC, 22 March (7:00 am, 23 March, local time), a series of three fine lines was detected over Yorke Peninsula to the west of Adelaide, in the reflectivity data from the S1 Doppler radar (see Figure 8).

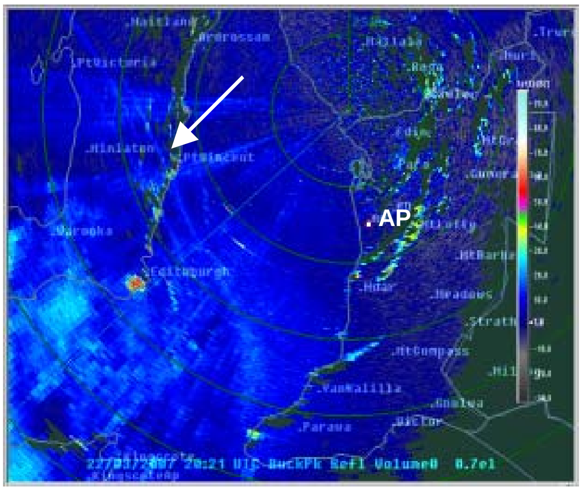


Fig 8: *Reflectivity PPI image at 0.7° from the Adelaide S1 radar at 2020 UTC 22 March (6:50 am, 23 March, local time), showing a series of fine lines west of the radar. Adelaide Airport denoted by AP. 25 km range rings.*

Over the next 20-30 minutes, it became evident from the velocity data, in particular, that there was a temporary, but marked change in wind direction associated with this "wave feature". Reflectivity and velocity PPI images at 2100 UTC, 22 March (7:30 am, 23 March, local time) are shown in Figures 9 and 10.

The Doppler velocity data in Figure 10 shows "blue" inbound velocities associated with the leading wave extending from northwest of the radar to south southwest of the radar. This indicates a wind in the leading wave at this location from about 290 degrees. The surface wind at Adelaide Airport at this time was northerly at 7-8 m/s, suggesting that the passage of the disturbance was likely to cause a temporary wind shift of about 90 degrees.

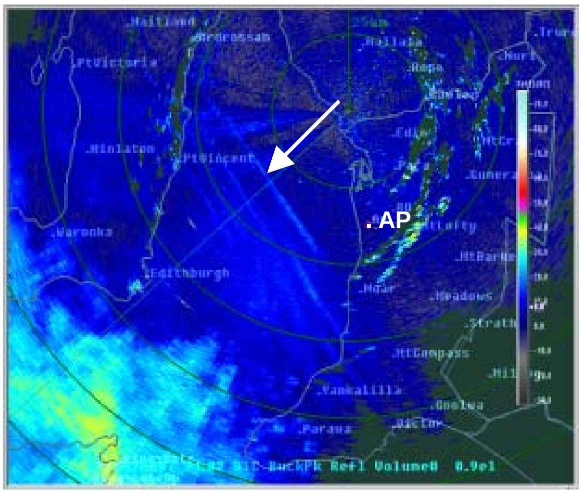


Fig 9: *Reflectivity PPI image, as per Figure 8, but at 2100 UTC 22 March 2007 (7:30 am, 23 March, local time). Leading line about 25 km west of the Airport.*

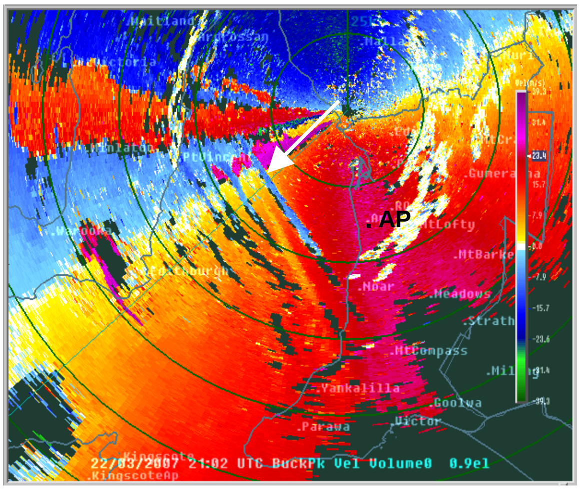


Fig 10: *Velocity PPI corresponding to the reflectivity PPI in Fig 9, at 2100 UTC 22 March. "Blue" inbound velocities with the leading line indicate an associated marked change in wind direction. Nyquist velocity is 40 m/s.*

The forecaster also recognised the potential for this shallow feature to dramatically increase the vertical wind shear over Adelaide Airport and issued a Wind Shear Warning. The situation was considered particularly hazardous, because there wasn't any cloud or other visible clue to alert pilots to the potential hazard.

Thus as a direct consequence of the S1 Doppler data, the short term forecast for Adelaide Airport was updated to forecast a 90 degree change in wind direction with 30 minutes lead-time and a Wind Shear Warning was issued 20 minutes prior to the surface wind shift occurring at the Airport.

While the lead-time was short, it is extremely unlikely that any advance notice of this potentially hazardous event would have occurred without the data from the Adelaide S1 Doppler radar.

4.3 Adelaide - 27 March 2007

On 27 March 2007, the Terminal Area Forecast (TAF) for Adelaide Airport was for a northwest wind, turning west, then southwest during the evening, in association with a frontal band of rain showers. There were no warnings of hazardous conditions in place.

However, the front intensified not far to the west of Adelaide and moved through the Airport at 1130 UTC (9:00 pm, local time) as a sharp discontinuity in wind direction and a burst of squally winds of 10-14 m/s with gusts to 22 m/s. The significant change in wind direction resulted in the tail wind component exceeding the operating limits for some aircraft, necessitating a switch in landing runways. The sudden onset of gusty conditions also hampered tarmac operations for a short period.

In the lead-up to this event, the intensifying front had not been visible on satellite imagery and was first detected on radar at about 0930 UTC (7:00 pm local time) in clear air, just over 100 km west of Adelaide and 40-50 km in advance of the band of rain showers approaching from the west. Figure 11 shows the clear air reflectivity PPI at this time.

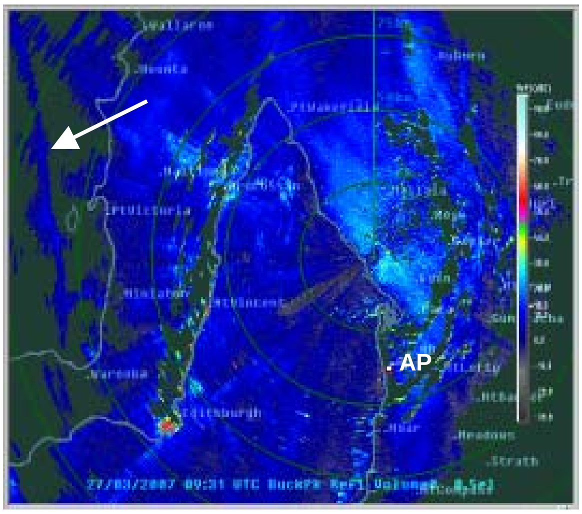


Fig 11: *Reflectivity PPI image at 0.5° from Adelaide S1 radar at 0930 UTC (7:00 pm, local time) 27 March. Adelaide Airport denoted by AP. Range rings at 25 km intervals. The approaching front can be seen as a north-south line 100 km west of the radar.*

By 1000 UTC (7:30 pm local time), the reflectivity data from the clear air and the Doppler velocity data (see Fig. 12 below) were sufficient to give the forecaster a good handle on several important characteristics of the frontal wind shift, despite it not yet having passed over any automatic weather stations (AWS).

The wind shift line was orientated almost north-south and was evident to a depth of about 2000 metres. The line was tracking eastwards at 12 m/s, which meant it was due at Adelaide Airport about 1130 UTC (9:00 pm local time). The Doppler velocity data along the frontal line indicated inbound velocities from 285 degrees at 18-22 m/s at a height of about 1200-1500 metres AGL. The inbound velocities of 18-22 m/s suggested that that surface wind gusts of similar strength could be anticipated.

In contrast, this frontal feature was not discernible at all on the Sellicks Hill general surveillance radar, which is a C-band radar with coarser resolution and lower sensitivity than the S1 Doppler, and located 45 km south of the Airport.

The initial detection of the frontal wind shift on radar and the forecaster's subsequent assessment of its characteristics, enabled the forecaster to update the terminal forecast and alert air traffic controllers verbally of the expected change in conditions; giving them important advance notice and the opportunity to take actions to maximise safety and minimise disruption.

Although conditions were not exceptionally severe, earlier forecasts had underplayed the situation, and had it not been for the additional data provided by the S1 Doppler radar, the squally winds associated with this front may have reached Adelaide Airport with even less warning or possibly no warning at all.

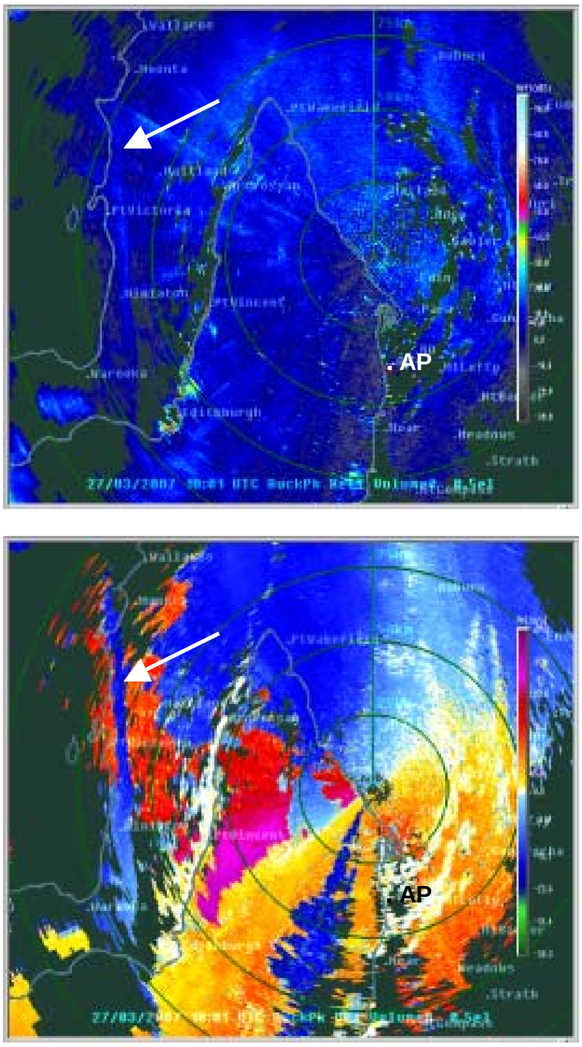


Fig 12: *Reflectivity (top) and velocity (below) PPI images as per Fig. 11, but for 1000 UTC (7:30 pm, local time) 27 March. Nyquist velocity is 40 m/s.*

5. FIRE WEATHER SERVICES

Adelaide RFC provides a comprehensive fire weather service to the general public and fire response agencies between October and April/May. The service comprises routine forecasts issued one to four days in advance for planning purposes combined with more detailed short term and location specific forecasts on days of extreme fire danger and when there are fires burning.

Location specific forecasts for going fires are used by fire agencies to ensure that attack strategies employed on a fire are appropriate to the current and forecast weather. Forecasts of changes in wind direction are especially important, as a long fire flank can suddenly turn into a wide fire front, with rapid increases in rate of spread and potentially dangerous conditions for fire fighters.

5.1 Adelaide - 10 January 2007

10 January 2007 was a day of extreme fire danger across much of South Australia, including the Adelaide and Mount Lofty Ranges region, where

temperatures were in the high 30's (degrees Celsius), relative humidity was around 10% and winds were from the northwest at 7-12 m/s. In addition, a shallow front was forecast to bring a wind change to the Adelaide area during the late afternoon.

Shortly after 0730 UTC (6:00 pm, local time) a fire ignited in steep terrain near Mount Bold Reservoir, 20 km south southeast of Adelaide City and 55 km south southeast of the Adelaide S1 radar. The fire burnt fiercely and spread quickly in the pre-frontal northwest flow.

A request for a forecast for the Mount Bold area was received at 0800 UTC (6:30 pm, local time), and at this time forecasters were already closely monitoring the wind change, using AWS data and data from the Adelaide S1 Doppler radar.

Figure 13 shows reflectivity and velocity PPI images at this time.

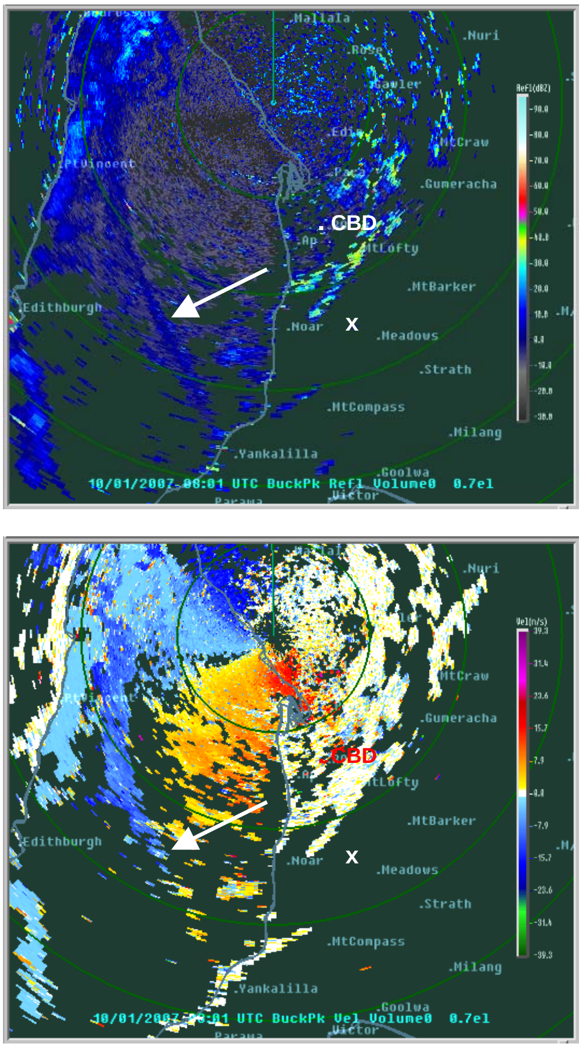


Fig 13: *Reflectivity (top) and velocity (below) PPI images at 0.7° from the Adelaide S1 radar at 0800 UTC (6:30 pm, local time) 10 January 2007. The location and orientation of the front (arrowed) can be seen in both. Adelaide City is denoted by CBD and the fire location by a white X. Range rings at 25 km intervals. Nyquist velocity is 40 m/s.*

Reflectivity and velocity data are often used in combination, as here, to determine the location, orientation, depth and movement of a wind change. The velocity data is used to help estimate the post-frontal wind speed.

In this situation, the radar data was a valuable addition to the point data from AWS, because it provided both spatial and temporal detail (radar data was updated every 10 minutes). This extra data helped the forecaster respond to the fire agency's forecast request quickly and contributed to quality of the forecast (the arrival time of the wind change at the Mount Bold fire was forecast to within a few minutes).

Figure 14 shows velocity PPI images at 0820 and 0840 UTC (6:50 pm and 7:10 pm, local time). These images show the subsequent progression of the wind change towards the fire. Interestingly, the smoke plume from the fire can also be seen, providing the forecaster with useful confirmation of the exact location of the fire.

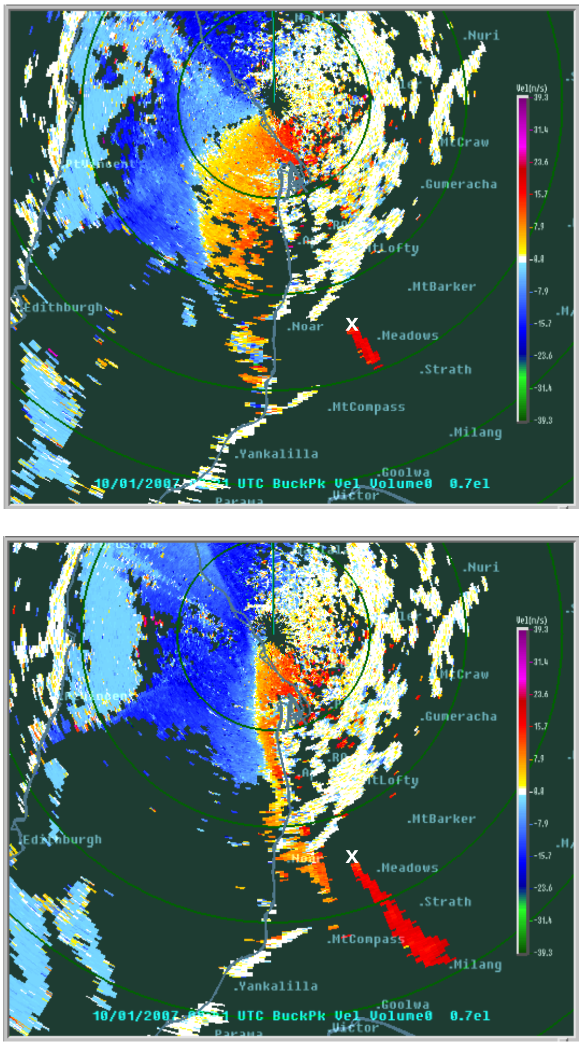


Fig 14: Velocity *PPI images at 0.7° as per Figure 13, but for 0820 UTC (top) and 0840 UTC (below) (6:50 pm and 7:10 pm, local time respectively). The "red" outbound velocities emanating from the X are from the fire's smoke plume.*

6. SUMMARY

Feedback from forecasters indicates that high resolution "clear-air" reflectivity and Doppler velocity data from the two S1 Doppler radars installed in 2005 have already had a positive impact on the quality of short term forecast and warning services provided by the Brisbane and Adelaide Regional Forecasting Centres. Specific examples have been described, covering severe thunderstorm, marine, aviation and fire weather, which serve to demonstrate that the benefits of S1 Doppler radar data extend well beyond severe thunderstorm warning services.

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Acknowledgements

The authors would like to thank Jeff Callaghan from the Bureau of Meteorology, Brisbane, Australia for contributing the MSLP analyses in Figures 3 and 4.