P13B.16 THE AUSTRALIAN NOWCASTING SYSTEM

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1. INTRODUCTION

1.1. *Rationale*

During the last decade there has been an increasing need and desire to use radar data quantitatively as well as qualitatively in Australia to underpin short-term weather forecast products. A major government funding initiative in 2003 led to the installation of state of the art Doppler radars covering major population centres in the east of the country. Whilst in the rest of the radar network twenty out of the Australian Bureau of Meteorology's (Bureau) 64 radars have been installed or completely refurbished during the last ten years. With increasing computer power, more sophisticated data visualisation technology, improved radar algorithms and a developing need for more quantitative warnings, a nowcasting platform was needed that would provide the infrastructure to improve the quality and specificity of short-term weather forecast products. This paper looks at the history of this Australian system, the components of the actual system and concludes with some future plans.

1.2. *History*

Development of a fast and efficient radar data transmission system started in the mid 1980s, with the first volume data being transmitted in the late 1980s. In the mid 1990s the Bureau developed partnerships with US agencies to run quantitative applications on Australian radar data. Initially the algorithms were implemented and run on the Bureau's radar data visualiser 3D-Rapic but it was quickly realised that this slowed down the performance of 3D-Rapic, implying a more integrated client-server configuration should be adopted.

The Bureau's research centre, BMRC, became part of the World Meteorological Organization's World Weather Research Program Forecast Development Project (FDP) at the Sydney 2000 Olympic Games, where various nowcasting systems from around the world were showcased. BMRC adopted a separate server to ingest the radar data and consolidated the running of the various algorithms, so that the output was ready in a timely fashion for the various nowcast clients.

One of the Bureau's nowcast clients, the Thunderstorm Integrated Forecasting System (TIFS), was developed in 1999 as a means of visualising the output from the various nowcasting systems deployed as part of the Sydney 2000 FDP. As noted in Bally et al. (2007) "The motivation for the original TIFS development was to facilitate the understanding of the component FDP systems by forecasters, and to provide an avenue for forecasters to interact with system output to produce new weather warning products. The main strategies employed were to use TIFS as an engine to render output from the FDP systems in a common format, and to provide an interface for forecasters to examine and modify the output from FDP component systems and to create graphical and text based warning products from them."

The Sydney 2000 FDP was the catalyst in combining radar data, algorithms and clients into the Australian Nowcasting System.

2. THE AUSTRALIAN NOWCASTING SYSTEM

2.1. *Radars and Radar data*

The Bureau currently operates a network of 64 radars around the country (Fig. 1), approximately half are dedicated to either Weather Watch or Windfinding functions, the remainder perform both roles. In Weather Watch mode radars are configured to perform at least a low level Constant Altitude PPI image and may also perform a full volume scan. Most radars are currently configured to collect this data once every ten minutes, however there are selected radars that have an update schedule of five minutes. The radar data is processed onsite and streamed to the appropriate state Regional Office. The radar data is encoded in the Bureau's Rapic format which uses data compression to reduce communications bandwidth and data storage requirements. From the Regional Office it is streamed to clients, such as local radar viewers, a central archive in

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Melbourne and Nowcast Servers, which are situated in Melbourne and Brisbane. Volume data is streamed scan by scan to Nowcast Servers in real time so that data is available as quickly as possible. Refer to Donaldson (2007) for further details.

Fig. 1: The Australian Bureau of Meteorology's Radar network as of mid 2007.

2.2. *Nowcast Applications Server (NAS)*

The Nowcast Applications Server (NAS) was designed to integrate and consolidate the nowcasting processing for multiple radars into dedicated servers. It was decided to utilise x86 based Linux servers in order to take advantage of the performance benefits these platforms were offering at the time, as well as the attractive price performance characteristics. In addition this decision suited the radar applications the Bureau would be using. The NAS is also designed with deep storage so it can maintain a 3 to 12 month "cache" of both raw Rapic data and nowcast products, which allow the client applications to access the data for research or review.

Major components of the NAS are the Rapic Data Server, radar algorithms WDSS (Warning Decision Support System), Rainfields and TITAN (Thunderstorm Identification, Tracking, Analysis and Nowcasting) and the File Alteration Monitor.

- **Rapic Data Server (RDS)**

The Rapic Data Server (RDS) component of the NAS collects radar data from multiple sources and makes it available for use by clients either through real time forwarding through socket streams or through file outputs to be picked up by other NAS components such as WDSS, TITAN and Rainfields. The RDS also converts the Rapic format radar data to NEXRAD Level II format for the WDSS processing although there are plans to modify the Bureau's WDSS implementation to use Rapic format data directly. Both TITAN and Rainfields use Rapic format radar data files for processing. The RDS includes infrastructure to keep in-memory cache of hours of Rapic format data to initialise clients such as 3D-Rapic with recent data on start-up. The RDS also organises both base and volume scan Rapic format data from all of the networked radars into indexed database chunks of hundreds of megabytes and organises these into a searchable index that can extend to terabytes of radar data if required.

- **Warning Decision Support System (WDSS)**

One suite of radar algorithm products produced by the Nowcast Server is the WDSS Severe Storm Analysis Program (SSAP) products. This uses software written by NSSL (National Severe Storms Laboratory) adapted by the Bureau for Australia. Output includes the cell tracking SCIT algorithm (Johnson et al. 1998), Hail Detection Algorithm (HDA, Witt et al. 1998), Mesocyclone Detection Algorithm (MDA, Stumpf et al. 1998), Tornado Detection Algorithm (TDA, Mitchell et al. 1998) and the Damaging Downburst Prediction and Detection Algorithm (DDPDA, Smith et al. 2004)

The following are the main modifications that the Bureau have done to the original NSSL WDSS code:

Dynamic VCP: WDSS, being based on the NEXRAD radar system, expects a very limited set of VCPs (volume scanning patterns). In the Australian context, radars can have many more VCPs. Consequently the Bureau has modified the RDS to generate correctly formatted VCP files and insert them for use by the WDSS code, on the fly.

Three kilometre storm thresholding: the WDSS system, being tuned for US VCPs where elevation tilt spacing is at least 1˚, does not handle the Australian elevation tilt spacings well, where close to the ground the elevation spacing can be 0.4 or 0.5˚. For this reason the Bureau introduced a filter to remove from consideration storms less than 3km in depth (matching the TITAN storm depth threshold). This has reduced the number of storm cell false alarms generated by WDSS.

Not re-using cell IDs for 2 volumes: The WDSS system tracks storms through time. Unfortunately, when a storm ends its life, its storm cell ID is released for re-use, resulting in confusion downstream in the Bureau's 3D-Rapic software. This system ties together cell IDs into visible tracks on the screen, and thus had the capacity to tie together unrelated storms. For this reason the Bureau modified the WDSS software to hold back reuse of cell IDs until 3D-Rapic did not attempt to relate them.

- **Thunderstorm Identification, Tracking, Analysis and Nowcasting (TITAN)**

NCARs (National Centre for Atmospheric Research) TITAN algorithm (Dixon et al. 1993) output is also produced by the Nowcast Server. Its primary use is as a thunderstorm cell tracker. Refer to Potts et al. (2007) for more details.

Currently the Bureau is producing and using both WDSS and TITAN algorithm output. The rationale is that TITAN provides a representation of the areal extent of a thunderstorm, which is useful in graphical thunderstorm warning products. Whereas WDSS is much more focussed on the core of the thunderstorm and severe characteristics associated with it. For the warning product, information on both area likely to be affected and the severe phenomena possible is critical.

- **Rainfields**

One of the Bureau-developed algorithms being run on the radar data is Rainfields (Seed 2007), which combines real-time quality controlled radar data with rain gauge information to produce fields of rainfall accumulations. The rainfields base time step data is kept on the NAS in a database with pre-set accumulations and other products being produced and stored. Clients query the database using an API to retrieve rainfall data and construct accumulations of various time-periods. Rainfields also currently produces forecast products out to 90 minutes.

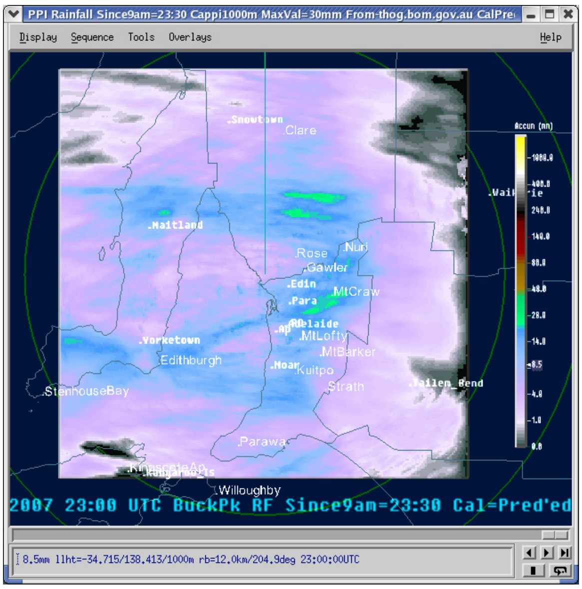

Fig. 2: Example of a Rainfields 23.5hr accumulation since 9am local time, displayed in 3D-Rapic.

- **TITAN Alerts**

The TITAN component of the NAS provides salient information for the generation of thunderstorm alerts. The alerts use configurable criteria, based on maximum dBZ, height of storm top, storm volume, storm mass and VIL (Vertical Integrated Liquid). Currently the Bureau typically uses a maximum dBZ threshold of 45 dBZ and VIL of 10 kg.m^{-2} for selection (depending on the region). Selected storms accessible in TITAN product files (Storms_to_Tifs) are then processed by the Nowcast Server and passed to regional AIFS (Australian Integrated Forecasting System, Kelly and Gigliotti 1997) servers (depending on the location of the originating radar).

The alerts are injected into the existing AIFS alerting system, where they appear on users AIFS workstation as a user-configurable text-based desktop GUI (graphical user interface) application.

- **File Alteration Monitor (FAM)**

The Linux system's FAM provides a daemon and an API which applications can use for notification of changes in specific files or directories. fam_mon is the Bureau's implementation of the Linux system's FAM API which can be used to trigger alerts and launch processes to create new Nowcast products.

This avoids having to use resource intensive and relatively high latency polling for the many hundreds of files generated by the NAS every hour. The monitoring aspect allows timeout events to be logged if products are not generated within an expected time-frame, which can be used to trigger alerts. Nowcast products reported to be on time trigger status logs and processes that generate more Nowcast products. For example TITAN Storms-to-TIFS products are generated via fam_mon if and only if TITAN products are on time.

- **Client-Server Strategies**

Real time radar data is made available from the server both as a socket data stream to the client as it is being received, as well as being made available as a file for client applications on completion of each volumetric set.

Each of the NAS applications has their own native API to allow clients to access their output products. The client applications must therefore either include that client API, or read/access the NAS product files directly. There is currently a Nowcast process which converts TITAN output to the Bureau's axf format (a self-describing text format). The WDSS products are made available in an XML (eXtended Markup Language) format. Rainfields is currently only available through a SOAP (Simple Object Access Protocol) interface. All Nowcast product files, logs, status and configuration files per Nowcast server are available via the web.

- **Nowcast Server Software Infrastructure**

The NAS is comprised of a variety of Nowcast components or applications.

The NAS system is administered using a set of custom Linux shell scripts. Each component can be administered independently due to the software's modular structure. The goal is to ensure that there is control over a NAS component without affecting another. Logically NAS components require radar data and hence the RDS process is started first. The final process to start is FAM which monitors the NAS system and all the Nowcast products, reporting on which products are late and triggering processes for products that are generated on time.

A simple but verbose Nowcast monitoring tool was implemented to help users monitor all intermediate and final Nowcast products, watch the system run in near-real-time and to assist in NAS system checks. The Nowcast product and system monitoring reports are accessed via the web.

- **Deployment in Australia**

Current server configurations utilising 2 dual core Intel XEON processors and 8GB of memory allow approximately 15 radars to be processed on a single server. There are typically 430 Nowcast-specific processes running on a Nowcast Server. This allows for another 100 or so Linux system processes required to run on the server.

Operational rollout of the Nowcast Servers in Australia has followed a process where beta-testing occurred in an environment that mimics operations. Once tested the main Nowcast Server hub was located in the Bureau's head office in Melbourne with a disaster recovery hub in Brisbane, following the style of other major Bureau computer system setups. There is at least one primary and fallback Nowcast Server in each of the two sites. All Nowcast Server clients are connected to two servers for data redundancy.

2.3. *Nowcast Client Systems and Services*

With various radar algorithm products available on the Nowcast Server a number of clients use either push or pull technology to access those products, to then use as part of a display system or to form a basis for a forecast product.

- **Web Display**

The Bureau has a very successful and popular web radar display (Donaldson et al, 2007). The Bureau's main website consistently rates as the most popular government website in Australia and in the top 20 Australian websites, largely due to its radar portal. One type of product it displays is based on output of Rainfields in the form of rainfall accumulations over various time periods. An example is shown in Figure 3.

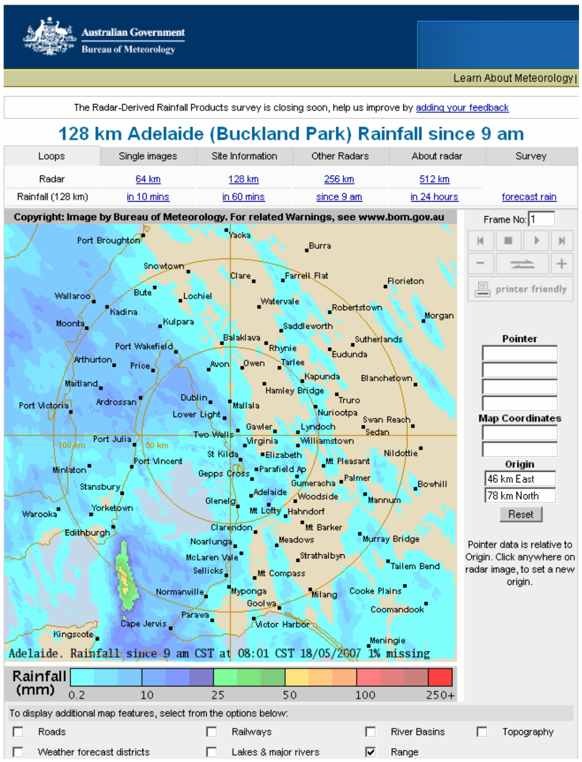

Fig. 3: Example of a Rainfields since 9am accumulation product in the Bureau's web radar viewer.

- **3D-Rapic**

A major client of Nowcast Server products is 3D-Rapic (Purdam 2007). This system is the main operational radar data visualiser for the Bureau and is the major viewing platform for radar algorithm output when forecasters are diagnosing severe weather threat from convection.

3D-Rapic is able to receive radar data direct from radars, or relayed via other rapic data servers.

NAS products are fetched using the TITAN, WDSS and Rainfields APIs which have been incorporated within 3D-Rapic. Surface and lightning observations are also fetched via URLs for real-time display.

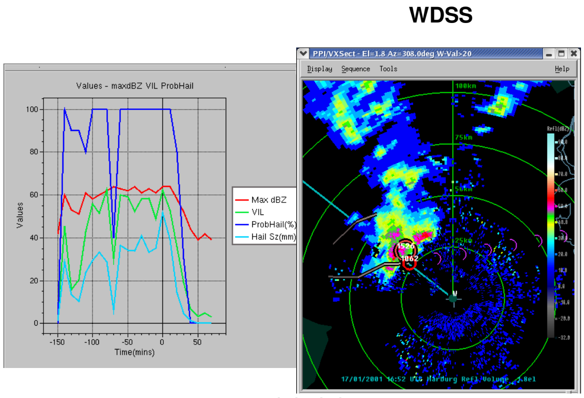

Fig. 4: Example of WDSS SCIT and HDA output incorporated into 3D-Rapic

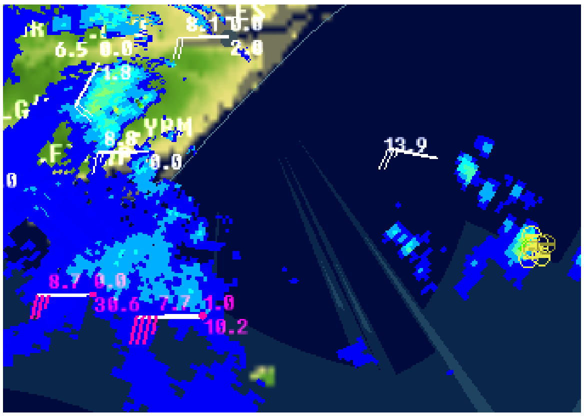

Fig. 5: Example of surface (wind barbs in knots) and lightning observations (yellow circles) combined with radar data, viewed in 3D-Rapic

- **TIFS**

The output of the radar algorithms described in Section 2.2 are used as forecast guidance by the Thunderstorm Interactive Forecast System (TIFS) warning production system, as detailed in Bally et al. (2007). TIFS has a graphical user interface (GUI) through which forecasters can view and edit the output of radar algorithms to produce text and graphical thunderstorm warnings. TIFS is used operationally by the Bureau of Meteorology in Australia to create both general warnings for thunderstorms, and also highly detailed thunderstorm nowcasts based on tracking and forecasting individual thunderstorm cells. TIFS can ingest a variety of data, including NWP guidance and lightning strike data, but the most crucial data needed for efficient operation are thunderstorm cell detections and forecast tracks such as those provided by TITAN.

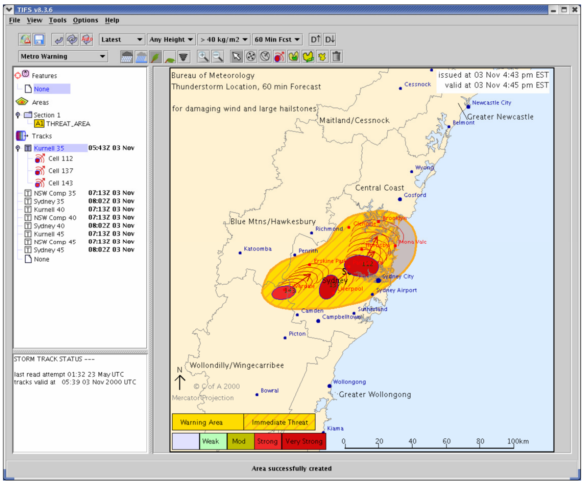

Fig. 6: Example of TIFS GUI with a set of TITAN cells and forecast tracks. A forecaster drawn yellow 'threat' area is also displayed.

Figure 6 shows the TIFS GUI and a group of TITAN identified cells and forecast tracks over the Sydney area. The Yellow area around the cells and tracks is a forecaster drawn "Immediate Threat Area". The tree in the left-hand panel shows the sets of forecast guidance available, from which the forecaster can choose the most appropriate to use as the basis of the Thunderstorm warning. Forecasters can change and move the cell detections and forecast tracks to correct for deficiencies in the automated cell detection and tracking. Corrections are not usually required, but can be important in some situations, such as in the transition phase between ordinary and super cellular structure which is often accompanied by a rapid change in cell direction and speed that trackers may take a few radar scans (10 to 20 mins) to pick up.

Once forecaster interaction is complete, TIFS creates graphical and detailed automatically generated text warnings for distribution to the public.

- **ATSAS**

A specialized aviation product based on TITAN output from the Nowcast Server is the Automated Thunderstorm Alert Service (ATSAS), (Potts et al. 2007), where location and movement of thunderstorms and the presence of lightning near airports is shown, updated in real-time.

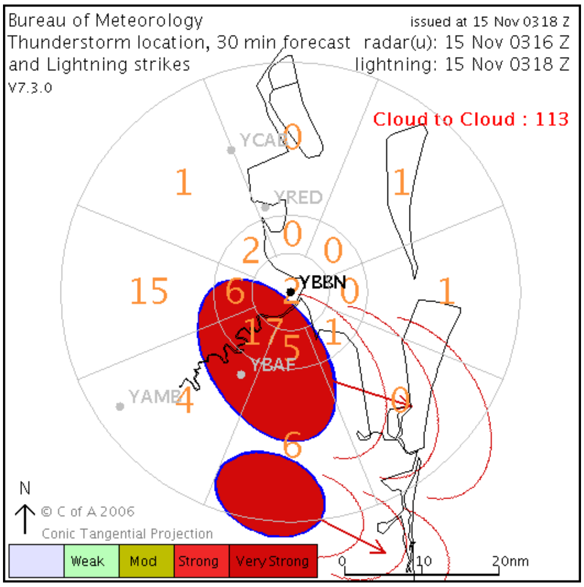

Fig. 7: ATSAS product provided for clients at Brisbane Airport, showing current thunderstorm location and forecast with lightning flashes recorded in the last 10 minutes in each sector.

- **Downstream applications that used Rainfields data**

Rainfields data is used to produce probabilistic products by introducing stochastic noise in the analysis. Multiple forecasts are then run on separate servers and results are then passed back to the Rainfields database and made available to Nowcast clients, refer to Seed (2007) for further details.

3. FUTURE PLANS

- **NAS**

Emerging multi-core processors should offer substantial gains in Nowcast server performance, which should help to offset increasing server loading due to increasing numbers of radars, higher resolution radar data and an increasing availability of Doppler data. Recent enhancements to the Rainfields algorithms utilising ensemble techniques require very large amounts of processing resource which may need to be carried out on their own dedicated servers or supercomputers.

The fam_mon functionality mentioned in Section 2.2 has been incorporated into the RDS and there are plans in place to allow clients to request the RDS to monitor for product file changes on the NAS and notify the clients to allow them to pick up the new products from the NAS as soon as they are created without the need for frequent polling. It is hoped that this will simplify the more complex client-server interfaces currently in use, whilst maintaining or improving product delivery latencies. For example it is planned to replace TITAN,WDSS and Rainfields specific API dependencies with a simplified event driven URL product file read mechanism where a Nowcast client subscribes to products from the NAS and is then notified when new products are available to be fetched via URL. It is planned that cell based products such as TITAN and WDSS will be made available in a standardised XML format (Ebert et al. 2007) and gridded data such as the Rainfields products made available as NetCDF files.

It is also planned for a more streamlined approach for surface and lightning observations to be stored on the NAS and passed to clients such as 3D-Rapic.

- **Monitoring - Agents**

Future versions of the Nowcasting software may incorporate Intelligent Alerts (Mathieson et al. 2004). This is an agent based (Bellifemine et al. 2007) alerting system intended to be very flexible. The underlying architecture is a collection of agents communicating via the publish-subscribe pattern. In this system, sources of information (services) provide their subscribers (clients) with updates when necessary, the clients process one or more streams of data from services to generate alerts (i.e., discrepancies between Terminal Aerodrome Forecasts (TAFs) and observations, or for thunderstorms) or value added information streams. Eventually GUIs running as agents subscribing to alert services can warn forecasters of important events. Since the whole network runs in a data-driven mode, these alerts will appear without delay.

Currently the Bureau is prototyping this system both Bureau-wide, and as a component of the Nowcast server. In this latter context, the system will alert for thunderstorms, and for problems with radars, eventually providing a gateway for general problem management. Those with access to the Bureau intranet can see the system in action at http://titandev2.ho.bom.gov.au/~sandy/ia/. It is hoped that this system will eventually supplant the current AIFS alerting system.

- **Monitoring – End to End**

With the greater expectation for timely short-term warning products, there is a growing need to determine quickly if there is a problem or dataflow break in the feed from the radar through the radar data server, Nowcast Application Server and out to the client application level especially if severe thunderstorms are occurring.

Currently the NAS has monitoring tools that facilitate this process for the NAS' processes and products only.

Work is currently underway within the Bureau to consolidate other system tools so that there is end-to-end monitoring of all the systems dedicated to severe storm warnings.

- **TIFS**

The current development focus for TIFS is on developing the strike probability technique based on a probabilistic combination of data from a group of storm tracking and analysis systems, treated as an ensemble. As detailed in Bally et al. (2007) initial products will be for a general thunderstorm threat, with products for specific phenomenon associated with severe convective weather, including flash floods, hail and damaging wind gusts to follow.

Currently, the decisions about which cells to warn for are manual, assisted by a facility to filter cells with low VIL and low top height, and aided by the ability for the forecaster to inspect other cell characteristics diagnosed by radar algorithms. There is scope for improved decision support within the TIFS system to improve the discrimination of severe from non-severe cells. Better support is also needed to assist the forecaster in recognising situations where the automated cell tracking may not be performing well and is in need of correction.

- **Polarimetric/Merged radar data**

The Bureau has acquired the CP2 radar, which has dual wavelength (S and X band) and polarimetric/Doppler capability. CP2 is seen as test bed for the development, testing and intercomparison of algorithms before operational use by the Bureau, see Keenan (2007) for further details.

Although Australia does not have the radar overlapping coverage of some countries, work is planned to improve the merging of radar data from Australian radars. Exciting progress has been achieved in Rainfields use of merged radar data (Seed 2007) but this needs to be complemented by other Nowcast algorithms use of merged radar data.

- **Beijing 2008**

The Australian Nowcast System will be one of the systems participating in the World Meteorological Organization's World Weather Research Programme (WWRP) Beijing Olympics (2008) Forecast Demonstration Project (FDP). Some of the system development driven by this project will become incorporated into the operational Australian system. Participation in this project also provides an invaluable opportunity to benchmark against similar nowcast systems from around the world.

4. SUMMARY

With the development of the Australian Nowcasting System, Australia is well-placed to take advantage of current and emerging radar technologies and systems, to translate the radar data into more accurate and specific short-term weather forecasts and warnings.

5. REFERENCES:

Bally, J., A. J. Bannister and D. Scurrah, 2007: TIFS developments inspired by the Beijing 2008 FDP. *Preprints, 33rd AMS Conf. Radar Meteorology (Cairns, Australia), 6-10 August 2007, Amer. Meteor. Soc.*

Bellifemine, F. L., Giovanni Caire, Dominic Greenwood, 2007: *Developing Multi-Agent Systems with JADE. Wiley, NJ, USA.*

Dixon, M., and G. Wiener, 1993: TITAN: Thunderstorm Identification, Tracking, Analysis, and Nowcasting—A Radar-based Methodology. *J. Atmos. Oceanic Technol.,* **10**, 785–797

Donaldson, A., and R. Smyth, S. Fisher, R. Davidson, D. Adams, F. Longo, and J. Lubkowski, 2007: Distribution of weather radar imagery via the internet at the Australian Bureau of Meteorology. *Preprints, 33rd AMS Conf. Radar Meteorology (Cairns, Australia), 6-10 August 2007, Amer. Meteor. Soc.*

Ebert, E., S. Dance, D. Scurrah, R. Potts, and E. Dozortseva, 2007: An XML format for nowcast data. *Preprints, 33rd AMS Conf. Radar Meteorology (Cairns, Australia), 6-10 August 2007, Amer. Meteor. Soc.*

Keenan, T., J. W. Wilson, J. Lutz, K. Glasson, and P. T. May, 2007: Rationale and use of the CP2 Testbed in Brisbane, Australia. *Preprints, 33rd AMS Conf. Radar Meteorology (Cairns, Australia), 6-10 August 2007, Amer. Meteor. Soc.*

Kelly, J., P. Gigliotti, 1997; The Australian Integrated Forecast System (AIFS): Overview and Current Status. *13th, Conf. Interactive Information and Processing Systems for Meteorology, Oceanography and Hydrology, Long Beach, California.*

Mathieson, I., Dance, S, Padgham, L, Gorman, M, and Winikoff, M, 2004: An Open Meteorological Alerting System: Issues and Solutions. *Computer Science 2004* (CRPIT Volume 26)

Potts, R., J. Bally and T. Williams, 2007: An automated thunderstorm alert service for airport operations. *Preprints, 33rd AMS Conf. Radar*

Meteorology (Cairns, Australia), 6-10 August 2007, Amer. Meteor. Soc.

Purdam, P. J., 2007: 3D-Rapic—The Australian radar visualisation system. *Preprints, 33rd AMS Conf. Radar Meteorology (Cairns, Australia), 6-10 August 2007, Amer. Meteor. Soc.*