The Impact of Advanced Nowcasting Systems on Severe Weather Warning during the Sydney 2000 Forecast Demonstration Project: 3 November 2000

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ABSTRACT

One of the principal aims of the Sydney 2000 Forecast Demonstration Project was to assess the utility of advanced nowcasting systems to operational severe weather forecasters. This paper describes the application of the products of a variety of systems by forecasters during a severe weather event in Sydney, Australia, on 3 November 2000. During this day a severe storm developed to the south of the metropolitan area and tracked north producing large, damaging hail, heavy rainfall, and at least three tornadoes. A number of severe weather warnings were issued by the Australian Bureau of Meteorology to a variety of customers throughout the day.

This paper investigates how the novel nowcast products were used by the forecasters and the impact they had on the forecast and warning dissemination procedure. The products used are contrasted with those that were available or could have been made available at various stages of the storm development and the efficiency of use of these products is discussed. The severe weather forecasters expressed their satisfaction with the systems and believed that the additional information enhanced the quality and timeliness of the warnings issued during the event.

1. Introduction

One of the objectives of the World Weather Research Programme (WWRP) Sydney 2000 Forecast Demonstration Project (FDP; Keenan et al. 2002) was to investigate the manner in which nowcast products can be presented to operational forecasters and to ascertain if these products are capable of having an impact on severe weather forecasting. Bally (2001) describes the Web-based display by which forecasters could view nowcasting information. Warnings were semiautomatically dispatched to the State Emergency Services (SES) and Bridgeclimb, a commercial operation conducting tours of the Sydney Harbour Bridge.

On 3 November 2000 a severe storm tracked across the Sydney metropolitan area, causing significant damage from hail and tornadoes (Sills et al. 2004, in this issue). The severe weather forecasters on duty had access to the FDP systems’ products for a number of months, but only in semioperational states. In operational, fully functional modes the systems had been running for 2 months at this stage with products displayed on the forecasters’ desktop. In that period there had been some weak storms that had given the forecasters only a small opportunity to become accustomed to the new systems. The third of November was the first severe storm during which the forecasters found added information necessary.

During a severe weather event a forecaster’s duties are multiple. Apart from analyzing a variety of data to determine the best forecast of future conditions, they must simultaneously disseminate forecasts to a number of clients using a range of methods. These may include fielding telephone inquiries from the media and the public, and recording broadcasts. Time is therefore limited and the most important job, that of producing the best possible forecast of severe weather, can suffer. It is therefore essential that any new tools that are placed before the forecaster serve to reduce the time required to do this job as well as to improve the forecast. It is very easy to continually add more and more data for the forecaster to analyze, but this simply increases the

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Table 1. WWRP systems available during the Forecast Demonstration Project.

<table>
<thead>
<tr>
<th>System</th>
<th>Acronym</th>
<th>Organization</th>
<th>References</th>
</tr>
</thead>
<tbody>
<tr>
<td>Canadian Radar Decision Support system</td>
<td>CARDS</td>
<td>Environment Canada</td>
<td></td>
</tr>
<tr>
<td>Generating Advanced Nowcasts for Deployment in Operational Landsurface Flood forecasts</td>
<td>Gandolf</td>
<td>Met Office–University of Salford</td>
<td>Pierce et al. (2000)</td>
</tr>
<tr>
<td>C-band polarimetric radar hydrometeor classification</td>
<td>CHYD</td>
<td>BMRC</td>
<td>Keenan et al. (1998)</td>
</tr>
<tr>
<td>Thunderstorm Identification, Tracking, Analysis, and Nowcasting</td>
<td>TITAN</td>
<td>BoM</td>
<td>Dixon and Wiener (1993)</td>
</tr>
</tbody>
</table>

amount of time needed to discover the critical information and make the best forecast.

This paper presents an assessment of the benefit to forecasters afforded by the presence and accessibility of the advanced nowcasting systems, both in terms of the lead time and utility of warnings. In making this assessment the authors draw upon their observations on 3 November and the logs kept by both FDP participants and operational forecasters. The observations are discussed chronologically and the utility of each individual system highlighted at each stage of the storm. The impact on warning dissemination is discussed subsequently.

In section 2 the structure and organization of the project is briefly described. Section 3 provides an overview of the events of the day and this, in turn, is followed by section 4 that describes how the system products were used at different stages of the storm development on 3 November. For each stage of the storm notable features are described and the contributions of the FDP systems to the nowcasting of the significant weather observed during that stage are assessed. Strengths and weaknesses of the nowcasts are identified and a description is given of which products were available and used by the forecasters, and which were not. Section 5 contains discussions of the impact of the WWRP products on the forecasting process during the day and an analysis of the advantages, disadvantages, and limitations of the system products. There is a look forward to the future possible developments in nowcasting and their integration into operational offices. Finally, the conclusions section provides suggestions and recommendations relating to the installation, utility, and effectiveness of advanced nowcasting systems in an operational environment.

2. Sydney 2000 Forecast Demonstration Project

a. Systems present and products displayed

The systems present in Sydney and their origins are shown in Table 1. The system displays had all been designed to operate in isolation, as prior to this project each system had been used alone. There was little time available to give full consideration to the complementarity of the systems and how best to optimize displays with minimum repetition. This led to discrepancies between color scales and some nonoptimal selections of product displays. The cell tracking displays used a small range of colors in an attempt to indicate storm severity as classified by cell-top height. Also prior and forecast tracks were not clearly distinguished by color.

The details of the products produced and displayed by each system can be found in Keenan et al. (2002) and Fox et al. (2001) and are summarized in Table 2. An example of the display from 3 November 2000 is shown in Fig. 1. Twelve panels were displayed on the two screens of the interactive Web display. The two screens had a broad separation between severe weather nowcasting and precipitation products. All of the panels displayed the same cutout area corresponding to the New South Wales (NSW) Severe Weather Warning Area (SWWA). This encompassed the Sydney metropolitan area and the entire range of Olympic sites.

It was possible to click with the mouse on many of the 12 panels. This would bring up a display related to the image clicked on, which would replace half of the 12-panel display. The information accessible by clicking on an individual panel varied and the products available by this procedure are listed in Table 2 for the systems discussed in this paper. The usual image available from a system is referred to as the front panel and that obtained by clicking on this image is referred to as the rear panel. It was very noticeable during the FDP that the forecasters had little time to investigate the information contained in the rear panels. Therefore, the systems that presented their most important features “up front” were of greater use, especially during severe weather events. This was particularly evident during 3 November, as the forecasters were faced with a multitude of tasks and decisions for a lengthy period. Those systems whose major output took the form of animated loops that could only be viewed at the expense of cova
erating other displays were less used. For this reason, this paper concentrates on the impact of the products that were readily accessible, but reserves some space for recommendations as to how the other products could be made more available.

All of the systems analyzed and generated products for a wider area than shown on the common Web display (Fig. 1). In particular, the systems designed to nowcast widespread rainfall displayed only a small fraction of their analysis domain. This restricted the application of their products, as the forecast motion of large-scale structures could not be observed. It was felt, overall, that the consistency of product display was preferable to each system showing the domain considered most suitable by that system’s designers.

This paper concentrates on a single series of convective events during which the focus of attention was on severe weather; therefore, little consideration is made of the systems and products that were designed to forecast precipitation fields [the Nowcasting and Initialisation for Modelling Using Regional Observation Data (Nimrod; Golding 1998); the Spectral Prognosis approach (S-PROG; Seed 2003)]. As it happens, the precipitation products [Nimrod, the Generating Advanced Nowcasts for Deployment in Operational Land-surface Flood Forecasts system (Gandolf), and S-PROG] were those that had little additional information on their front-panel display and little information pertinent to severe weather situations on their rear panels. They were, however, used extensively and appreciated during other situations (Anderson-Berry et al. 2004, in this issue).

It is notable that some systems used different detection methods to derive the same feature. For example, in the case of hail, the C-band polarimetric radar (C-Pol) used a direct observation by dual-polarization radar (Keenan et al. 1998), while the Canadian Radar Decision Support system (CARDS) and the Warning Decision Support System (WDSS) used different empirical algorithms that related vertical radar reflectivity profiles within the storm to the occurrence of severe hail. CARDS used a relationship dependent upon the maximum height of the 50-dBZ reflectivity and the freezing level. The WDSS hail detection algorithm is based upon a statistical relationship to assess the probability of hail from the size of the convective cell and the vertically integrated liquid water (VIL) (Kitzmuller et al. 1995). The CARDS algorithm, actually developed locally in the New South Wales (NSW) forecast office (Treloar 1998), is a function that yields maximum hail size from the height of a number of radar reflectivities within the storm.

### b. Products available at the WWRP desk

Due to limitations on the display available on the forecasters’ desk, many useful products were not shown. Table 3 lists the products that each system produced and displayed, both on the Web-based display available at the forecaster desk and on their own systems in the WWRP area. The WWRP system operators were able to view more information from their own systems and were able to analyze and interpret that information in addition to the information available to the forecasters. Therefore, if a WWRP representative was able to determine some important characteristic of a storm that was not available to the forecasters, that information could be passed to the WWRP “champion” (discussed below), who could then pass it on to the forecasting team. This ensured that valuable information could reach the forecasters with minimal disruption to oper-

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### Table 2. Products generated by the nowcasting systems. These are divided by their availability to the operational forecast team.

<table>
<thead>
<tr>
<th>System</th>
<th>Products displayed on front panel</th>
<th>Products displayed on rear panel</th>
<th>Products not displayed on desktop</th>
<th>Potential products not generated</th>
</tr>
</thead>
<tbody>
<tr>
<td>WDSS: panel 1</td>
<td>WDSS cell identifications and forecast tracks</td>
<td>N/A</td>
<td>TVS detection was not operational</td>
<td>Automated boundary detection and extrapolation</td>
</tr>
<tr>
<td>WDSS: panel 2</td>
<td>Cell attributes</td>
<td>No “hidden” panel</td>
<td>Rainfall rate</td>
<td></td>
</tr>
<tr>
<td>ANC</td>
<td>Boundary positions (present and forecast), overlaying adjoining wind field</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Gandolf</td>
<td>Rainfall, reflectivity</td>
<td>Animated loop of forecast reflectivity</td>
<td>Severe weather potential forecasts; rainfall forecast accumulations</td>
<td>Lightning and microburst forecasts; forecasts from T+120 to T+180</td>
</tr>
<tr>
<td>CHYD</td>
<td>Hydrometeor discrimination</td>
<td>30-, 60-min prior hydrometeor discrimination</td>
<td></td>
<td></td>
</tr>
<tr>
<td>TITAN</td>
<td>TITAN 35- and 45-dBZ tracks</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>CARDS</td>
<td>Rainfall meteogram</td>
<td>TITAN 35-dBZ tracks with CARDS severe weather detections</td>
<td>Selectable 3D cross sections of radar data were available as a separate Web-based product</td>
<td>Tracks for other reflectivity thresholds</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>CARDS is under constant development and many new products are now available</td>
</tr>
</tbody>
</table>
Fig. 1. Example of 12-panel FDP Web display available to operational severe weather forecasters on 3 Nov 2000. The two screens would appear side by side with the upper screen on the left. Starting with the first screen and going clockwise from top left the panels depict the following: 1) WWRP forecast policy, 2) WDSS SCIT tracks, 3) WDSS cell attribute table, 4) CARDS meteogram, 5) ANC adjoint winds, boundary, and cell positions, and 6) TITAN 45-dBZ tracks. On the second screen, 1) C-Pol hydrometeor classification, 2) Kurnell radar reflectivity, 3) ANC precipitation, 4) S-PROG precipitation, 5) Gandolf product, and 6) Nimrod precipitation.
ations. As the forecasters became more familiar with the systems, they often approached the representatives of individual systems to discover more specific information.

In most cases the WWRP desk display covered the entire domain for which the system produced nowcasts, rather than the selected area available on the combined Web display. This enabled some features to be seen sooner on the WWRP desk than on the Web display. The Auto-nowcaster (ANC), WDSS, and CARDS had the ability (on the WWRP desk) to zoom in on selected areas of interest and look in detail at storm features. This allowed for close examination of the structure of cells and their potential for severe weather. Part of the CARDS display was available as a separate interactive Web tool. This allowed forecasters to view reflectivity cross sections through cells along any chosen direction (not only radials).

Also in Table 3 is a record of those products that the WWRP representatives considered the most valuable for nowcasting. There is a general consensus regarding some of the most valuable indicators of severe weather, for example, the direct notification of the maximum reflectivity in a cell and the height at which it occurs.

In the final column is a list of products that have been developed since the 2000 project, which would be available to forecasters if systems were installed now. A number of these new products have come about as a result of the experience gained in Sydney and the cross-pollination of ideas resulting from the interaction of the different groups present.

c. Forecaster interaction

One of the primary objectives of the project was to demonstrate the nowcasting technology in an operational forecast setting. The Bureau of Meteorology (BoM), as project host, allowed the products of the nowcast systems to be made available to its operational severe weather forecasters under a strict protocol. This involved the composite display system designed within the bureau (described above) and a roster of designated project representatives who liaised with the operational forecasters. During a severe weather event only the designated representative on duty, or champion, was to interact with the forecasters. All decisions regarding the issuing of alerts and warnings lay with the operational forecast team. One experimental tool specifically designed for the FDP was Thunderbox (now referred to as TIFS) (Bally 2001), which used FDP cell track products as a basis for warning areas.

This allowed semiautomatic dissemination of graphic and text warnings to selected clients (e.g., State Emergency Services). Although the tool was managed by the FDP participants, it was overseen by the forecasters and all warnings issued had to conform to the current forecast policy, which was disseminated by “traditional” means. All warnings issued, whether or not they used FDP products, and, in particular, if they were issued through the Thunderbox system, had to agree with the official warning policy of the BoM office valid at the time. The official text warnings remained a priority and the Thunderbox warnings were often issued in a less timely manner, but were used in conjunction with the official warnings. In theory the Thunderbox system could have expedited the issuance of warnings, but, naturally, the text warnings were given priority during the project.

The WWRP champion was responsible for the interpretation of nowcast products and drawing the attention of the severe weather team to important features within them. This gave the forecasters exposure to the novel products without being crowded and confused by all the individuals involved in the project. The display included a text summary of each system’s operational status and a message board to highlight any notable features iden-
tified by the systems. This was completed by the champion and could be updated at any time.

Prior to the event of 3 November the setup had worked reasonably well, but with a limited amount of severe weather there had not been a significant test of how the forecasters would use the available information or how the interaction with the WWRP groups would proceed. The regime, in fact, proved effective, with efficient transfer of information to the forecasters.

3. Overview of events for 3 November 2000

The Sydney forecast issued at 1730 UTC (valid for 20 h) mentioned “A few showers and thunderstorms developing during the afternoon.” Times in this paper are reported in UTC, which is 11 h behind Sydney local time.

The morning wind profile (Sills et al. 2004) indicated relatively light steering, so the critical question in the forecasters’ minds was whether or not the storms expected to develop over the higher ground around Sydney could become organized enough to reach the Sydney metropolitan area. The focus of the low-level convergence was to the west of Sydney and thunderstorms were often observed to develop in this region and move over populated areas. The instability on the day could be described as moderate to high convective available potential energy (CAPE) although there was some uncertainty as to how much midlevel drying would occur during the day. Midlevel drying would increase the instability of a moist parcel that ascended and would, therefore, encourage greater convective development.

The Thunderstorm Outlook, a product issued daily by the NSW Regional Forecasting Centre, indicated the area of possible thunderstorm development in NSW before midnight that night. This chart has three levels of probability: Chance, Likely, and Possibly Severe. If the term Possibly Severe is used, then some mention of severe thunderstorms is made in routine products. On 3 November, forecasters issued a Thunderstorm Outlook at 2302 UTC with much of the eastern half of NSW within the Likely area and parts of the central coast and ranges marked Possibly Severe. Sydney was not included in this Possibly Severe area due to some doubts as to whether storms would become organized and remain severe as they moved into the area. The 0025 UTC issuance of the Sydney forecast used the wording “Cloudy at times with a few showers and the chance of thunderstorms, chiefly in the afternoon and evening.” This issuance of the forecast was valid until midnight the next day and forecasters took this into account when wording the forecast.

Storms started forming before 0100 UTC and within an hour some had developed into severe thunderstorms that were thought to have produced large hail. At 0307 UTC the warning that had been valid for the surrounding areas was extended to the Sydney metropolitan area, with storms then showing enough organization for forecasters to be confident that severe weather would be experienced. At that time there was a single complex of cells, which was producing persistent severe weather (large hail and heavy rain), moving from the southwest toward Campbelltown and the metropolitan area. Shortly after 0400 UTC large hail was observed in Campbelltown and, by 0500 UTC, the storm was affecting Sydney’s western suburbs. The storm peaked around this time with damage due to giant hail and strong winds, including tornadoes. By 0600 UTC the storm was dissipating and moving out of the metropolitan area. The severe thunderstorm warning was canceled at 0700 UTC. The overall track of the main storm is shown in Fig. 2 and locations mentioned in the text are noted.

A detailed examination of the storm structure and evolution is given by Sills et al. (2004). However, in order to facilitate the discussion of the use of FDP products on that day, it is necessary to present a synopsis of the major occurrences. Table 4 provides a summary of the actions of the severe weather forecasters (mostly in terms of the warnings issued), observations that were received during the event, and the guidance being offered by the FDP systems. It also shows a summary of the events throughout the period of the storms. The left-hand columns show forecaster actions and observations, while the right-hand side shows FDP system outputs. Care must be taken in the interpretation of spotter observations as these are recorded at the time they are received. The actual time of the observed event will be earlier than that recorded in the log; however, it is not possible to retrieve the actual timing of the events.

4. Forecaster use of FDP products

In the following sections particular situations are explored with a detailed discussion of the forecasters’ responses to the situation and their usage of the FDP products.

a. Storm initiation

In the early stages of storm development several small cells formed, but it was difficult to anticipate which deserved attention. Early in the event (about 0130 UTC) the forecasters’ attention was drawn to the possible presence of hail, diagnosed only by the FDP systems, in a cell to the northwest of Sydney. This was the first indication of severe weather and allowed for a severe thunderstorm warning (STW) to be made earlier than it would have been by the forecasters using conventional systems alone.

The greatest benefit in the initiation stage was the identification of those cells most likely to develop strongly. This was achieved to some extent by Gandolf, but most successfully by ANC. This system predicted the interaction between the sea-breeze front and the most southerly of the cells visible on the radar at around 0200 UTC (Fig. 3). The system showed the imminent col-
Fig. 2. Map of Sydney and region showing locations of instrumentation as well as storm track, tornado damage tracks, and large hail report locations on 3 Nov 2000. The letters show the locations of locations mentioned in the text: B, Bowral; C, Campbelltown; F, Fairfield; G, Greystanes; L, Liverpool; and P, Parramatta. The last four all lie within the western suburbs of Sydney.

location of the cell and the sea-breeze front and the probability that the storm would intensify through this interaction. On the other hand, this image fails to show the subsequent steering of the cell along the front. The Thunderbox product, shown in Fig. 4, used the Thunderstorm Identification, Tracking, Analysis, and Nowcasting (TITAN) nowcast track to generate a threat area. In preparing these warnings the forecasters used the tracks provided as a base and then extended the envelope of the threat area within the Thunderbox system to encompass what they perceived to be the true extent of possible severe weather (Bally 2001). This in general indicates a measure of the uncertainty in both cell speed and direction indicated by these products. The tracking algorithms showed the trajectory of the cell over Bowral toward Wollongong allowing warnings of severe hail to be disseminated to the emergency services and the media for these areas. However, all the systems showed the motion of the storm to be primarily eastward. There was no indication of the northward turning that was observed when the cell encountered the sea-breeze front, as the tracking algorithms do not allow for deviation from a linear path. The information regarding the position of the sea-breeze front from ANC provided an indication that turning may occur, but this was only incorporated into warning products once it began. Therefore, there was no apparent threat to the Campbelltown area at that time, nor for the succeeding hour, but a warning for the Wollongong coastal district was issued. There was also an emphasis on the threat posed by the cells to the northwest of Sydney, which were diagnosed as moving toward the western suburbs. In fact, although cells continued to develop in the Blue Mountain region, none of these propagated into the coastal plain. This demonstrates the deficiency of the cell tracking systems: the forecasters’ experience was that these cells would dissipate as they moved to the east, but the automated systems, which had no development/dissipation routines, produced forecasts of cell positions for these dissipating storms. On the other hand, as Fig. 3 shows, systems such as ANC, which had cell development routines, did forecast the dissipation of these cells. The threat area delineation based on the 0200 UTC tracks was quickly adjusted by the issuing of a further warning at 0220 UTC, which showed the storm steering farther northward toward Campbelltown (Fig. 5). This latter warning was issued as the forecasters
Table 4. Timeline of events during 3 Nov 2000 showing comparison between forecasts and warnings issued, observations, and FDP system products. Spotter observations are shown in italics. Note that the times recorded for spotter observations are those of when the reports were received, not the actual time of the observation: STA, severe thunderstorm advisory; STW, severe thunderstorm warning; VHR, very high rainfall; SES, State Emergency Services; f/c, forecast.

<table>
<thead>
<tr>
<th>Time (UTC)</th>
<th>Warnings and observations</th>
<th>Time (UTC)</th>
<th>FDP products</th>
</tr>
</thead>
<tbody>
<tr>
<td>0058</td>
<td>STA: CT, HUN, ILL: large hail, VHR to 0700 UTC</td>
<td></td>
<td></td>
</tr>
<tr>
<td>0115</td>
<td>STW: Hawkesbury, Blue Mountains, Wollondilly to Wingecarribee: hail, wind, VHR to 0215 UTC, SES</td>
<td></td>
<td>Thunderbox (0105 UTC) issued including cell at Bowral</td>
</tr>
<tr>
<td>0120</td>
<td>ANC f/c development of Bowral cell</td>
<td>0120</td>
<td></td>
</tr>
<tr>
<td>0145</td>
<td>ANC f/c development at sea-breeze front near Wollongong</td>
<td>0145</td>
<td></td>
</tr>
<tr>
<td>0150</td>
<td>WDSS showing hail over Bowral</td>
<td>0150</td>
<td></td>
</tr>
<tr>
<td>0155</td>
<td>STA extended: south coast, CC, CT, HUN, ILL: hail, wind, rain to 0700 UTC, SES</td>
<td></td>
<td></td>
</tr>
<tr>
<td>0210</td>
<td>STW: Hawkesbury, Blue Mountains, Wollondilly, Wollongong, Shell Harbour–Kiama: 1 h SES</td>
<td></td>
<td>Thunderbox (0200): many cells moving W–E</td>
</tr>
<tr>
<td>0215</td>
<td>CARDS showing 5.5-cm hail NE of Bowral</td>
<td>0215</td>
<td></td>
</tr>
<tr>
<td>0235</td>
<td>Thunderbox (0220): more emphasis on cell NE of Bowral, rack turned northerly from W–E</td>
<td>0235</td>
<td></td>
</tr>
<tr>
<td>0240</td>
<td>WDSS showing &gt;5 cm hail</td>
<td>0240</td>
<td></td>
</tr>
<tr>
<td>0305</td>
<td>STW: Reissue including metropolitan, S and W parts, SES HQ, SES southern</td>
<td></td>
<td>Thunderbox (0303): main cell track over Campbelltown (60 min), then toward metropolitan area</td>
</tr>
<tr>
<td>0345</td>
<td>Picton 1–2-cm hail, severe rain</td>
<td></td>
<td></td>
</tr>
<tr>
<td>0400</td>
<td>STW: reissued, SES HQ</td>
<td></td>
<td></td>
</tr>
<tr>
<td>0407</td>
<td>CARDS: hail 5.5 cm</td>
<td>0407</td>
<td></td>
</tr>
<tr>
<td>0420</td>
<td>TITAN: 45 tracks toward metropolitan in hour</td>
<td>0420</td>
<td></td>
</tr>
<tr>
<td>0445</td>
<td>Summary: development expected to continue along sea-breeze front</td>
<td>0445</td>
<td></td>
</tr>
<tr>
<td>0450</td>
<td>4–5-cm hail, NW Campbelltown; 1 cm Sutherland; small, Menai; 1.5–4 cm, Moorebank, reaching Liverpool</td>
<td></td>
<td></td>
</tr>
<tr>
<td>0455</td>
<td>STW: Reissued for metropolitan area only (others removed); SES 0500</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
Table 4. (Continued)

<table>
<thead>
<tr>
<th>Time (UTC)</th>
<th>Warnings and observations</th>
<th>Time (UTC)</th>
<th>FDP products</th>
</tr>
</thead>
<tbody>
<tr>
<td>0455</td>
<td>Appin: 24 mm in 8 min</td>
<td>0500–0520</td>
<td>Storm clearly visible from BoM office</td>
</tr>
<tr>
<td>0505</td>
<td>Large hail, Liverpool; 5 cm, Wakely (near Liverpool); 5 min</td>
<td>0515</td>
<td>ANC showing mesocyclone signature and possible TVS; information passed to severe weather forecasters (reflection in 0525 STW)</td>
</tr>
<tr>
<td>0520</td>
<td>2 cm, Merrylands</td>
<td>0525</td>
<td>Thunderbox (0523): two cells converging in western suburbs, cell moving out of city and weakening</td>
</tr>
<tr>
<td>0522</td>
<td>STW: Reissued with upgraded wording (radar); SES 0530</td>
<td></td>
<td>WDSS: mesocyclone in storm 100, plus 100% probability of severe hail</td>
</tr>
<tr>
<td>0525</td>
<td>Tornado, Parramatta</td>
<td>0530</td>
<td>CARDS: mesocyclone detection; hail size 10 cm in cell 100</td>
</tr>
<tr>
<td>0530</td>
<td>2-cm hail, Homebush</td>
<td>0535</td>
<td>From WWRP policy it is apparent that attention is focused on WDSS and CARDS or current state and track</td>
</tr>
<tr>
<td>0541</td>
<td>Wentworthville, cloud rotation; 2 cm</td>
<td></td>
<td>WDSS: mesocyclone in storm 100</td>
</tr>
<tr>
<td>0600</td>
<td>2 cm, Castle Hill; 5 cm, Greystanes; heavy rain and roof off, Fairfield</td>
<td>0533</td>
<td>CARDS: mesocyclone detection; microburst detected; hail size 5 cm in cell 100</td>
</tr>
<tr>
<td>0600</td>
<td>STW: reissued and extended to Wollongilly, Wingecarribee, Wollongong, Shellharbour, Kiama, metropolitan area; SES 0605 UTC</td>
<td>0535</td>
<td>WDSS, CARDS: mesocyclone; hail, 5 cm; confirmed &gt;2 cm by C-Pol</td>
</tr>
<tr>
<td>0600</td>
<td>2-cm hail at Ryde, Eastwood</td>
<td></td>
<td></td>
</tr>
<tr>
<td>0605</td>
<td>SES 20 requests assistance</td>
<td></td>
<td></td>
</tr>
<tr>
<td>0610</td>
<td>2-cm hail, Turramurra</td>
<td></td>
<td></td>
</tr>
<tr>
<td>0700</td>
<td>1-cm hail, Asquith</td>
<td></td>
<td></td>
</tr>
<tr>
<td>0700</td>
<td>STW canceled</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>STA reissued covering ILL, CT, HUN, NT, NSWSP, and SC; valid through 1000 UTC</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

noted the imminent convergence and recognized the potential for development and steering.

All this led to a forecast of severe convection inland of Wollongong that proved very accurate. The convection was initially forecast to move to the east (as indicated by the standard cell tracking systems such as TITAN), but it was evident from ANC that there would be some steering of the cell along the sea-breeze front, along with development of convection in this area. The information was conveyed to the forecasters and they were able to monitor the situation in this area and observe the rapid development earlier than they might otherwise have done. This provided an opportunity to warn for areas in the path of the storm of the probability of severe weather, and this was certainly the case for Campbelltown where 4–5-cm hail was later reported.

b. Storm development

The systems in place provided a great deal of information regarding the environment in which storms were developing and the progress of this development. Much of that information was more accurate and at a far better resolution than that available from models, which had no indication of the small-scale features critical to maintaining powerful storms.

One system designed to explicitly forecast storm development was Gandolf, which is designed to forecast storm development using a life cycle model of thunderstorm evolution (Pierce et al. 2000). Gandolf uses mesoscale model data to determine the atmospheric environment within which the storm exists. This exhibited problems that stemmed from the coarseness of the mesoscale model data that were crucial to its diagnosis of storm development (Sleigh 2002). Thus, it did not forecast cells to develop as well as it was intended to do.

ANC, with its ability to identify convergence lines and, hence, areas of ascent, produced the most useful information regarding possible storm development. While ANC displayed detected convergence lines, the interpretation of the information these provided was not clear. There was a great deal of uncertainty as to whether cells would develop at the sea-breeze front prior to crossing the boundary and then dissipate, or if they
would be steered along the front, resulting in continued and prolonged development of cells and motion toward the metropolitan area.

As shown by Sills et al. (2004) there was a complex interaction between several low-level boundaries, and the development of the mesocyclones and tornadoes could not have been unambiguously predicted with the current understanding of such phenomena. Not all these small-scale features could be clearly resolved in real time and their influence on the storm system was not possible to predict. However, strong indicators of environmental conditions conducive to maintaining the severe weather, such as convergence zones, were available from ANC and this information was used.

The forecasters appeared less concerned with future development than with the current state of the storm and its projected path. This was natural given the constraints upon them in terms of time, the development-related products available, and the requirements of the forecast users. They used other products and their knowledge of storm behavior to judge the likely progression of storms based upon the environment into which the storms were moving.

The use of information to gauge convective development and forecast continued development is hard to assess. The systems specifically designed to diagnose these aspects (Gandolf, ANC) did not have complementary display systems that enabled the forecasters to analyze the information easily. To assess the current state of the cell and its development trend, the fore-

**Fig. 3.** Predicted collocation of initial storm cell with sea-breeze front as forecast by ANC at 0200 UTC.

**Fig. 4.** Thunderbox product based on TITAN tracks of 0200 UTC. These show the convective cell moving to the east over Wollongong and out to sea. They also show some threat to the western suburbs of Sydney from cells that failed to propagate from the mountain areas in which they developed.

**Fig. 5.** Thunderbox product from 0220 UTC showing a revision of the proposed storm track as the cell interacts with the sea-breeze front.
casters, under the time constraints of a critical situation, used more accessible and familiar tools. The operational radar viewer used by the BoM, a three-dimensional radar picture (3D-Rapic), enabled the forecasters to examine the overall structure of the storms, identifying features such as bounded weak echo regions (BWERs), high-altitude reflectivity cores, and so on. The forecasters gained much from the combination of these with the information relayed to them by the WWRP participants, who had expertise in the interpretation of their own products.

**Boundaries**

One product that was available and, perhaps, underused on the day was the ANC convergence boundary detection system. Forecasters commented that there was not sufficient time during the event to assess the information regarding convergence zones that was presented by ANC. This appears to be a function of the forecasters’ inexperience with this product and its presentation. Despite this the forecasters did use the boundaries in one important way: When forecasting development and motion of storms, forecasters attempted to examine the environment into which the storms were moving. The information on boundary position made a significant input to the forecasters’ judgment on storm persistence and development. Analysis by the ANC team, experienced in the use of the products and having full access to the system, indicated potential areas of development and, at certain times, this information was relayed to the forecasters.

ANC can determine the strength of the associated convergence and nowcast the position and strength of boundaries. It can also correlate the area of convergence (and future convergence) with other parameters that indicate potential for storm initiation and growth. One deficiency of ANC, at present, is that it cannot represent orographic influences on convergence and ascent. Wilson et al. (2001) demonstrated that, had the full ANC system been available, it would have had the capability of identifying those areas on the northern side of the main storm, where new development took place, up to an hour in advance. However, with the limitations on the display, this capability was not available to the operational forecasters, and it is doubtful that it would have been used due to the time constraints. It should be noted, however, that there is considerable potential for forecast improvement by using convergence boundary products, especially in terms of nowcasting the persistence or increasing severity of storms. However, as Sills et al. (2004) show, the development of the storm to the point where it spawned tornadoes involved a number of boundaries, not all of which were identified on the day. There still remained enough indicators of mesocyclonic development potential for forecasters to recognize the threat of the storm and react appropriately.

**c. Storm motion**

The impression of users at the time of the event was that, although the cell tracking algorithms (WDSS and TITAN) did a good job, they were occasionally unstable in that they oscillated to the right of the main, left-turning cell. Wilson et al. (2004, in this issue) reveal that, although the tracks were far less erratic than thought, they did indeed tend to show the storms moving farther to the right than actually occurred. The tracks imply a single coherent storm, whereas over the period of hours a succession of cells developed and dissipated. However, during the critical, most damaging phase of the storm a single supercell tracked more slowly than, and to the left of, the forecast positions. This did not appear to prevent the forecasters from using the information to augment their expertise and produce excellent forecasts of areas under the threat of severe weather.

The important point is that a single glance at system output can be misleading. It is natural that, for a given forecast, the track may be in error, but by repeated viewing one can determine the turning of the storm (from the visible past track) even when the forecast track is in error. The forecast tracks also formed the basis of the Thunderbox (Bally 2001) dissemination system and their reliability was therefore critical to the success of that system.

The forecast speed of cell motion appears to have been very well analyzed by the tracking routines [the Storm Cell Identification and Tracking algorithm (SCIT), TITAN]. An examination of the forecast tracks of the storm centroids as produced by the WDSS and TITAN systems, especially those used and broadcast with Thunderbox, revealed many instances when the projected position of the storm corresponded to observations of storm locations up to 1 h in advance. It must be made clear that the forecasters did not use the tracks in such a deterministic manner. Forecasters have an image of the area that may be affected and issue warnings accordingly. This is shown by the way the warnings issued through Thunderbox used the tracks as a basis around which an envelope, or “threat area,” where severe weather is likely to be experienced, is delineated.

A true measure of the accuracy of the forecast storm tracks (Brown et al. 2001) may not realistically reflect the value of the forecast as an indicator of threat to a given area. An example of this, the threat area delineated by the Thunderbox product at 0303 UTC (Fig. 6), was based upon the TITAN tracks of that time and encompassed Campbelltown. This suggested that the storm would reach that area approximately 60 min hence. The tracks produced 50 min later retained the threat to this town and indicated that the storm would arrive in the following 10 min (Fig. 7). The severity of the storm was conveyed by the storm signatures and attributes provided by the WDSS and CARDS systems. The hail detections of the systems were apparent over Camp-
belltown shortly after 0400 UTC, and reports of large hail arrived just after this time.

d. Hail detection

Figure 6 shows a Thunderbox product with a 60-min forecast track of a cell from 0303 UTC. The delineated threat area just encompassed Campbelltown, suggesting that severe weather would occur there in the subsequent 60 min. Three products showed the presence of severe hail in this cell: CARDS, WDSS, and C-Pol. Both C-Pol and WDSS indicated the presence of hail greater than 2 cm in diameter, while CARDS estimated the maximum hail diameter at over 5 cm. Other evidence of consistency with reflectivity patterns, such as reflectivity cross sections available from CARDS, was presented and this gave further confidence to the forecasters that these hail detections were accurate. Another warning, shown in Fig. 7, with the time stamp 0353 UTC, confirmed this initial warning prior to the onset of severe weather (in the form of large hail and heavy rainfall). Had this product reached the clients at this time it would have given a clear warning that severe weather would impact on Campbelltown in the following 10 min, with the center of the storm passing over approximately 30 min later. The forecasters’ log shows this warning was actually issued at 0400 UTC.

At 0410 UTC C-Pol detected a large area of the convective cell that contained hail in excess of 2-cm diameter over Campbelltown (Fig. 8) and continued this detection for the next 30 min. This was corroborated by the WDSS system, which analyzed hail greater than 2 cm. As confirmation of the three systems’ independent hail detections, observations were reported and included 2–3-cm diameter hail in Campbelltown from 0415 to 0430 UTC, followed by hail reaching sizes between 4 and 5 cm northwest of the town at 0450 UTC. Such prompt confirmation of the FDP systems’ ability to accurately detect severe weather phenomena gave the forecasters great confidence in all the systems’ outputs and allowed rapid assimilation of the information later in the event when time became very limited for decision making.

e. Damaging wind warnings

Figure 9 shows the 0423 UTC TITAN tracks (generated while the storm was still centered over Campbelltown) were used as the basis for a Thunderbox product that was not actually issued until around 0455 UTC, although an official text warning was issued earlier. The delay was due to a detailed discussion among the forecast staff regarding the severity of the warning to be issued, along with a large number of other matters that required urgent attention. These tracks remained the basis for the warning, however, as they were thought to provide a clear indication of the storm’s progress and likely area of influence. At that stage the storm was
propagating quite slowly such that the delineation of the storm area and the forecast track were still valid some time later. Figure 9b shows the radar reflectivity image from which the forecast tracks were generated at this time.

The BoM has an operational arrangement for the specific forecasting and warning of tornadoes, which is to be used only when there is real confidence that a tornado is likely and, in effect, is used when there is knowledge of the existence of a tornado. The BoM forecasters have
a capability to upgrade the wording within warnings to mention destructive, instead of damaging, winds when applicable. A warning of very destructive winds was issued at 0523 UTC along with an additional statement that “this is a particularly dangerous storm.” These warnings are shown in Figs. 10 and 11.

This upgraded warning was partly a result of information coming from the ANC system. FDP experts detected signs of a mesocyclone and possibly a tornado vortex signature (TVS) in ANC fields at 0515 UTC, but the detection was not automatic and confirmed those detections of mesocyclonic vortices found by WDSS and CARDS. The ANC information was not displayed on the FDP products page, but the information was deemed so important that it was conveyed in person to the severe weather forecasting team. The wind warning was, however, not issued specifically on the basis of forecaster belief in the probable development of tornadoes, but due to the high probability that damaging winds would be generated by the storm, either in the form of tornadoes or downbursts. At that time the storm was visible from the BoM office, which is situated on the 16th floor of a building in central Sydney. Forecasters and FDP participants were able to see the wall cloud and dust being blown by a rear-flank downdraft.

At 0525 UTC (at the time the upgraded warning was being issued) both WDSS and CARDS detected signs of mesocyclone development and severe hail. In fact, CARDS reported the largest hail of the day—10 cm in diameter. At this point in the event CARDS and WDSS became the focus of attention. WDSS in particular, with its clear graphics and complementary cell attribute table, allowed a rapid assessment of the severe weather associated with individual storm cells. CARDS had the added advantage of clear thunderstorm tracks and superimposed severe weather detections, but these were in its rear panel.

Spotter reports of rotation and tornadic vortices were logged starting at 0530 UTC, but were related to observations made earlier (Sills et al. 2004). There was a further spotter report of cloud rotation at 0541 UTC. It is difficult to accurately locate these events from the reports, but they do confirm the presence of vortices at the time the systems detected them and after warnings had been issued. Some time before 0600 UTC a corrugated iron roof was peeled off, leading to a flooded building in Greystanes, by what a damage survey team later determined to be a tornado. This tornado was the strongest of the day, peaking at F1 intensity and damaging a number of properties and felling many trees.

Fig. 9. (a) Thunderbox warning issued at 0455 UTC but based on tracks generated at 0423 UTC. This shows a clear threat of severe weather to the western suburbs of Sydney within the next 30 min. (b) Raw radar reflectivity image from C-Pol at 0420 UTC showing storm location and intensity at the time when the product shown in (a) was generated.
At approximately 0515 UTC reports of golf-ball-sized hail at Greystanes were received and it was near this area that the roof of a school building collapsed under the weight of accumulated hail. Nearby, another school-block roof was lost to strong winds at approximately the same time. The damage survey suggested that, although this was close to the tornado tracks, it was not actually within them and the pattern of the damage suggested that it was most likely caused by straight-line winds. Similar damage was caused by both nontornadic and tornadic winds and, although tornadoes were present, it is debatable whether the inclusion of a specific tornado warning would have been of additional benefit to the “very destructive wind” warning.

At 0601 UTC the severe thunderstorm warning was reissued, continuing the very destructive winds advisory for a further hour (Fig. 11). This warning and the previous 0523 UTC warning actually postdated most of the damaging severe winds. However, a timely hindcast was of great use to the SES, which are required to attend to and aid areas that have suffered damage as swiftly as possible.

5. Discussion

Although there will be a full examination of the accuracy of nowcast products generated throughout the FDP (Brown et al. 2001), the evidence from this particular day suggests that the forecasters adapted to the new technologies, which were of great benefit. A further study looked at the impact of the FDP products on the operational forecasts and warning dissemination, as well as the forecasters’ experience of using the products (Anderson-Berry et al. 2004). The initial study of this single case has raised a number of issues with regard to the display of radar-based products and the training and support required prior to and during implementation of novel systems.

The provision of severe storm signatures was one of the greatest successes of the day. The CARDS empirical algorithm was an excellent indicator of the presence of large and giant hail, and frequently agreed with WDSS and C-Pol, which had a similar capability to estimate maximum hail size. The agreement was consistent over time and increased the forecasters’ confidence in all WWRP products, thus benefiting both forecasters and WWRP personnel. Hail detection was a particular success and also served as valuable notification of the potential for other severe weather. Throughout the day spotter reports arrived confirming the accuracy of the detections and increased the forecasters’ willingness to use, and their confidence in, the full range of WWRP products.

The recognition of mesocyclone signatures by CARDS and WDSS was also very beneficial. This alerted the forecasters to the presence of strong rotation within the storm, which prompted the issuing of warnings for severe and damaging winds prior to the reporting of the tornadoes and severe gusts.

When forecasting severe thunderstorms, there are a vast number of scenarios the forecaster has to consider—not the least of which is dealing with the potential that a relatively small-scale feature may make the difference between a “normal” thunderstorm and well-
organized convection. The third of November saw forecasters updating their policy as more and more information became available. The WWRP systems used on the day gave forecasters information on potential severity and movement of cells. Interaction between FDP groups and operational forecasters occurred from very early in the event when storms were first developing and continued throughout the afternoon. One of the key points to note regarding such systems is that they are not intended to replace forecasters, but to reduce the risk of forecasters missing vital information. They increase the amount of time a forecaster has available for assessing the thunderstorms, facilitating the identification of those storms that have the greatest potential for severe weather.

The time stamps of the warnings issued through the experimental Thunderbox graphical warning system were later than the valid times of the cell tracks upon which they were based. This was inevitable, but in some cases the time difference was considerable. This suggests that warnings could have been issued somewhat earlier than they were, although there were other factors to consider. Primary among these was the extensive workload of the forecasters during such a severe event. Although these factors played a part and explain some of the delay, there remained the opportunity to deliver (and update) useful graphical warnings in an even more timely fashion. It must be stressed, however, that the issuing of these experimental warnings was a lower priority than the official text warnings that were disseminated in a very timely fashion and benefited from the added information of the FDP products.

There was a considerable amount of information available that was either not fully exploited, not communicated, or not treated with adequate confidence. However, as this was the first severe event that took place with the systems present, their usage and impact was exceptionally beneficial.

Individual system developers were responsible for the basic appearance of their products on the project Web page. These products were placed against a standard background and incorporated into the Web interface. There were, therefore, variations in the manner in which information was presented to the forecasters. Some of this variation was natural given the different types of products generated by the systems, but much was a result of discrepancies between the resources available to differing groups involved in the project.

The two areas of difference were in the utility of the front- and rear-panel displays. There was a stark contrast between front-panel images of forecast cell tracks (e.g., WDSS, TITAN) and images that were, in effect, simply a rendering of the current radar image. When a rear panel was accessed, it replaced half of the 12-panel display, causing other information (useful for comparison) to be hidden. Therefore, one could not maintain rear-panel products on view for any period.

When analyzing the forecasters’ usage of products, it is difficult to unravel the effect of product quality from that of the product display. This is especially the case during a high-impact event, such as that of 3 November 2000, when forecasters’ time is at a premium. Similarly, those systems whose front page carried no useful information (other than a reproduction of current radar, e.g., Gandolf, S-PROG) were looked at less. The use of these systems’ “hidden products” required the investment of time by the forecaster, who had no indication that there was a potential reward in the exercise in the form of added information regarding storm character or future behavior.

On the other side of the coin were the WDSS cell tracks and table. This provided an instant heads-up regarding the relative importance of the convective cells, their current attributes, and possible future positions.

Two further examples of displays were the ANC and CARDS systems, which fell somewhere between WDSS and Gandolf in their ease of utility and interpretation. The ANC front page contained a great deal of useful information, including convergence line positions, forecast positions of storms and convergence lines, and wind fields. Although this information was displayed, it required interpretation and needed some study; this became awkward in situations where time was limited. The CARDS severe storm signature product was combined with TITAN 35-dBZ tracks. At times this threshold proved too low, resulting in a crowded and confusing display when a large number of separate cells were identified (especially during widespread rainfall). This led to the decision to move this product to the back page and replace it with a meteogram-style image produced by the CARDS system. The original display had a great deal to offer, was presented simply, and was similar to the WDSS product. This would have allowed comparison between the two systems and possible reconfiguration of nowcasts, whereas the replacement provided little useful information during a severe storm event. Despite being a rear panel, the CARDS/TITAN product was a single click away, was a clear image and so was used. This problem may have been solved by incorporating an adaptive reflectivity threshold into the TITAN tracking display or increasing the threshold (to 40 dBZ) and putting the product in the front-panel display.

Overall there was too much displayed and the systems were separated from the forecasters’ primary nowcast tools. In order for the products to be used effectively it is necessary to integrate the systems both to reduce the complexity of the display and to incorporate the useful features into the forecasters’ workbench. Some aspects of this integration have already been demonstrated in trials of a combined Auto-nowcaster–WDSS system (Roberts et al. 2001) and Met Office development of a single precipitation nowcasting system that uses features of both Nimrod and Gandolf.

Another lesson learned was that there was no simple way of verifying the accuracy of some of the products: suspicion was automatically cast on detections of me-
socyclones and TVS signatures, for example. Although one would expect confidence in those systems to improve with use, one could also design a system that automatically provides a window that displays 3D radar information for the vicinity of the signature. This would enable forecasters to investigate the structure of the storm producing the severe weather signal. CARDS provided a separate system that was used at times by the forecasters. This allowed reflectivity cross sections to be observed through any part of any convective cell through the construction of synthetic range-height indicators (RHIs), allowing structures such as BWERs and elevated hail cores to be observed. However, this Web-based tool was not integrated into the main forecast or FDP system, instead having to be called up separately; thus, another level of complexity was added to the desktop display.

All this suggests that, in the future, intelligent selection of the systems whose products are displayed during particular events is required. The redundancy of systems designed for the nowcasting of stratiform precipitation during severe convective weather, and vice versa, needs to be reflected in a total system that “hides” products at appropriate times. This would allow forecasters to focus more on the products relevant to a given situation. This implies that the system be designed to conduct the advisory role carried out by the “champion” during the FDP. Yet there is a need to go even further than this. Certain products can be removed (not produced) or made inaccessible when the atmospheric conditions do not warrant their use. For example, Gandolf contains a neural network cloud classifier that uses satellite imagery to determine the nature of a precipitation system and “decide” whether or not to run its object-oriented model of convective storms (Pankiewicz 1997).

6. Conclusions

It was clear that the advanced nowcast systems available during this event were of benefit to the severe weather forecasting team. In particular, certain aspects of the storm, including its initial development, the presence of severe hail, and the likelihood of destructive winds, were indicated clearly and in a more timely fashion. This allowed the forecasters to issue warnings of severe hail and “very damaging winds” earlier than they may have done in the absence of the systems. It is hard to gauge the real benefit of even a few minutes of additional warning time on these hazards.

The most notable advantage offered by the WWRP systems was that the forecasters were able to more efficiently focus upon areas of the storm that were of most concern (using the tools that they were most familiar with, such as 3D-Rapic). Coupled to this was the added confidence given by the systems that forecasters were correct in their analyses. This contributed to the improved warning dissemination.

On the downside the quantity of information was immense and, given the constraints of time under which forecasters work during severe weather events, much was overlooked. The presence of the “champion” lessened the neglect of vital information, but in a standard forecasting office such an individual would not be on hand. It is therefore crucial that, prior to the installation and reliance upon such systems, severe weather forecasters undergo complete training and familiarization with the system.

As previously mentioned, each of the systems had its benefits. However, it would not be practical to install all of them in a forecast office. The ideal solution would be the combination of the most valuable elements of each of the systems in a single package. This does not appear feasible at present, since each of the systems works on a different principle. An alternative would be to run all the systems simultaneously along with an algorithm that automatically decides, given the meteorological situation and the products being generated, what to present to the forecasters. This possibility is also problematic, as the running of all systems would be very costly and would involve considerable computing facilities, as well as technical support.

For the moment, it is suggested that regions that could benefit from improved nowcasting of severe weather should examine the technology currently available (and being continuously developed) with a view to what is of most potential benefit in that region. Such a decision would depend upon local climatology, the instruments and data available, as well as benefits to be gained versus cost.

The displays of the different systems vary in their state of operational development and functionality. Those with clearer graphics and simpler presentation were more beneficial to the forecasters during the case study examined here. Within the time constraints of a severe weather event, product presentation is critical.

In severe weather situations, forecasters may not have the time to examine all the systems simultaneously. The displays of the different systems vary in their state of operational development and functionality. Those with clearer graphics and simpler presentation were more beneficial to the forecasters during the case study examined here. Within the time constraints of a severe weather event, product presentation is critical.

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