An end-to-end severe thunderstorm forecasting system in Australia: overview and training issues

Tony Bannister and Roger Deslandes
Bureau of Meteorology
Melbourne, Victoria, Australia

Introduction

In July 2003 the Australian Government committed AUS$62.2 million dollars over a five year period to upgrade the Australian Bureau of Meteorology's weather service provision. The bulk of this funding is committed to acquiring and implementing radar hardware. Funding has also been directed at the development and operational implementation of radar data display software tools, algorithm-based warning decision tools and a graphically based thunderstorm warning production system.

A National Thunderstorm Forecast Guidance System (NTFGS), used to display Numerical Weather Prediction (NWP) data, was also deployed for operational use around Australia in the latter part of 2003. This system, in conjunction with the newly developed software used to display radar data (3D-Rapic) with algorithm-based overlays and warning production tools (Thunderstorm Interactive Forecasting System; TIFS), constitute a tool set that can be used end-to-end in the process of diagnosing potential severe weather environments, assessing storm severity on radar and the issuing of warnings.

There are differing time scales for the severe thunderstorm forecasting process, ranging from days ahead where the NTFGS provides support through to the nowcast scale (0 – 3 hours) where 3D-Rapic and TIFS are the underpining tools.

In order to utilise these forecast systems in a meaningful way it is important that the service requirements and forecast process be well defined and that forecasters have a clear understanding of these. The required scientific knowledge and system skills distilled from analysing the forecast process are embodied in radar and severe thunderstorm forecast competencies.

The radar and severe thunderstorm forecast competencies are the cornerstone of a focused, service-relevant training program that forecasters are undertaking as an integral part of the introduction of the new systems to Regional Forecasting Centres (RFCs) in Australia.

Section 2 of this paper presents an overview of each of the systems. Section 3 discusses training issues associated with implementation of the forecast systems. A major conclusion of this paper in section 4 is that forecasters must have an understanding of the algorithms for them to be used meaningfully. Such algorithms add value to decision making when used carefully in conjunction with the base data and other data types.

System overview

Outlook period to 48 hours - National Thunderstorm Forecast Guidance System

The NTFGS is a software package that displays those output fields from the 0.125º Australian operational NWP model (Meso-LAPS) that are relevant in diagnosing (severe) thunderstorm potential out to 48 hours from model initialization(Hanstrum, 2003). One of the core elements of the system is a web-based GUI interface refered to as the mesoviewer. Forecasters can view 3 hourly mesoLAPS NWP data (Puri et al., 1998) in a way that reinforces the (severe) thunderstorm forecast process.

Algorithms used to determine threat areas for thunderstorms, supercell thunderstorms, tropical squall lines, damaging winds, large hail, tornadoes and heavy convective precipitation potential, utilise an ingredients-based approach. A level of threat at a model grid-point is displayed when the component diagnostics that constitute the threat simultaneously reach pre-determined threshold values. The NTFGS threshold values are based on those found in the literature (for example, Treloar and Hanstrum, 2002) and forecast experience. A subset of the NTFGS threat algorithms and associated ingredients appears in Table 1.

One of the great strengths of the NTFGS mesoviewer is that it allows forecasters to efficiently overlay and composite model fields and algorithm threat maps. The algorithm ingredients can also be readily viewed. "In an operational setting this guidance can be used to focus the attention of forecasters onto observations in the threat areas to determine whether the signal in the model is also present in the real atmosphere" (Hanstrum, 2003).

Table 1: NTFGS algorithm ingredients and thresholds for storm type threat. Where
- Lifted Index is the temperature difference between a near-surface parcel lifted dry-adiabatically to saturation and then moist-adiabatically to 500 hPa and the environmental temperature at 500 hPa.
- CIN is the energy needed to lift an air parcel vertically and pseudoadiabatically from its originating level to its level of free convection.

Storm type	Algorithm Ingredients
Surface-based Thunderstorm (warm-season, 850 hPa temperature > 12C)	• Lifted Index (500 hPa) ≤ -1.0 for lowest 50 hPa mixed layer • Low-level ascent > 10 $hPa.hr^{-1}$. • Convective inhibition |CIN| < 25 $J.kg^{-1}$. • Cold cloud depth > 3.0 km • Updraft reaches –20C or colder (in order that electrification can occur).
Thunderstorm (elevated)	• As for surface-based decisions except check for up-motion and instability above the surface up to 500 hPa.
Supercell (warm-season)	Conditions for surface-based convection met and: Favourable: • Lifted Index (500 hPa) ≤ -4.0 • Deep Shear (surface to 2.5-4km) ≥ 30 knots Very favourable: • Lifted Index (500 hPa) ≤ -5.0 • Deep Shear (surface to 2.5-4km) ≥ 35 knots.

Nowcasting Visualization - 3D-Rapic

3D-Rapic (May et al., 2004) is a Linux OpenGL display system, written in C++, designed specifically for the display of volumetric (3 dimensional) weather radar data. The display allows the volumetric data to be interactively viewed in a number of different ways, such as:
- PPI (Plan Position Indicator, constant radar elevation view);
- RHI (Range Height Indicator, constant radar azimuth view);
- Echo Tops (shows the highest echoes that exceed a given threshold. These are colour coded and 3D rendered according to height);
- VIL (a Vertically Integrated Liquid product calculated from the volumetric data to show the mass of water in a column above the earth's surface (units of $kg.m^{-2}$);
- CAPPI (Constant Altitude PPI, assembled from each PPI scan closest to the desired altitude).

A number of different radars and representations may be simultaneously displayed on the display screen. A key feature of the system is the speed and flexibility of use. The user has full control over viewing of the volumetric data.

The system was designed and built by the Australian Bureau of Meteorology and is now used operationally in several southeast Asian countries as well as being the main radar data viewing platform in the Australian Bureau of Meteorology. It contains the necessary communications and database infrastructure to allow data from a number of volumetric and standard surveillance radar sites to be automatically collected, viewed and stored.

Nowcasting, radar-based algorithms

TITAN

The Thunderstorm Identification, Tracking Analysis and Nowcasting (TITAN) system (Dixon and Wiener, 1993) is a radar-based application that identifies and tracks storm cells and provides short-term forecasts of their movement and size. Thunderstorm detection and forecasts are based on 3-D Cartesian radar data. The application has some geometric logic to deal with thunderstorm mergers and splits and tracks various parameters of the storm cell such as maximum dBZ and its height, cell top and bottom.
The application was initially developed at the National Center for Atmospheric Research (NCAR), Boulder, CO, USA, and has been integrated with the 3D-Rapic system for use in Australia.

In the TITAN system a ‘storm’ is defined as a contiguous volume that exceeds thresholds for reflectivity and size. The current reflectivity thresholds used in Australia are 35, 40 and 45 dBZ.

WDSS

The Australian Bureau of Meteorology Research Centre has adapted the Severe Storm Analysis Program (SSAP) of the National Severe Storms Laboratory's severe-weather Warning Decision Support System (NSSL WDSS) for use with Australian radar data, with 3D-Rapic being the primary viewing platform. SSAP consists of severe weather detection and prediction algorithms. The SSAP components currently used in Australia are the Storm-Cell Identification and Tracking (SCIT) algorithm (Johnson et al., 1998) and the cell-based Hail Detection Algorithm (HDA), Witt et al., 1998.

The SCIT algorithm works differently to TITAN in that the radar data is used in its native polar state and a ‘storm cell’ is defined as the smallest contiguous volume with the largest contiguous reflectivity that exceeds a size threshold, using seven reflectivity thresholds (30 – 60 dBZ in steps of 5 dBZ), in essence it is identifying and tracking individual storm cores. Like TITAN it tracks various cell parameters. The HDA is currently being assessed in the Australian context but initial work indicates similar results to that reported in the USA (Witt et al., 1998).

As new Doppler radars are installed in Australia the Meso-cyclone Detection Algorithm (MDA), Stumpf et al., 1998, Tornado Detection Algorithm (TDA), Mitchell et al., 1998, and Damaging Downburst Prediction and Detection Algorithm (DDPDA), Travis et al., 2004, will be tested and brought online.

Forecast production - Thunderstorm Interactive Forecast System (TIFS)

The Australian Bureau of Meteorology has developed the Thunderstorm Interactive Forecast System (TIFS) (John Bally 2004) for interactively producing severe weather warnings and other forecasts from thunderstorm tracks, automatically diagnosed from radar data. TIFS is designed to apply recent advances in radar-based thunderstorm cell detection and tracking techniques to the efficient production of operational forecasts and warnings. The system ingests automated thunderstorm cell detections and tracks, allows graphical editing by forecasters, and produces graphical and text products from the edited data. The text generator uses a simple template filling approach. The graphical products include a map of areas that have been affected by storms, and are forecast to be affected by storms, as well as meteograms for selected locations. It is presently being introduced into forecasting operations in Australia.

Training issues

A comprehensive training program was associated with the national release of the NTFGS in the latter half of 2003 (Deslandes, 2003). Regional Forecast Centres that have had the latest Linux-based 3D-RAPIC, radar algorithms and TIFS software recently deployed are currently undertaking extensive regional training.

The process of developing the training programs and associated radar-based case studies has also facilitated improvements in the ongoing development of the systems themselves and associated operational service procedures.

The approach to training adopted for this project is rooted in up-to-date severe thunderstorm and radar competencies (Bell, 2003). This ensures that the training resources are highly focused on addressing the skills and knowledge that forecasters require. The train-the-trainer model used in this project is a highly efficient way to train regional forecasters. Regional trainers have a much stronger understanding of local office culture and local forecast procedures than centrally based trainers and are directly available to office staff after the official training has concluded.

The development of training case studies by the regional trainers themselves in a centrally co-ordinated workshop forum and follow-up train-the-trainer days to revisit the supporting background knowledge has ensured a strong sense of ownership and understanding of the training material. The web-based delivery of the training material ensures that forecasters can easily access the resources to refresh their knowledge. During the training sessions forecasters apply their knowledge and skills in a service-focused context through case studies that utilise the actual forecast systems. After the training forecasters are cross-checked against core competencies to ensure that they are familiar with systems and procedures.

Discussion and conclusions

The NWP data provides a dynamically, spatially and temporally consistent dataset in which to apply conceptual models and interpret observations.

Once storms have formed the WDSS and TITAN algorithms displayed in 3D-Rapic provide objective radar-based guidance. If forecasters are to make the best possible decisions based on the data at hand it is important that they are able to understand and assess the validity of algorithm output by analysing the (NWP or radar) base-data in the context of observations.

Once forecasters decide to issue warnings for an event, the use of TIFS has been shown (Bally 2004) to facilitate the timely issuing of consistent graphical and text cell-based warnings.

The Australian Bureau of Meteorology is well-positioned with the upgrade of its radar network, some excellent thunderstorm forecasting, radar analysis and forecast production tools, combined with well-targeted training, to improve the scope and effectiveness of its Severe Thunderstorm Warning service over the next few years.

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