P13B.20MV A CASE-STUDY OF A SEVERE THUNDERSTORM WARNING EVENT IN SYDNEY, AUSTRALIA: COMBINING FORECASTER INPUT WITH AUTOMATED NOWCAST GUIDANCE

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1. INTRODUCTION

On 31 October 2006, a severe thunderstorm crossed the Newcastle area, north of Sydney, Australia, bringing large hailstone and damaging wind. This event was not especially severe, and is not presented as an example of a major storm. Rather, the event is used to demonstrate the operation of the severe thunderstorm warning service in the greater Sydney region, showing how integration of manual radar analysis and automated nowcast guidance, together with sophisticated display software and warning preparation systems can provide an effective warning service.

2. BACKGROUND

Sydney and nearby areas are one of the most severe thunderstorm prone regions of Australia. The region is also densely populated with the coastal plain between Newcastle and Wollongong (see Figure 1) being home to some 5 million people, about 25% of Australia's total population. A severe hailstorm in Sydney in April 1999 produced hail at least 9 cm in diameter, damaging some 20 000 properties and more than 60 000 motor vehicles. The damage bill for this storm reached an estimated 2.2 billion Australian dollars (Bureau of Meteorology, 2006).

A two-tiered warning service operates in the state of NSW, of which Sydney is a part. The basic service is available to all parts of the state, even those large areas without radar coverage. These warnings, updated every 3 hours, or as necessary, delineate the areas currently affected, or soon to be affected, by severe thunderstorms.

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Figure 1. *The greater Sydney area, showing the location of major cities and towns, and the four weather watch radars in the area. The boundaries shown are the subdivisions of the region for which detailed cell-based Severe Thunderstorm Warnings are issued.*

A more detailed "cell-based" warning service is provided in the populous greater Sydney region, extending from Newcastle to south of Wollongong (a north/south distance of some 230 km), and from the coast west to the Blue Mountains (an east/west distance of about 100 km). These warnings are updated every 30 minutes.

The greater Sydney region is served by four radars (Figure 1). The main Sydney radar at Letterbox (EEC WSR74S/92-14) is an S-band radar with 2 degree beamwidth. The Kurnell radar (WF100-6C/12) is a C-band system with 1 degree beamwidth, and is currently the only radar in the region with Doppler capability. The Newcastle radar (EEC WSR74S/99-14) provides coverage for the northern half of the warning area, and is an S-band 2 degree beamwidth system. The Canberra radar (EEC WSR74S/96-14) has similar specifications and provides additional coverage for southern parts of the region. All radars perform a full 15-tilt volume scan every 10 minutes, except for Kurnell which gives an 11-tilt volume every 5 minutes.

An AMS Gematronic METEOR 1500S radar to be installed at Terrey Hills, Sydney during 2007 as part of the Radar Network and Doppler Service Upgrade Project (RNDSUP) will significantly enhance coverage.

3. VIEWING AND ANALYSING RADAR DATA

Radar data are visualised using a sophisticated display package called 3D-Rapic described by Purdam (2007). This allows forecasters to view reflectivity and velocity data (where available) on any elevation angle tilt or on any user-defined CAPPI surface. RHI type scans, assembled from the volumetric data, can be viewed easily, as can vertical cross-sections along any user-defined line. Derived data like VIL are also readily displayed. Recent enhancements include display of storm-relative velocity, and overlay of nowcast guidance from the TITAN and WDSS systems (see below for further detail).

Radar data for Newcastle radar, as displayed by 3D-Rapic, for 0420Z on 31 October 2006 is shown in Figures 2, 3, 4 and 5.

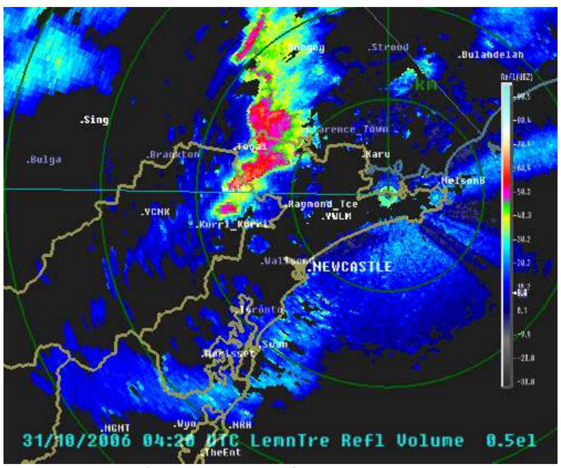

Figure 2. *Reflectivity data for Newcastle radar on a 0.5degree elevation angle PPI at 0420Z 31 October 2006. Range rings are at 25 km intervals. Newcastle city is near the centre of the image. The thick gold line outlines the border and internal subdivisions of the region for which detailed cell-based warnings are prepared.*

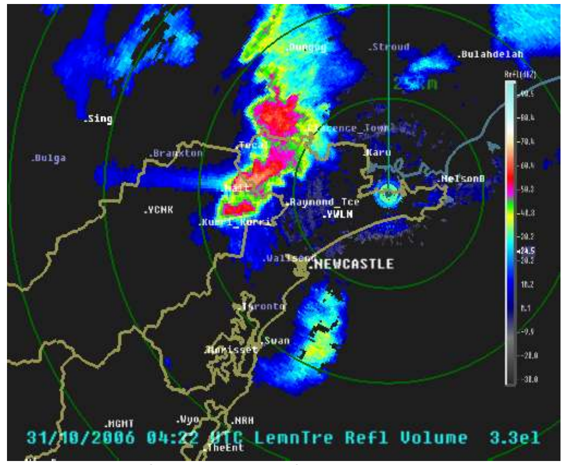

Figure 3. *Reflectivity data for Newcastle radar on a 3.3degree elevation angle PPI at 0420Z on 31 October 2006.*

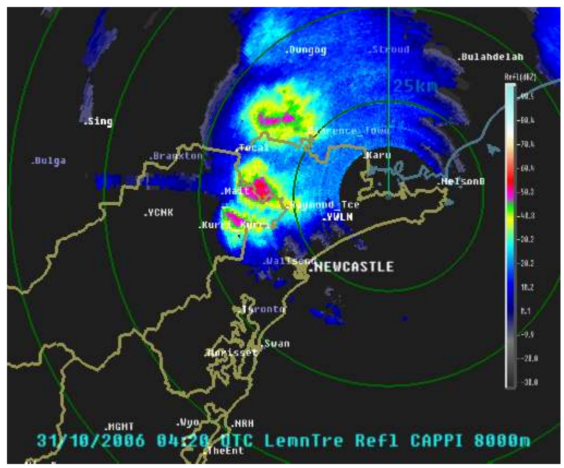

Figure 4. *Reflectivity data for Newcastle radar on an 8 km elevation CAPPI at 0420Z on 31 October 2006.*

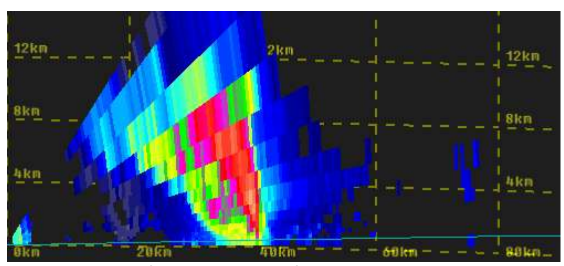

Figure 5. *Reflectivity data for Newcastle radar on an RHI along the azimuth highlighted in Figure 2.*

The figures show a thunderstorm complex to the west and northwest of the radar. The southern end of the complex is generating a marked hail spike on the 3.3 degree elevation tilt (also evident on neighbouring tilts, not shown). The intense reflectivity in the storm extends to climatologically high levels for the relatively low freezing level of the day (60 dBZ returns were reported to 8 km), and well above the threshold for large hail given by a locally developed hail size nomogram based on 50dBZ height and freezing level (Treloar, 1996).

Development over the previous 30 minutes (not shown) suggest that the system is in the process of splitting, with the southern end of the complex developing rapidly and moving towards the southeast.

Structurally, this southern storm has a well-developed weak echo region with its top displaced well to the east-southeast over the inflow flank of the system.

Figure 6 shows velocity data from Kurnell Doppler radar, which is nearly 150 km away to the south-southwest.

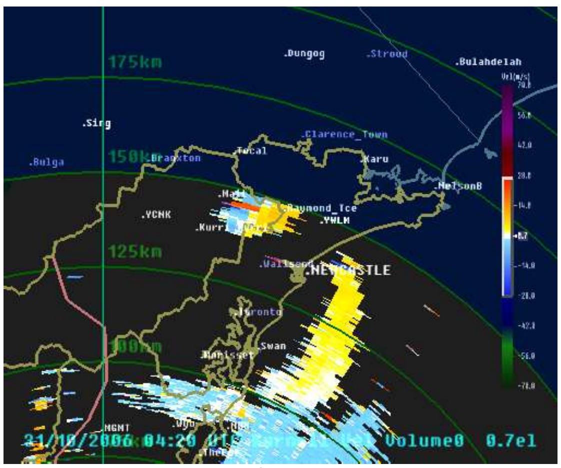

Figure 6. *Velocity data for Kurnell radar on a 0.7degree elevation angle PPI at 0420Z on 31 October 2006. Outbound winds are shaded range and red, inbound winds in blue. The storm of interest is nearly 150 km distant from Kurnell radar and the PPI at this distance is about 3100 metres above ground level.*

This shows evidence of anticyclonic (anticlockwise) rotation in mid-levels of the storm, supporting the interpretation of this as the right-moving member of a split pair.

The radar data, coupled with an analysis of the near-storm environment, suggest that a warning for large hail and damaging wind is warranted for the whole storm complex, and especially for the storm at southern end of the system, which is developing supercellular characteristics.

One important consideration is the future tracks of the storms. This is complicated by the recent storm split. Manual extrapolation of the most recent movement of the intense hail-spike producing core of the southern storm is shown in Figure 7, and shows the storm tracking over the densely populated western and southern suburbs of Newcastle. This area has a population of some 280, 000. Such a movement would be a major concern to the forecaster.

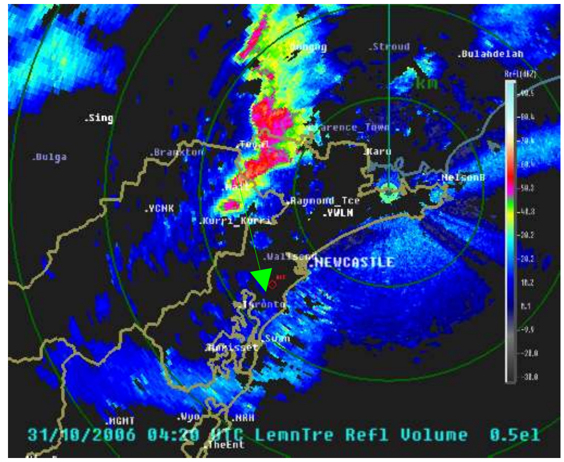

Figure 7. *Forecast track of southern storm cell based on its recent movement. The head of the green arrow shows the position of the cell in 60 minutes time, deduced by manual extrapolation.*

4. AUTOMATED NOWCAST GUIDANCE

The volumetric data from the radars is also processed and analysed automatically using the TITAN and WDSS algorithms (TITAN is described by Dixon and Wiener (1993), WDSS by Eilts *et al* (1996)). These systems were imported and adapted for use in Australia as part of RNDSUP (Canterford *et al*, 2007).

TITAN identifies convective cells in the reflectivity data, tracks these over time, and estimates an extrapolation-based forecast track. The WDSS SCIT algorithm similarly identifies and tracks convective cores. The WDSS HDA algorithm for estimating hail probability and hail size, based on the disposition of storm reflectivity relative to the freezing level and -20˚C level, is now operational in Australia. The WDSS Doppler-velocity-based MDA, TVS and DDPDA algorithms for mesocyclones, tornadoes and downbursts respectively, have been adapted for Australian radars and are currently under test.

Figure 8 shows the 45 dBZ TITAN data overlayed on the Newcastle radar data at 0420Z on 31 October 2006.

This shows how the forecaster can view TITAN data in 3D-Rapic.

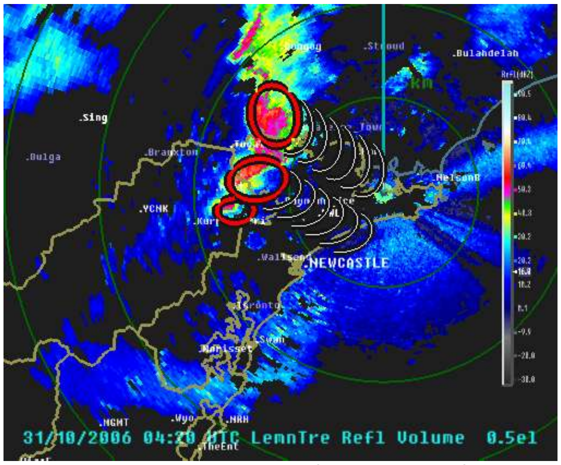

Figure 8. *Newcastle radar reflectivity data for 0420Z 31 October 2006 (0.5 degree elevation angle PPI), with 45 dBZ TITAN cells (red ellipses) and forecast tracks (white arcs showing the leading edge of cell at 10 minute intervals) overlayed.*

TITAN resolved three cells in the storm complex to the northwest of Newcastle at this time. Forecast storm movements were to the east-southeast, tracking the intense southern portion of the storm complex across to the coast just to the north of Newcastle. This movement is significantly different to the one produced by manual extrapolation. Splitting storms are by nature more difficult for TITAN to cope with, and TITAN tracks would be given less credibility by the forecaster in this situation.

The WDSS HDA algorithm (not shown) predicted a maximum expected hail size of 4.7 cm at this time, confirming concerns of large hail in association with this storm.

5. BACKGROUND TO WARNING PREPARATION

Having concluded that a warning is necessary following analysis of the radar data in 3D-Rapic and integration of algorithmic and observational data from the near storm environment, the forecaster moves to the TIFS software (Thunderstorm Interactive Forecasting System, described by Bally (2001)) to begin preparation of the warning.

TIFS is a graphical forecast preparation system where the forecaster depicts, on a map background, the location and forecast tracks of severe thunderstorms, or of thunderstorm cells that are expected to become severe during the validity of the warning (warnings typically describe developments over the following hour and are updated every 30 minutes). The forecaster also outlines a ‘threat area’ showing the area potentially under threat from severe weather during the warning validity. This threat area enables the forecaster to draw a buffer zone around cell tracks to allow for uncertainty in cell motion. It also allows the inclusion of areas favoured for thunderstorm intensification or new cell development, but which may not be under threat from currently existing cells.

The great benefit of TIFS is that it automatically generates the text for a worded warning that describes the location of severe cells and the localities they are forecast to affect, as well as the areas encompassed by the threat area. This text updates automatically with each forecaster graphical edit. This automatic text generation frees the forecaster from the laborious and time-consuming process of geographically referencing cells and crafting the warning text. It speeds warning preparation and also ensures consistency between the worded warning and the graphic, which will also be disseminated.

6. PREPARING A WARNING

On opening TIFS, the forecaster gets to view guidance on current cell locations and forecast tracks. At present guidance is limited to TITAN detections for each radar (and a composite product) at 35, 40 and 45 dBZ thresholds. Work is underway to incorporate other tracking guidance, like WDSS and lightning-based tracks into TIFS (see Bally (2007) for details).

The forecaster’s first task is to select the most appropriate track-set from which the warning will be derived. The higher threshold 45dBZ tracks are useful because they exclude many of the non-severe thunderstorms cells. However, the 45dBZ cells can, on occasion, be too “compact” and may not therefore accurately represent the potential extent of severe weather. 35dBZ TITAN naturally produces larger cells, but can also include many weak non-severe thunderstorms.

The decision about which track-set to use is not crucial, as cells can be added and deleted as necessary, and cell properties like position, size and velocity can all be modified later, but choosing the most appropriate track-set will speed the warning preparation process.

The 45 dBZ TITAN tracks for the Newcastle radar at 0420Z on 31 October 2006 are shown in Figure 9, as they would be seen by the forecaster in TIFS.

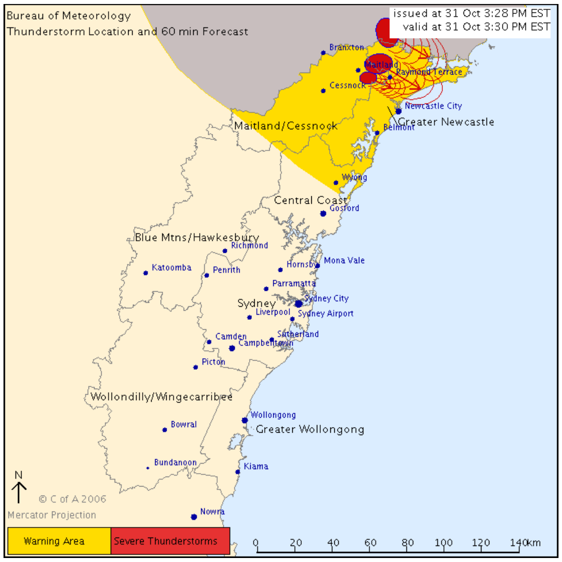

Figure 9. *TIFS graphical editor screen showing 45 dBZ TITAN cells and tracks derived from Newcastle radar data at 0420Z 31 October 2006. The map subdivisions show the coverage area of the cell-based warning service. As shown here, a yellow and grey shaded area will be displayed, depicting the coverage of a larger scale, more general, Severe Thunderstorm Warning that typically precedes the issue of a cell-based warning.*

Having decided, in 3D-Rapic, which cells are of concern, the next step in warning preparation is to remove all other cells from the TIFS display. This is important because all the cells remaining on the graphic will generate text and will be described as severe. The graphic should show only cells that the forecaster judges to be severe, or expects to become severe within the validity of the warning.

Weak cells can be suppressed easily in TIFS using VIL and/or height filters that are accessible from the TIFS interface. Using these in a trial-and-error fashion will usually allow the forecaster to remove most non-severe cells very quickly. Any remaining non-severe cells can then be deleted manually, one by one, in a point and click fashion.

At 0420Z on 31 October 2006, there were no other cells in the greater Sydney region, so no filtering or cell deletion would have been required.

The next task in warning preparation is to edit the properties and tracks of the severe thunderstorm cells that remain on the TIFS graphical editor interface.

The TITAN forecast track is calculated using a weighted mean of the cell's scan-to-scan velocity for the current and the five previous radar volume scans; more weighting being given to recent movement to improve TITAN's responsiveness to changes in direction or speed.

The forecaster can sometimes improve on the track guidance by manually tracking the cell in 3D-Rapic, or by anticipating changes in direction caused by, say, interaction with a radar-detected boundary. The forecaster also has access to WDSS velocities in 3D-Rapic, and can easily compare and assess the various track guidance on that platform.

Less often, it may be necessary to fine-tune the location or size of a TITAN thunderstorm cell to better represent the area likely to be affected by severe weather. TITAN cells are cores of intense reflectivity, and therefore usually correlate well with heavy rainfall and large hail. The correlation with severe wind is less strict however. Supercell thunderstorms are an obvious example of this – the most damaging winds associated with the rear-flank downdraft lie on the left-rear flank of the typical left-moving southern hemisphere supercell, and therefore to the left of the storm's reflectivity core. The forecaster may need to expand the cell on its left flank to cater for this.

In TIFS, cell properties and velocity can be modified quickly, if necessary, with a few mouse clicks.

At 0420Z on 31 October 2006, TITAN resolved three cells in the thunderstorm complex to the northwest of Newcastle. The two southernmost cells are arguably parts of a single larger storm (in fact TITAN did merge these two cells into one on subsequent volume scans). The forecaster might reasonably decide to merge these two cells for simplicity of presentation.

Given the manual extrapolation already discussed, the forecaster would also have been well advised to adjust the track of the southern cell(s) significantly to the right of the raw TITAN vector. How far to take this deviation would be open to debate, with a compromise velocity somewhere between manual extrapolation and TITAN a likely outcome.

Figure 10 shows the edited version of the 45dBZ TITAN tracks on TIFS. The two southern cells have been combined into a single larger cell, and the velocity of the cell has been adjusted so that the cell now tracks southeast-wards across Newcastle.

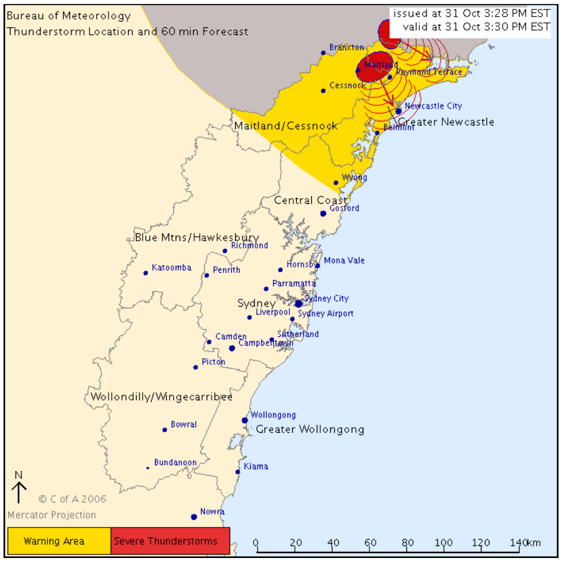

Figure 10. *TIFS graphic after manual editing of cells and cell velocities*.

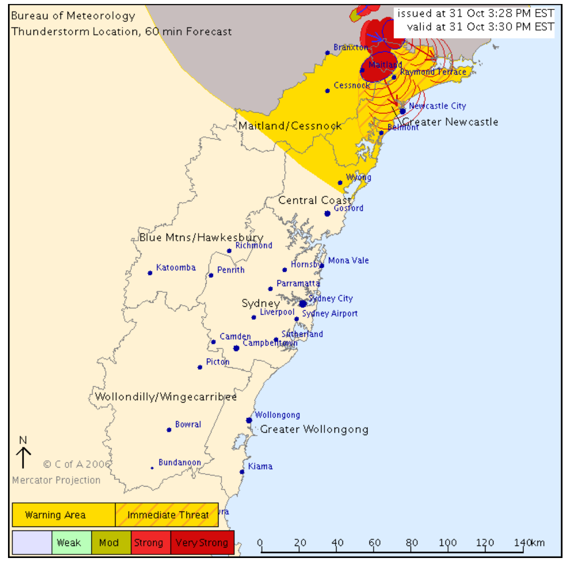

Figure 11. *TIFS graphic after addition of immediate threat area. This is indicated by the faint diagonal hashing.*

At this stage the forecaster also has the opportunity to label exceptional cells as “very dangerous”. This labelling produces an annotation on the graphic and enhances the description of the storm in the worded warning. This facility is reserved for the most damaging of storms (producing either hail greater than 5 cm diameter, winds stronger than 125 km/h, or tornadoes). Though the southern cell was showing supercellular characteristics at 0420Z on 31 October, the “very dangerous” label may not have been warranted at this time. (The forecasters on the day did add the “very dangerous” label about 30 minutes later.)

The forecaster also needs to draw an “immediate threat area” around the cells to depict areas potentially at risk from severe weather during the coming hour. It would be sensible to draw a buffer on the right flank of the southern cell at this time to make allowance for the cell potentially deviating even further to the right than forecast. Such a threat area has been added to the TIFS graphic in Figure 11.

Once happy that the TIFS graphic faithfully represents the situation, the forecaster should review the automatically generated warning text. This is available in a separate window. The phenomena mentioned in the warning text are selected by clicking buttons on the TIFS interface. Damaging winds and large hail would be selected in this case (other options are destructive winds, tornadoes, very heavy rain and flash flooding).

The warning text will list the local government areas affected by the Warning. These regions are automatically chosen by TIFS on the basis of the forecaster’s threat area and the thunderstorm cells and tracks.

The warning text describes the current location of severe thunderstorms, and the suburbs, towns and localities to be affected in the next 30 minutes and the next 60 minutes. This text is automatically composed by TIFS on the basis of the cells and tracks on the graphic. The forecaster can increase or decrease the level of detail in the text – the number of placenames mentioned – by clicking a button on the TIFS interface.

The forecaster can edit the warning text as required before transmission. Changes should be limited to fine-tuning of the text; more substantial changes are avoided as they risk introducing inconsistencies between the text and graphic products. If, after reviewing the text, the forecaster decides that significant changes are required, he/she should return to the TIFS graphical editor and make the requisite changes there. These changes then flow automatically in the text warning.

7. TRANSMITTING THE WARNING

When happy with the warning graphic and the warning text, the forecaster disseminates the warning by hitting the Issue button on the TIFS interface.

On dissemination, the warning text and graphic are sent immediately to the Bureau web-page for use by the general public. The Warning text is faxed to numerous clients, notably radio and televisions stations servicing the affected areas. A digital text and image are also available to users, including private meteorological companies.

The warning, as it would appear on the Web, is shown is shown in Figures 12 and 13.

The State Emergency Service (SES) has responsibility for emergency response in the state of New South Wales. They have access to an enhanced warning graphic that shows the past tracks of storm cells as well as the current storm location and forecast tracks available to other users. By combining the past storm tracks with their own ‘requests for assistance’ data, the SES can identify storm damage swathes and more efficiently deploy their resources to the areas of greatest need. The SES version of the warning graphic is shown in Figure 14.

IDN65152

Australian Government Bureau of Meteorology
New South Wales

TOP PRIORITY FOR IMMEDIATE BROADCAST

SEVERE THUNDERSTORM WARNING - SYDNEY/NEWCASTLE/WOLLONGONG REGION

for DAMAGING WIND and LARGE HAILSTONES

For people in the
Greater Newcastle and parts of the
Maitland/Cessnock areas.

Issued at 3:28 PM Tuesday, 31 October 2006.

The Bureau of Meteorology warns that, at 3:30 PM, severe thunderstorms were detected on weather radar near Maitland, Raymond Terrace and Clarence Town. These thunderstorms are moving towards the southeast. They are forecast to affect Wallsend, Medowie and Karuah by 4:00 PM and Newcastle City, Belmont and Charlestown by 4:30 PM.

Damaging winds and large hailstones are likely.

The State Emergency Service advises that people should:
* Move your car under cover or away from trees.
* Secure or put away loose items around your house, yard and balcony.
* Keep clear of fallen power lines.
* Unplug computers and appliances.
* Avoid using the phone during the storm.
* Stay indoors away from windows, and keep children and pets indoors as well.
* For emergency help in floods and storms, ring your local SES Unit on 13 2500.
* In the ACT, ring the ACT Emergency Service on 6207 8455

The next warning is due to be issued by 4:25 PM.

A more general severe thunderstorm warning is also current for the Mid North Coast, Hunter and parts of the Northwest Slopes and Northern Tablelands districts.

Warnings are also available through TV and Radio broadcasts, the Bureau's website at www.bom.gov.au or call 1300 659 218. The Bureau and State Emergency Service would appreciate warnings being broadcast regularly.

Figure 12. *The Severe Thunderstorm Warning text as it would appear on the Web.*

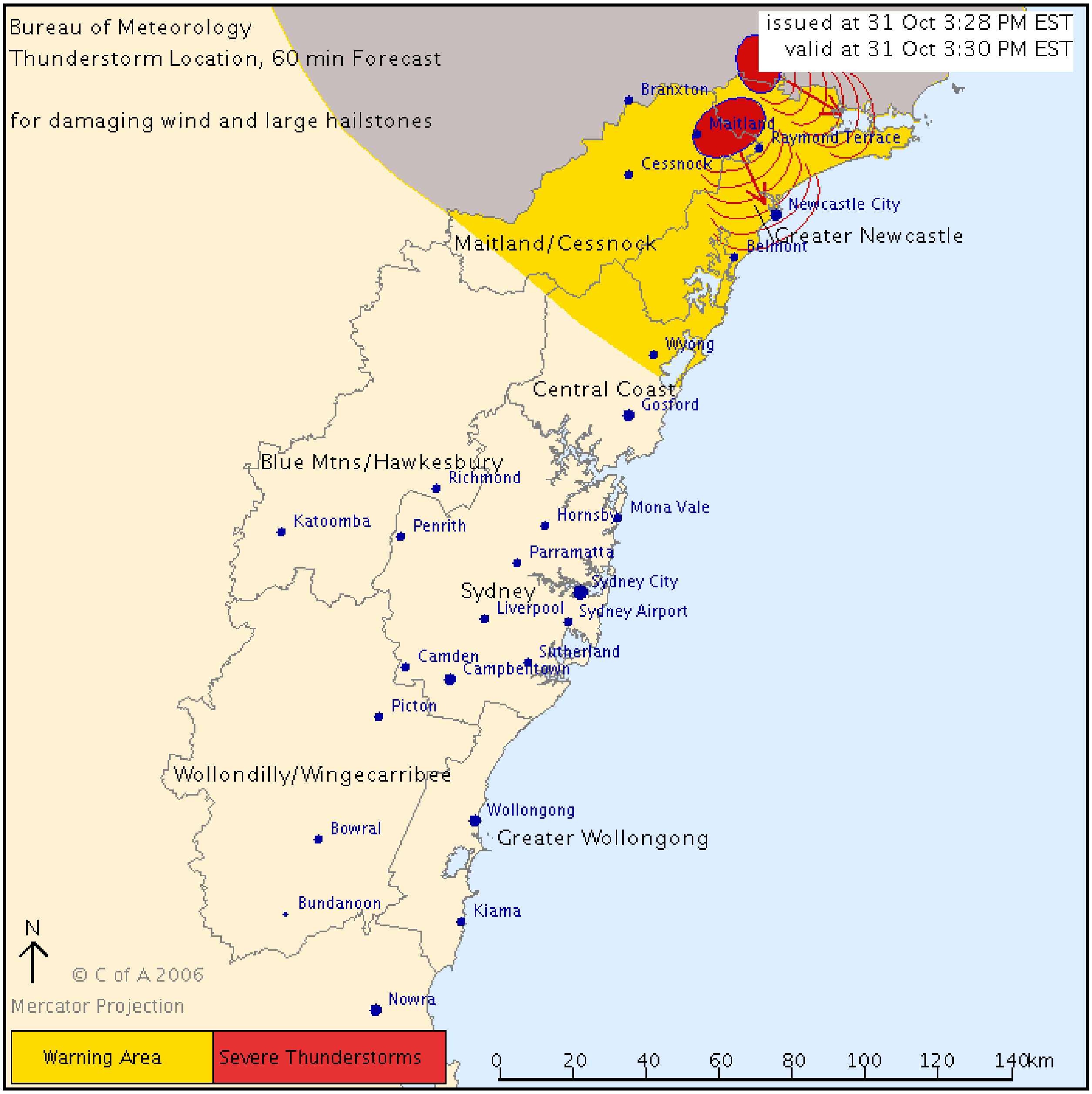

Figure 13. *The Severe Thunderstorm Warning graphic as it would appear on the Web for use by the media and the general public.*

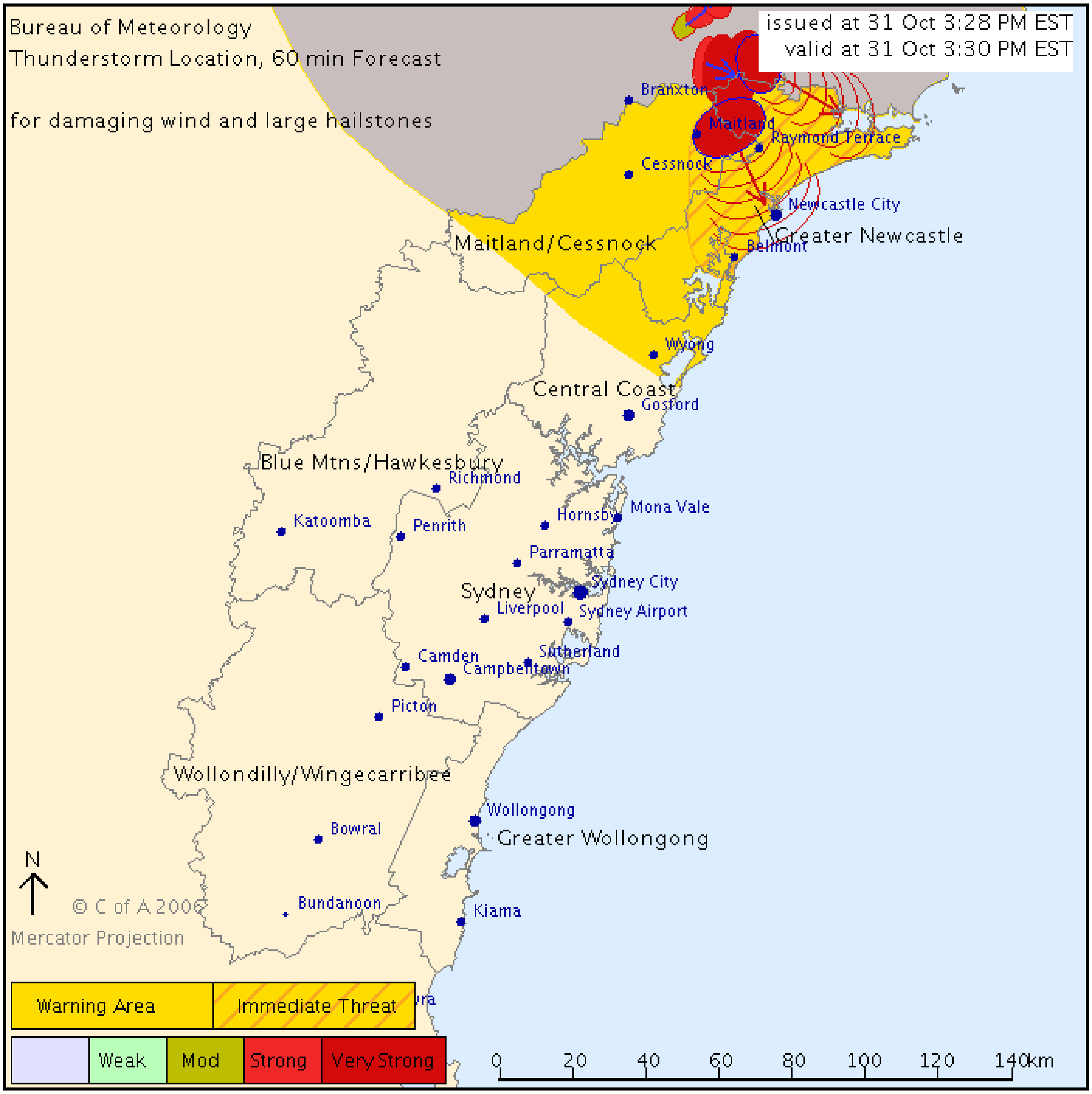

Figure 14. *The enhanced Severe Thunderstorm Warning graphic available to the State Emergency Service. In addition to the severe thunderstorm locations and forecast tracks it shows the "immediate threat area" and also the past tracks of the severe thunderstorm cells. The past cells are colour coded according to TITAN cell VIL to give the user an approximate estimate of thunderstorm severity.*

8. FUTURE ENHANCEMENTS TO CURRENT PROCEDURES

A weakness in current operational practice is the disconnect between warning decision-making and warning preparation. The radar characteristics of thunderstorms are analysed in 3D-Rapic, and it is on this platform that the decision about the need for a warning is generally made. Having made this decision, the forecaster needs to move to another platform – TIFS - to actually prepare the warning. Assessments of the disposition of severe weather relative to cells, and of future storm movement and development are made in 3D-Rapic, then must be transferred mentally to TIFS; the only commonality of the systems being that both can display TITAN tracks.

The interaction between the 3D-Rapic and TIFS software is being improved. One model for the future is that the cell and track editing that is currently done if TIFS would instead be done in 3D-Rapic. Threat areas could also be outlined in 3D-Rapic. This would enhance the use of radar data is warning preparation. The edited cells, tracks and threat areas would then be exported to TIFS, which would perform the automatic text generation to produce the worded warning. Last minute fine-tuning of graphic and text could be performed in TIFS before warning despatch. This model would streamline warning preparation and allow better integration of manual radar analysis into the warning process.

9. SUMMARY AND CONCLUSIONS

Severe Thunderstorm Warning operations in Sydney Australia utilize sophisticated radar display and warning preparation software, and make heavy use of nowcast guidance from TITAN and WDSS. While current systems could allow automation of the service, human input remains vital. Forecaster analysis of radar and near-storm environmental data, and integration of this into conceptual models of severe thunderstorms allows significant enhancement of the warning service. Current software systems enable this enhancement, and future software developments should streamline and encourage such forecaster input.

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