P13B.18 3D-RAPIC - THE AUSTRALIAN RADAR VISUALISATION SYSTEM

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1. INTRODUCTION

3D-Rapic is the Australian Bureau of Meteorology's (Bureau's) primary radar visualisation system. It allows users to analyse volumetric radar data from multiple radars. Major features include interactive panning and zooming and interactive vertical cross sections derived from volumetric scan sets of radar data.

2. HISTORY

The display of weather radar data in the Bureau began with dedicated on-site PPI and RHI consoles. Various schemes were developed over the years to communicate the radar situation including china graph pens onto transparencies which were faxed to the forecasting office, through to slow scan TV systems for remote display of the PPI data.

A major advance came with the advent of radar digitising systems which allowed the data to be transmitted via modems to remote displays. The Bureau started development of an in-house radar control, digitising, communications and display system in the early 1980's known as Rapic.

The radar end of the system was known as the Rapic Transmitter which was based on dedicated embedded computers. The first Rapic Transmitter software was developed in 1984 using assembly language. This system would typically run a 3 to 5 tilt surveillance scan sequence every ten minutes and digitise the data into a single CAPPI like product which was then transmitted to the remote displays.

The first displays were similarly based on embedded hardware with software written in assembler.

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The earliest Rapic data was sent using a binary synchronous format for compatibility with pre-existing systems. An asynchronous ASCII Rapic format was then developed to allow for the data to be more easily transmitted over standard leased line and dial-up modems and X.25 links. This new format also allowed for the data to be run length encoded for more efficient use of the low bandwidth communications links which were available at the time, typically between 2400 to 9600 baud. Average surveillance scans encoded in the ASCII Rapic format at 1degree, 2km range resolution and 7 levels were around 2kiloBytes(kB), and varied between 600 bytes up to 6kB.

At around the same time, personal computers were beginning to become affordable. Development of the Bureau's first PC based display known as PC-Rapic was begun in 1984, and was first used in operations around 1985. This was the first time that Bureau forecasters had direct access to real time radar data from multiple radars in the office.

PC-Rapic was DOS based and written primarily in Borland Turbo Pascal with low level machine language calls to achieve reasonable performance levels, writing directly to the EGA graphics card registers. It included infrastructure to fetch data via dial-up or leased line modems directly from the complete network of radars, which grew to 40 or 50 by the mid 1990's. PC-Rapic could display both PPIs and RHIs, with a feature which allowed the user to request an RHI at an azimuth specified using the mouse cursor. As well as providing basic PPI displays, it could also merge data from neighbouring radars and incorporated database infrastructure to allow months of radar data to be stored on the PC for review. PC-Rapic became quite popular and is still in use in Bureau regional offices after more than twenty years.

As the availability of real time surveillance radar data improved, a demand for access to more detailed radar data began to emerge with the introduction of Severe Weather Forecasters within the Bureau.

Enhancements were made to the Rapic Transmitters to allow 12 to 15 tilt volumetric scan sets sequences be performed at the radar with the data being communicated to forecasting offices. Clearly a more sophisticated radar display system was going to be required to allow forecasters to analyse the 12 to 15 PPI scans that made up each volume set.

At about this time, Silicon Graphics Inc. (SGI) released their first “affordable” 3D graphics Personal Iris workstation, which seemed to offer the level of graphics functionality that would be required by such a volumetric radar display. Proof of concept work prior to the development of 3D-Rapic was carried out in 1989 when SGI made one of these workstations available for a one week trial. During this time we were able to demonstrate a radar PPI rendering of polar radar data utilising the SGI “Iris GL” API. Iris GL allowed the polar radial data to be rendered as a strip of radial quadrilaterals without the need for a polar to Cartesian array conversion. The performance of this prototype was adequate to allow the user to interactively pan and zoom the PPI image.

Full scale development of the 3D-Rapic software began in 1991 with the first operational version available for use by forecasters in 1993. Apart from the ability to pan and zoom to examine details within PPIs, a key functionality of 3D-Rapic was the ability to perform RHI style vertical cross sections interactively controlled by the mouse location on the PPI, which has proved to be particularly valuable to severe weather forecasters.

Whilst ongoing development of 3D-Rapic has steadily delivered additional functionality and enhancements, the biggest single step has been the transition from the SGI platform to the much more commonly available Linux PC platform. The evolution of the PC gaming market has meant that amazing levels of both CPU and 3D graphics performance are now available on these platform at relatively low cost.

Another major enhancement has been the development of the Nowcast Applications Server (NAS) which processes volumetric radar data to generate nowcasting products such as storm cell and rainfall data. 3D-Rapic interfaces with the NAS to allow these nowcasting products to be overlayed on the underlying radar data.

3. DISPLAY FUNCTIONALITY

3.1 Display Types

3DRapic allows radar data to be displayed in the following forms:

3.1.1 PPI

The PPI (Plan Position Indicator) renders a constant elevation scan, most commonly from a plan point of view, but can also be rotated for alternative points of view. The display allows the user to interactively zoom and pan by holding mouse buttons down while moving the mouse. The scan data is continuously redrawn as the user moves around the data.

Scan elevations can be traversed using the up and down keyboard keys and the left/right keys can be used to step forward and backwards through previous and next volumetric sets. The radar data can either be rendered in blocky mode where the whole cell area is coloured according to the cell value or in an interpolated mode which interpolates the colouring between the cell values of neighbouring cells.

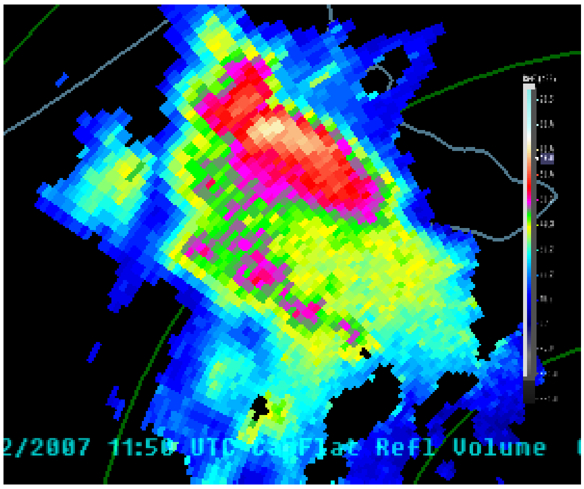

Figure 1. Blocky mode PPI

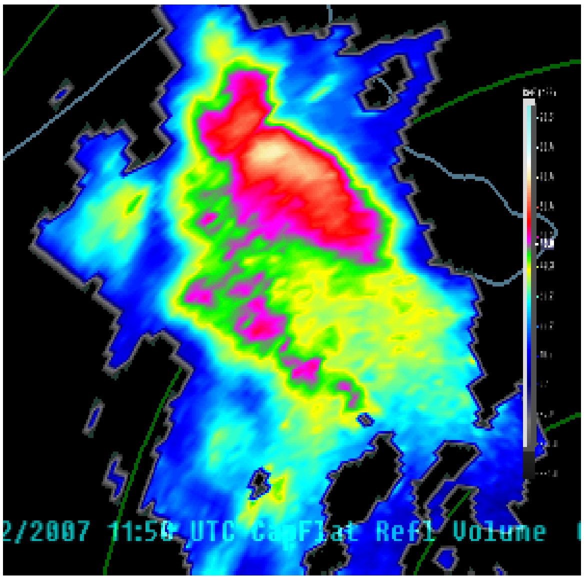

Figure 2. Interpolated mode PPI

3.1.2 CAPPI

The PPI window can also display Constant Altitude PPIs (CAPPIs) with a choice of nearest value, and a distance weighted interpolation of the scans above and below the desired altitude.

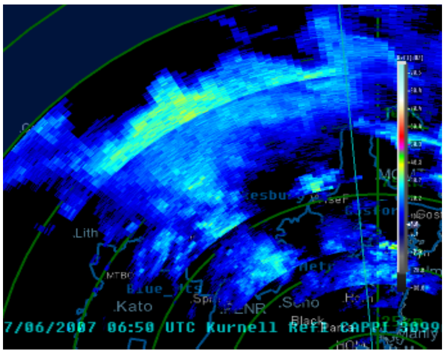

Figure 3. Nearest scan CAPPI

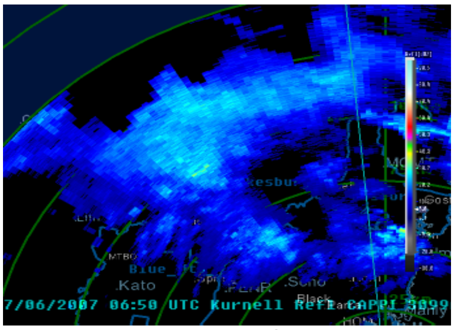

Figure 4. Interpolated scans CAPPI

3.1.3 PPI/RHI

The PPI/RHI (Range Height Indicator) display window includes two panes, one for the PPI display described above and the other for the RHI or vertical cross section display. A pane divider may be moved to change the division of the window area between the PPI and RHI. The PPI behaves as explained in Section 3.1.1, but also allows the user to use the mouse cursor with the right mouse button held down to control the azimuth of the RHI display. Likewise, the mouse may be used in the RHI window to control the elevation of the PPI display. The RHI window can either display a true RHI scan or more commonly will display an RHI derived from the radials at the given azimuth from all of the elevation tilts in the volumetric scan set.

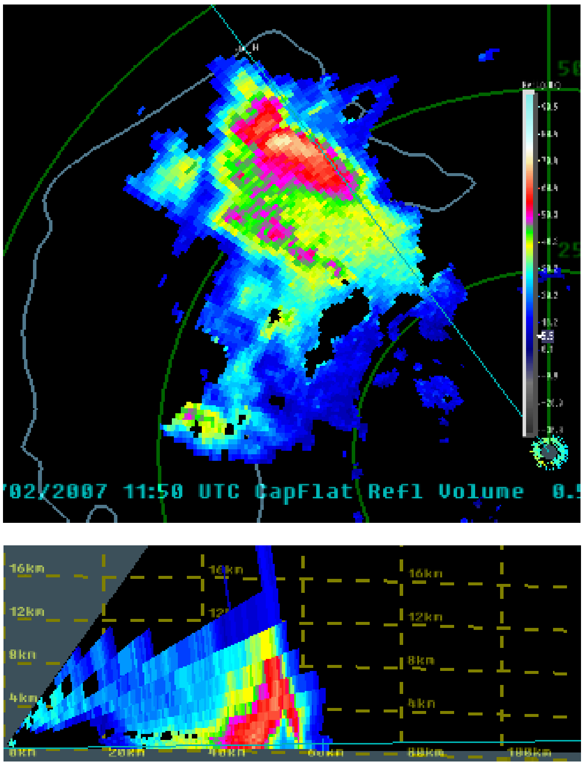

Figure 5. PPI/RHI display

3.1.4 PPI/VxSect

In VxSect mode the mouse cursor can be used to drag either end of the cross section line or can drag the location of the line with the same length and orientation by grabbing the centre of the line. The VxSect is derived from all of the volumetric data points that intersect with the cross section line both radially and azimuthally, and is constantly redrawn as the use moves the cross section line.

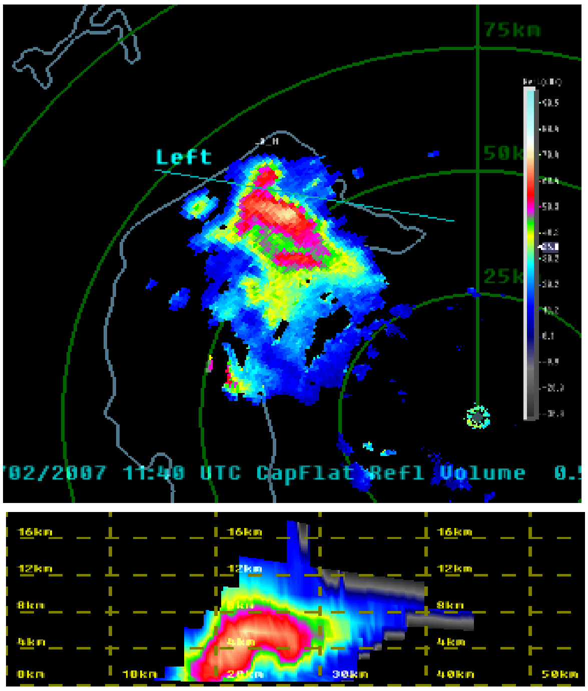

Figure 6. PPI/VxSect window pair

3.1.5 PPI/RHI/3D

The PPI/RHI/3D display opens a 2 pane PPI/RHI window as in Section 3.1.3 as well as a single paned 3D PPI/RHI window, where both the PPI and RHI or other VxSect are rendered in 3D. In addition to panning and zooming, this window can also be rotated to examine the correlated PPI and RHI. The position of the RHI or VxSect can be interactively moved using the mouse cursor within the PPI window and the elevation of the PPI can be selected through the RHI window. The display is constantly redrawn as the user moves the RHI/VxSect position.

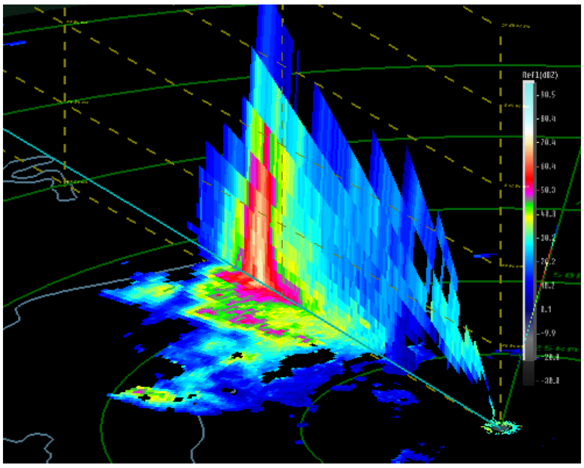
Figure 7. 3D PPI/RHI display

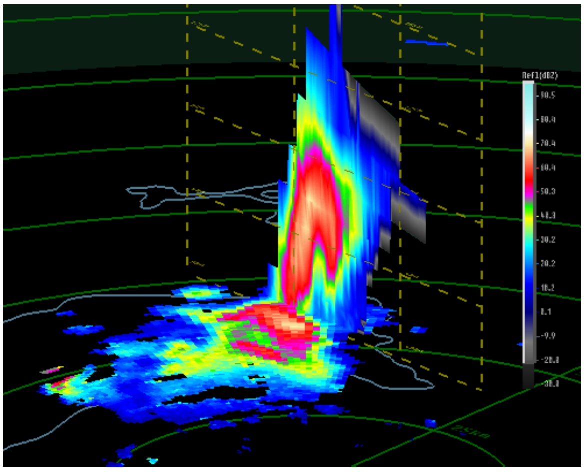
Figure 8. 3D PPI/VxSect display

3.1.6 3D Tops

The 3DTops display traverses the volumetric data set and renders the maximum echo height exceeding a user selectable reflectivity threshold colour coded according to height.

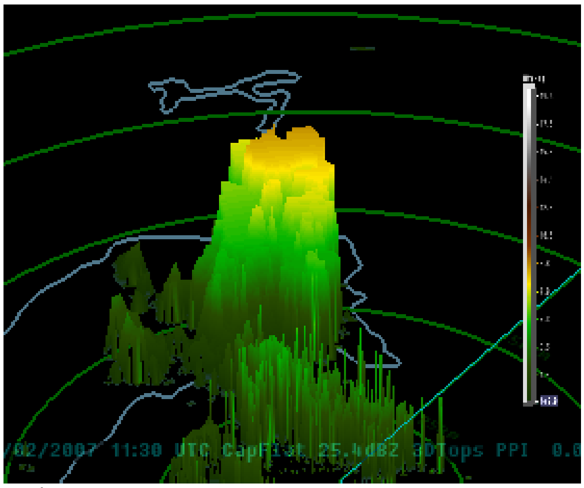
Figure 9. 3D Tops

3.1.7 Merged PPI

The merged PPI display can render any number of long range surveillance scans to provide an overview style display. The merge rendering uses a maximum reflectivity value approach where scan data from multiple radars overlaps. The merge is continually redrawn from the underlying per-radar polar data to a 3D spherical world co-ordinate system. Shaded coverage diagrams are drawn along with each contributing radar scan to provide indication of which radars are contributing to the merge, as well as the areas where radar coverage should be expected. The current implementation in the

Bureau is typically able to render the national merged radar product with around 60 radars at better than 10 frames per seconds.

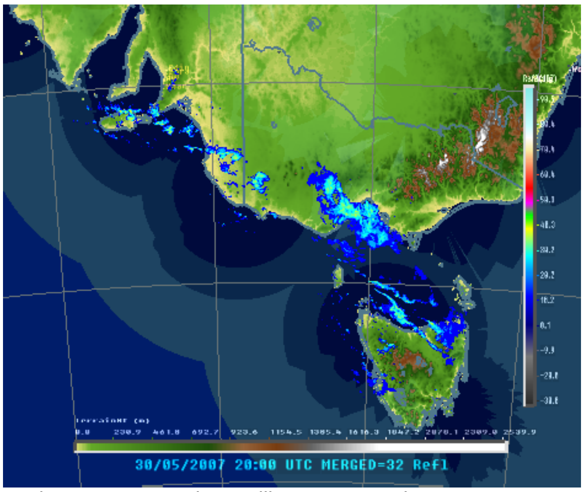

Figure 10. Merged surveillance PPI product

The data from each radar is rendered to follow the earth's curvature with range and is mapped in height according to the reflectivity to allow the graphics hardware depth buffering to ensure that only highest value is visible.

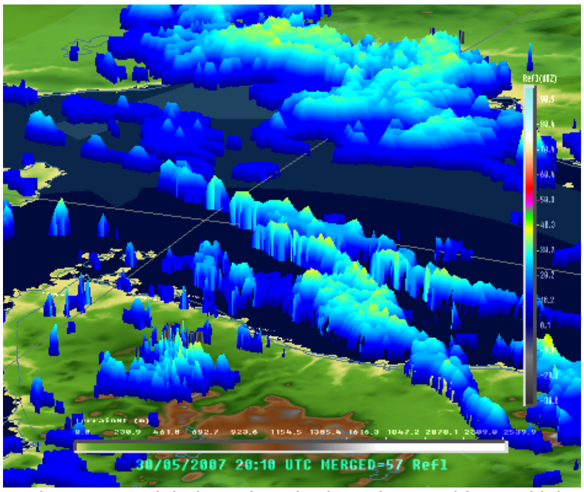

Figure 11. Height based method used to combine multiple radars

3.2 Radial Data Rendering

All of the radar displays are continually re-rendered from the underlying polar data as the user steps through the time sequence or changes the point of view through panning or zooming. A feature of this approach is that it allows increasing level of detail to be shown as the user zooms in.

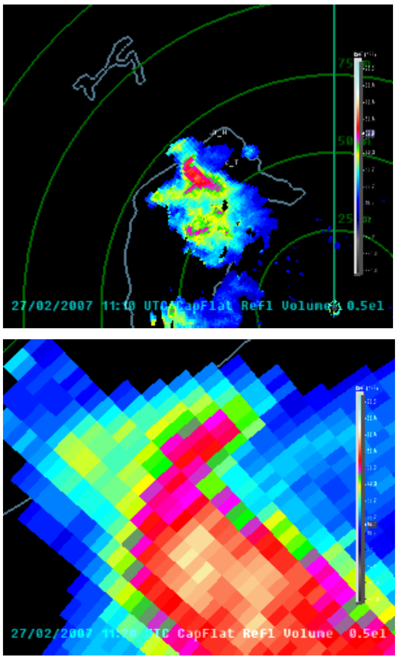

Figure 12. Increasing polar detail with zoom

3.3 Supported Data Types

3.3.1 Polar radar data

3D-Rapic currently supports the display of reflectivity, radial velocity, storm relative radial velocity and vertically integrated liquid (VIL) polar radar data products.

The storm relative radial velocity data is generated on the fly based on either manual setting of the correction vector or a vector taken from the currently selected storm cell's motion.

3.3.2 Rainfields Data

3D-Rapic has the ability to generate raw uncorrected Z-R based rainfall accumulation products for display, however the Rainfields (Seed 2007) products generated on the Nowcast Application Server (NAS) provide a far more sophisticated product, incorporating a number of mechanisms to correct the rain estimates such as rain gauge correction. 3D-Rapic can fetch various Rainfields accumulation products from the NAS. These products are in the form of cartesian grids which are rendered in 3D-Rapic using texture mapping techniques to map them efficiently to the same projection as the polar radar data.

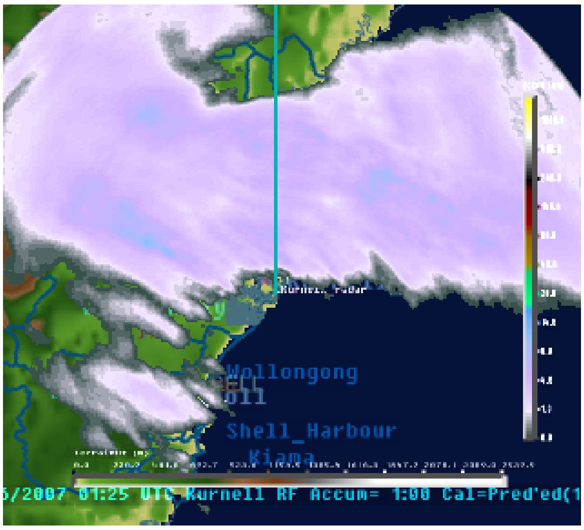

Figure 13. Rainfields overlay

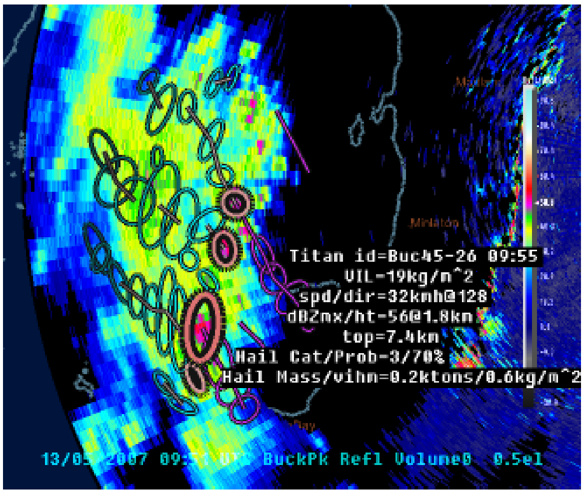

Figure 14. TITAN cell overlay

3.4 Meteorological Data Overlays

A number of map underlays and data overlays are provided. In general the underlays are static data such as vector maps, place name and terrain textures. Overlays are generally meteorological data such as nowcast products and other observations data.

Overlays and underlays can be toggled on and off using either menu options or key strokes.

3.4.1 WDSS and TITAN

The NCAR TITAN (Dixon et al. 1993) and NSSL WDSS (Eilts 1997) SCIT cell products from the Nowcast Applications Server (NAS) may be overlayed over the radar data as a layer with past, current, forward and forecast cell positions, track plots and annotations of cell details for the cell under the mouse cursor. A cell table is also available which lists cells in order of severity ranking. In the case of WDSS which generates SCIT cell, Meso and TVS data, the table context is set by the cell nearest the mouse cursor. Time series graphs of various properties of the current cell are currently available for the WDSS SCIT cell product, with plans to implement TITAN cell graphs shortly.

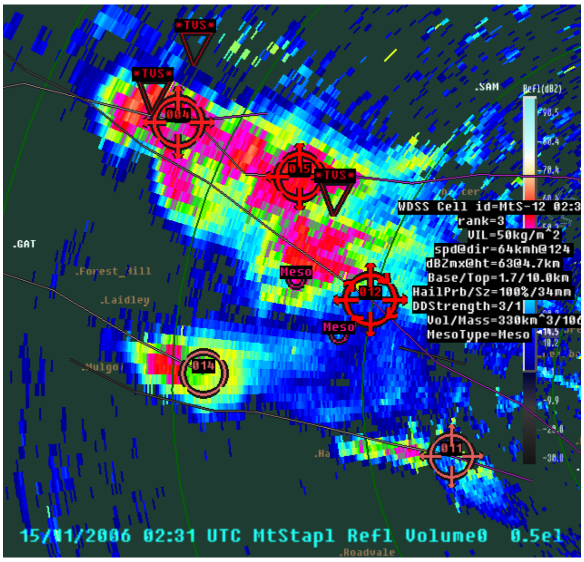

Figure 15. WDSS Cell overlay

Cell Table Mode: WDSS Cell, WDSS Meso, WDSS TVS, Titan

ID	Rank	VIL	maxdBZ/Ht	Base/Top	ProbHail/Sv	HailSz	Spd@Dir	Me
12	1	47	70.3@2.8km	0.3km/7.7km	100%/100%	69mm	62kmh@130	
22	2	47	66.7@5.4km	0.2km/7.0km	80%/80%	50mm	00kmh@115	
15	3	56	66.0@1.7km	0.3km/8.6km	100%/70%	30mm	60kmh@093	
18	4	45	60.3@5.0km	3.0km/9.6km	100%/70%	30mm	70kmh@123	
20	5	22	54.7@4.3km	3.7km/7.1km	80%/20%	13mm	38kmh@094	
23	6	6	48.3@2.2km	1.7km/5.4km	0%/0%	2mm	00kmh@115	
24	7	5	44.7@1.8km	1.8km/5.0km	0%/0%	0mm	00kmh@115	

Figure 16. WDSS Cell table

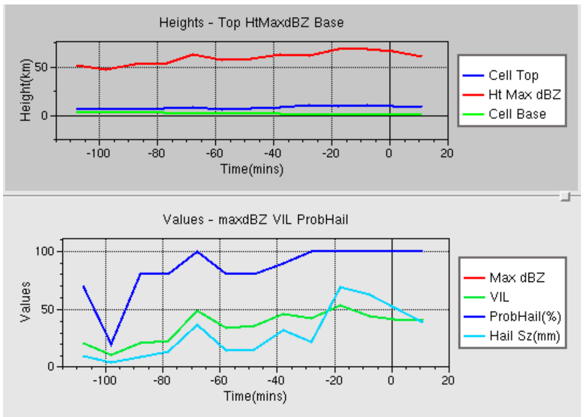

Figure 17. WDSS Cell time series graphs

3.4.2 Observations data

3D-Rapic supports overlay of observations data with wind barb indicators which provide wind speed and direction as well as a colour coded timeliness indictor of the observation. Typically temperature, dew point, 10 minute rainfall and since 9am rainfall. Time series data is stored to provide animated observations symbols with time. Colour coded alert thresholds based on wind speed as shown in Figure 18 below are also a feature of the observations overlay.

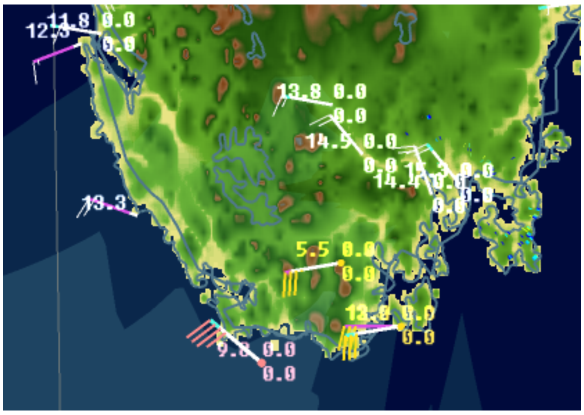

Figure 18. Observations data overlay

3.4.3 Lightning data

Overlay of lightning strike data is supported with options to allow strike colour to be modulated by strength and distinct positive and negative symbols.

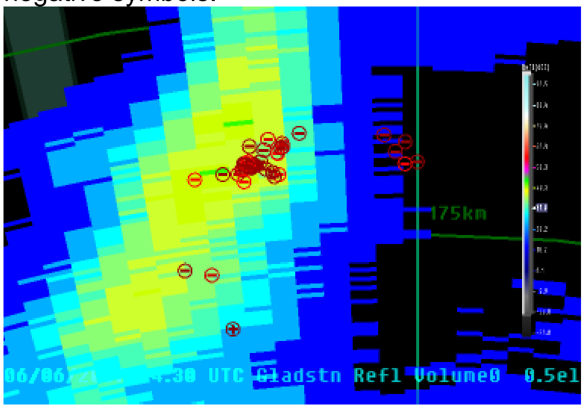

Figure 19. Lightning data overlay

3.5 Map Underlays

Map underlays are available in the form of either vector or terrain grids.

3.5.1 Vector Maps

Up to ten vector map underlay layers are available for each individual radar with another ten global maps which will be used in the absence of a per radar map. Each of the maps can contain any number of vector line segments, labels and circles with the option of embedded directives in the ASCII lat/long based maps to set properties such as colour, line width, text font, text rotation, vector fill and the view range at which the map or text is visible. Map layers may be toggled on or off using either menu selections or keyboard short cuts.

3.5.2 Terrain

Current terrain map support is via the use of “Dem” format maps. The terrain is rendered using OpenGL texture mapping to correctly map the terrain to the earth's surface, as well as allowing for a 3D rendering of the terrain. Due to the large array size of typical terrain data it is usually necessary to use a reduced resolution triangle mesh to render the 3D geometry. In order to provide a reasonable approximation of 3D features the mesh is perturbed to pick up the highest points in the reduced resolution mesh array.

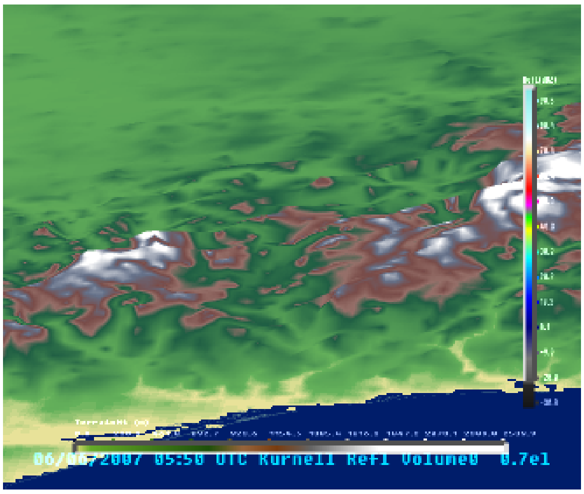

Figure 20. 3D Terrain underlay

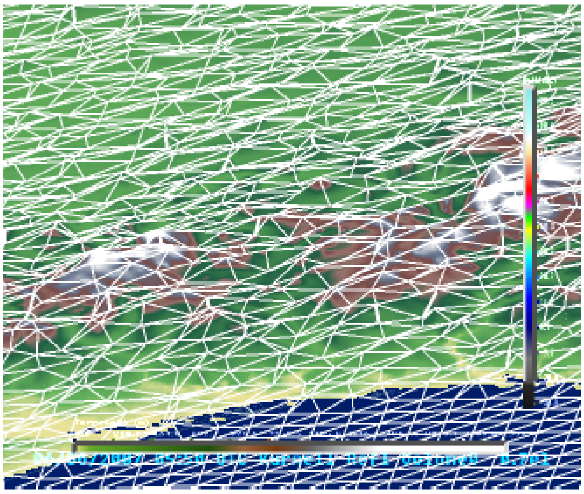

Figure 21. Perturbed texture map triangle mesh

4. USER INTERFACE

The 3DRapic user interface makes extensive use of the mouse in combination with mouse buttons to provide a quick and convenient mechanism for performing the most common operations such as panning, zooming and cross section control. Toggling of overlays etc. is provided by both menu options and keyboards shortcuts.

A synchronised cursor at the cursor position is rendered to all windows, including the relevant data values beneath that position. This provides an easy mechanism for correlating feature position between neighbouring radars or for example reflectivity and velocity windows for the same radar. In addition a linking mode allows for windows showing neighbouring radars to zoom and pan to the same point of view. Cross sections from neighbouring radars in separate windows will also both follow the cursor position.

The merged PPI window can also be used to select the radar to use for PPI/RHI analysis to avoid the need to manually select the radar of interest and again the position of the cross section.

4.1 Screen dump

The user can manually create a PNG screen dump of any display window either using a key stroke, or an automatic mode where a new image is created for each new radar scan received. Another mode allows the full sequence to be saved as a series of PNG images. All images created have date/time stamped file names.

5. RADAR DATA COMMUNICATIONS

3D-Rapic incorporates highly sophisticated communications infrastructure which can be used to build a fully featured stand alone radar network complete with real-time peer to peer scan-by-scan radar data forwarding. Alternatively it may be used in conjunction with the Nowcast Applications Server (NAS) which contains the communications component of 3D-Rapic as a stand alone Rapic Data Server. This infrastructure allows for multiple data sources with fallback to alternative sources in the event of failure or unavailability. Data is forwarded by each server as it is received which allows for timely reception of data over multiple network hops.

5.1 Nexrad Level II data

Functionality has been added to allow 3D-Rapic to read Nexrad Level II format files in real time. These files may be files made available on the workstation or could also be fetched by URL from a web server.

6. RADAR DATABASE

An integrated indexed database is built into 3D-Rapic which stores the data from multiple radars in database chunks which are typically 200MB to 500MB in size. A purging mechanism allows a number of these to be kept for review of the data.

7. REPLAY MODE

A replay mode is available for 3D-Rapic to allow for displaced real-time simulation of events, with optional time scaling. This facility is particularly useful for forecaster training.

8. NOWCAST APPLICATIONS SERVER INTERFACE

The Nowcast Applications Server (NAS) runs the nowcasting processing required to produce the TITAN, WDSS and Rainfields products for a number of volumetric scanning radars.

3D-Rapic currently contains the specific APIs to interface into each of these server products. Whilst this approach does work reasonably well, it does impose significant complexity with the various API library dependencies. Plans are therefore being made to move to a more generic client/server interface based on a server product event mechanism being passed to each client, then the client fetching the product file from the server using http. We are moving towards cell data files being encoded in an XML format and grid data in netCDF.

The radar data and observations data would continue to be transmitted as real time socket data streams.

9. TECHNICAL

The C++ programming language was chosen to implement 3D-Rapic and has been very successful both in terms of system performance and managing the complexity of what has become a large application. Extensive use has been made of multi-threading in order to allow the main user thread to be largely unaffected by the numerous communications and other processes that are required.

Probably the greatest performance gains have come in the OpenGL graphics. The first SGI workstation could render in the order of 5,000 polygons per second and cost around AU$40,000. Current generation graphics cards render in excess of 100,000,000 polygons per second, with a typical platform costing around AU$4,000.

As the system was initially developed in the early 1990's when the platforms were typically constrained to 16MB of memory, and very modest processing performance by today's standards, the coding and particularly the graphics rendering had to be very efficient. This has resulted in a system that has scaled very well, with the increasing level of graphics and processing performance in newer hardware more than compensating for the increased demands placed on the system due to significant increases in data resolution, doppler radar data and increases in the number of radars.

A typical Linux 3D-Rapic, ingesting surveillance data from the full 60 radar network and volumetric data from 15 to 20 radars, TITAN, WDSS , observations and lightning data, with a 2 hour sequence depth will run in a Resident Size of around 300MB, and a Virtual Size of 1GB.

New features in the OpenGL API are becoming available which offer further improvements in radar rendering performance. The latest 3D-Rapic implements radial rendering using vertex arrays, which has resulted in 20% to 100% improvements in performance. New Cg features which allow programs to run on the graphics chip and process each vertex or pixel as it is being rendered have been used to improve the quality of the interpolated radial rendering by interpolating by intensity rather than interpolating by RGB colours.

Whilst some use of texture mapping has been made for the rendering of Rainfields data, the use of 3D texture mapping for enhanced rendering and flexible cross section and other volumetric rendering effects is being evaluated.

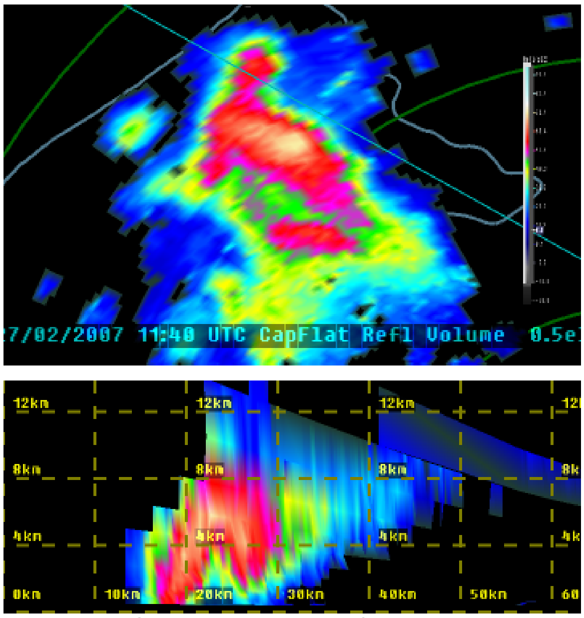

Figure 22. RGB interpolation - de-focused appearance

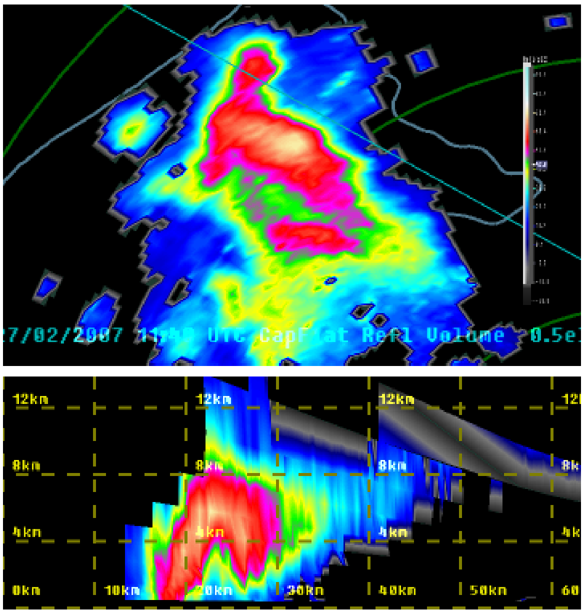

Figure 23. Intensity interpolation - contoured appearance

10. ACRONYMS AND ABBREVIATIONS

Bureau	Australian Bureau of Meteorology
PPI	Plan Position Indicator
CAPPI	Constant Altitude PPI
RHI	Range Height Indicator
VxSect	Vertical Cross Section
VIL	Vertically Integrated Liquid
kB	kiloByte
MB	MegaByte
NCAR	National Centre for Atmospheric Research
TITAN	Thunderstorm Identification Tracking Analysis and Nowcasting
NSSL	National Sever Storms Laboratory
WDSS	Warning Decision Support System
SGI	Silicon Graphics Inc.

11. REFERENCES:

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Conference on Radar Meteorology, 28th, Austin, TX; UNITED STATES; 7-12 Sept. 1997. 402, 403 pp. 1997

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33rd Conference on Radar Meteorology