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THE SEVERE THUNDERSTORM FORECAST AND WARNING PROCESS IN AUSTRALIA

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1. INTRODUCTION

The purpose of this paper is to give an overview of the thunderstorm forecast and warning methodology employed by the Bureau of Meteorology (hereafter "The Bureau") in Australia. Before launching into some more detail regarding the current Australian thunderstorm services, a quick description of the available infrastructure is in order.

Fig. 1: Australian forecast offices including the associated states that mark the area of responsibility for that office. Melbourne is the location of the Bureau's Head Office which is co-located with the Victorian RFC.

Most of the Australian weather forecasts and warnings are disseminated from one of the seven "Regional Forecast Centres" (RFCs) which are located in the capital city of each state (Fig. 1). Each of these offices is responsible for almost all the weather forecasts and warnings that affect the corresponding state. In particular, there are no centralized agencies that deal with severe thunderstorms or tropical cyclones such as the Storm Prediction Center (SPC) or the National Hurricane Center (NHC) in the U.S. Instead, the RFCs deal with these threats on a state-by-state basis.

There is some variations in how individual offices deal with severe thunderstorms. In terms of forecasts, some states simply mention thunderstorms as part of their public weather forecasts, while others have graphical thunderstorm forecasts for days 1 and 2. Likewise for severe thunderstorm warnings, products range from text-based areal to graphical cell-based warnings.
In this paper we will focus on the New South Wales (NSW) thunderstorm forecast and warning process as an example of the most advanced graphical thunderstorm service in Australia. In NSW the thunderstorm forecast and warning process is divided into three stages: thunderstorm forecasts out to two days, a state severe thunderstorm warning and Sydney Metropolitan warnings, a cell-based warning service for the densely populated area around Sydney. This paper will step through this three-stage process next.

2. THUNDERSTORM FORECASTS

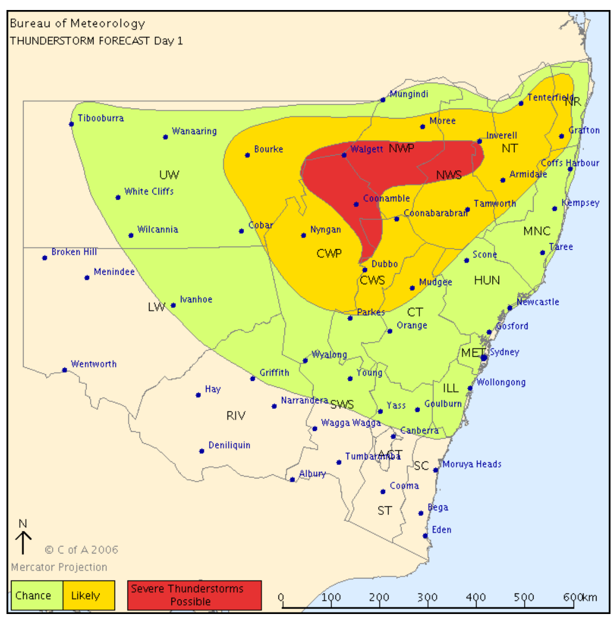

Fig. 2: Example of the graphical component of a NSW thunderstorm forecast for day 1.

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Figure 2 shows an example the graphical part of a NSW thunderstorm forecast for day 1 which has some similarities with the SPC's convective outlook for day 1. The graphical part is usually accompanied by a brief discussion of the meteorological reasoning behind the image (not shown).

Each morning a forecaster performs an analysis to identify environments that could potentially support convection or severe convection. Apart from the standard observations used to assess the instantaneous storm environment in the morning (e.g., soundings, surface observations, satellite imagery etc.) a popular predictive tool is the National Thunderstorm Forecast Guidance System (NTFGS; Hanstrum 2004; see Fig. 3 for a sample).

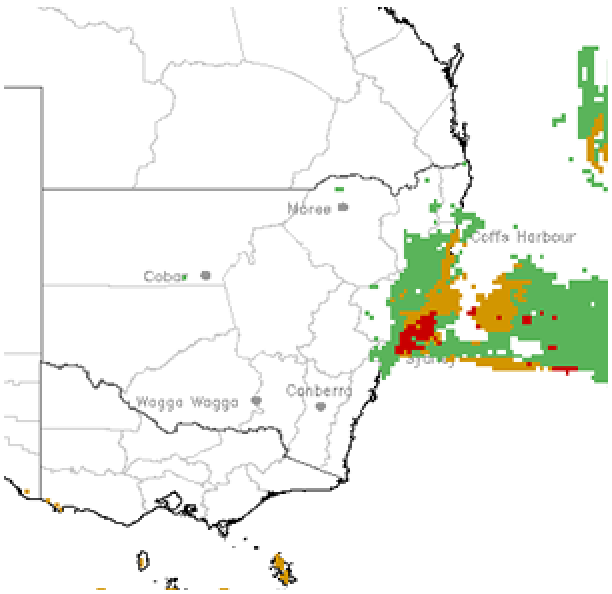


Fig. 3: NTFGS output (zoomed into NSW) summarizing the Meso-LAPS model-based diagnosis for surface-based thunderstorms (green), severe convective weather (large hail, damaging winds, tornadoes…; orange) and supercells (red) over a 24 h period (15z to 15z) based on the preceeding 12z model run.

The NTFGS is based on twice-daily runs of the 0.125^{o} Meso-LAPS model, Australia's mesoscale numerical weather prediction model (Puri et al. 1998). The NTFGS ingests raw Meso-LAPS model output. It then uses fixed on/off-type thresholds to diagnose environments favourable to a range of convective phenomena. The phenomena diagnosed include surface-based thunderstorms, elevated thunderstorms, supercells, large hail, damaging/destructive winds, tornadoes and microbursts, to name a few. For example, the NTFGS criteria for supercell thunderstorm environments are LI(500) <= -4^{o}C (warm season) or LI(700) <= -2^{o}C (cool season), EL <= -20^{o}C, maximum upmotion in the layer 0.9988 <= σ <= 0.85 is >= 10 hPa/h, CIN <= 25 J/kg, cold cloud depth >= 3 km and maximum vertical shear in the layer (0.9875 = σ and z <= 1.5-3.0 km; cool season) or the layer (0.9875 = σ and z <= 2.5-4.0 km; warm season) exceeds 30 knots. Here, σ marks the vertical sigma coordinate of the Meso-LAPS model, and the "warm season" is simply defined as T(850) >= 12^{o}C. EL stands for the temperature at equilibrium level for a surface parcel mixed through the lowest 50 hPa.

The forecaster can assess how Meso-LAPS arrived at its assessment through a tailored model viewer known as the web-based "Mesoviewer" (see Fig. 4 for the control interface).

Fig. 4: Web-based control interface for the Mesoviewer which allows a field by field overlay (see Fig. 5).

To assess on what basis the NTFGS painted red (supercell) pixels on the central NSW coast in Fig. 3, a forecaster would interrogate the underlying model output fields. The fields relevant to the NTFGS warm season supercell decision (listed above) can then be selected as "LI-500", "Shr-620", "EL", "Omega-850", "CIN" and "Cold-Cld" in the Mesoviewer (Fig. 4). An example of this ingredients-based model field overlay is shown in Fig. 5 which shows higher deep-layer shear values in the southern part of NSW while the instability is maximized along the NSW central coast where a surface frontal zone extended ESE away from the coastline. Under the assumption that the model-based deep layer shear values are credible, a forecaster is then able to use updated surface moisture information to modify the NTFGS supercell threat assessment of Fig. 5, for example.

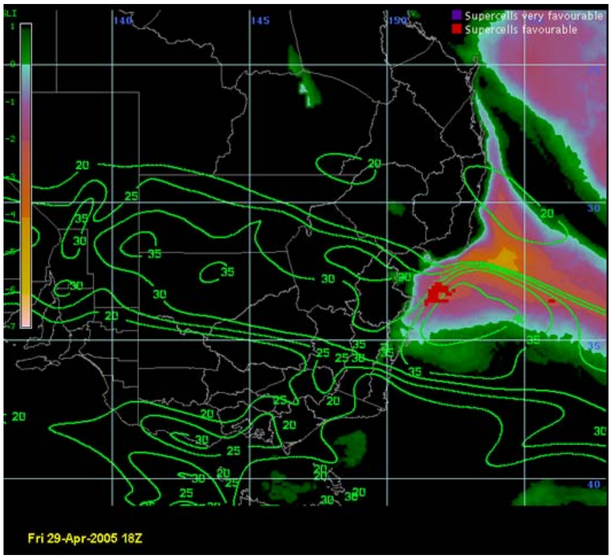


Fig. 5: Overlay of NTFGS-diagnosed supercell potential (red pixels) and two of the NTFGS warm season supercell ingredients, LI(500) (shaded) and surface-620 hPa bulk shear (green contours). The overlay represents the 3h time period 18-21z/20050429.

Once the forecaster has arrived at an opinion on where thunderstorms and severe thunderstorms are likely to occur within the state, the graphical forecast shown in Fig. 2 is crafted within the Thunderstorm Interactive Forecast Preparation System (TIFS; Bally 2004) and some meteorological reasoning for the graphics is added manually.

At present, the graphical thunderstorm forecast is only sent to emergency services, but its contents are reflected in text-based public forecasts. Graphical and text severe thunderstorm warnings are available to the public in NSW via the external web, for example.

3. STATE WARNINGS FOR SEVERE THUNDERSTORMS

Australia does not have county by county severe thunderstorm warnings given that (i) most inland areas of the Australian continent are largely uninhabited, (ii) there are large gaps in the radar coverage across the continent and (iii) current staffing levels in the seven RFCs would not allow such a labor-intensive warning service. Instead, a more generic state thunderstorm warning service exists for locations outside the metropolitan areas. Let's assume that the morning convective analysis is pointing towards the potential for severe thunderstorms for part of the state. A state warning is then likely to be issued once there is evidence of deep convection in that environment on radar, satellite and/or lightning imagery. A sample NSW state warning (graphical part only) is shown in Figure 6.

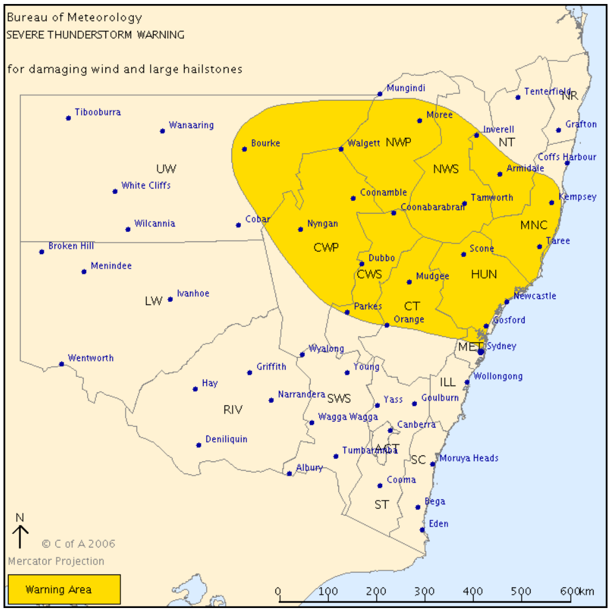


Fig. 6: Sample of the graphical part of a NSW state warning for severe thunderstorms which identifies damaging winds and large hail as the primary severe convective phenomena.

The validity period of a state severe thunderstorm warning is usually 3 hours. The basis for issuing state warnings is the onset of deep moist convection within an area diagnosed to have the potential for severe thunderstorms. Convective initiation is assessed through radar (where available) or from hourly satellite imagery and telephone reports from storm spotters. In this sense the Australian state severe thunderstorm warning resembles a blend between the SPC's severe thunderstorm watch and a radar-based warning for actual cells.

Just like the thunderstorm forecast, the state warning is also issued through TIFS which, this time, employs an automatic text generator to create an associated text warning (not shown). The text warning mentions the specific severe phenomena chosen by the forecaster with associated stabndard action statements and lists names of affected towns.

4. METRO WARNINGS FOR SEVERE THUNDERSTORMS

The generally high population density around the capital cities of each state (e.g., Sydney as the capital city of NSW) has led to the development of a higher-level cell-based severe thunderstorm warning. These cell-based warnings are referred to as Metropolitan or Metro Warnings. They are issued only for those severe thunderstorms that are likely to affect a "Metro Warning Area", a mesoscale-sized region extending around a capital city (see Fig. 7 for the Sydney Metro Warning Area).

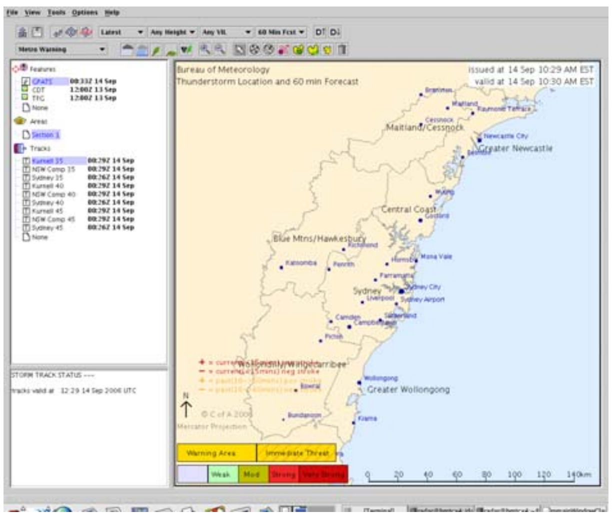


Fig. 7: The Greater Sydney Metropolitan Area (as part of the TIFS graphical metro warning interface). Within this area, cell-based metro warnings for severe thunderstorms are issued by the NSW RFC.

Unlike in the state warning scenario, now potentially severe storms that are likely to affect the Metro warning area are scrutinized by the warning forecaster for radar-based severity indicators such as those listed in Table 1 (Appendix A). Forecasters view the three-dimensional radar data using 3D-Rapic (May et al., 2004), a Linux OpenGL display system written in C++. Fig. 8 shows a sample 3D-Rapic image.

Apart from the forecaster's ability to detect radar-based indicators that are probabilistically associated with storm severity, a major challenge is to assess the significance of that indicator. In particular, radar velocity-based indicators are still an unfamiliar sight to most Australian forecasters given radar velocities are a relatively recent (a few years or less; since 1999 in Sydney) addition to operationally available observational datasets in most Australian forecast offices.

Intended as examples, there are a couple of tools in operational usage that serve as a quantitative guide to assess the significance of the 50 dBZ echo top height and midlevel rotational signature, respectively. The first tool is based on a hail climatology for the Sydney region where hail size reports are plotted against the corresponding 50 dBZ echo top heights as seen by the 2^{o} beam width Sydney S-band radar as well as the freezing level height from the Sydney airport (proximity) sounding (Fig. 9; Treloar 1998).

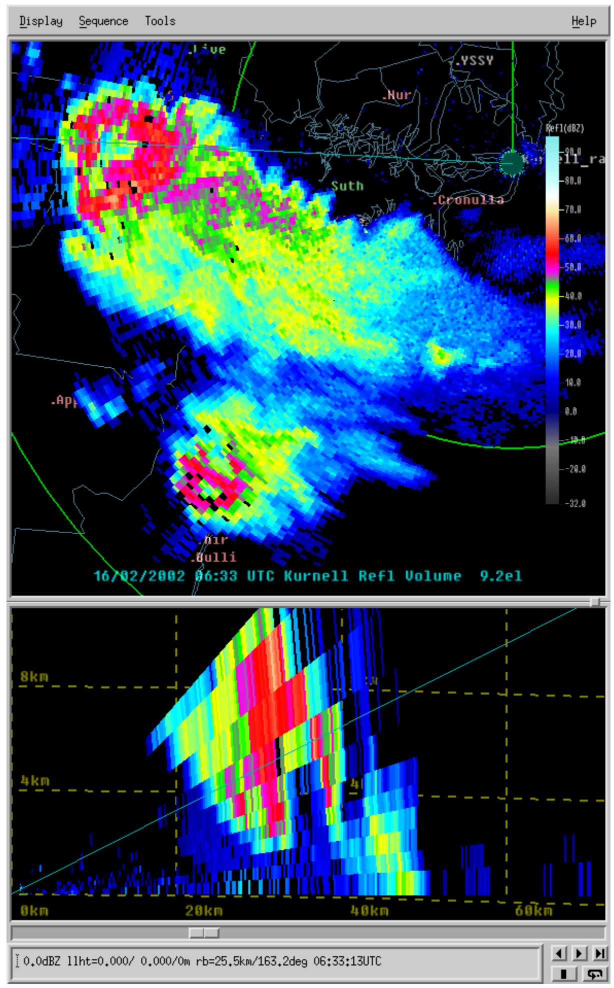


Fig. 8: 3D-Rapic PPI/RHI split image of a splitting supercell featuring a dominant left-mover. Both storms possess Bounded Weak Echo Regions (BWERs).

The resultant hail nomogram in Fig. 9 has found some acceptance in the Australian operational community. It is frequently used to configure a Constant Altitude PPI (CAPPI) display window which serves as a filtering tool separating "tall" from "not-so-tall" 50 dBZ cores. An alternative automated hail size assessment tool is the

Warning Decision Support System (WDSS) Hail Detection Algorithm (Witt et al. 1998).

A second tool aiding the forecaster in judging the significance of a rotational signature is the mesocyclone nomogram in Fig. 10 (NOAA 1995).

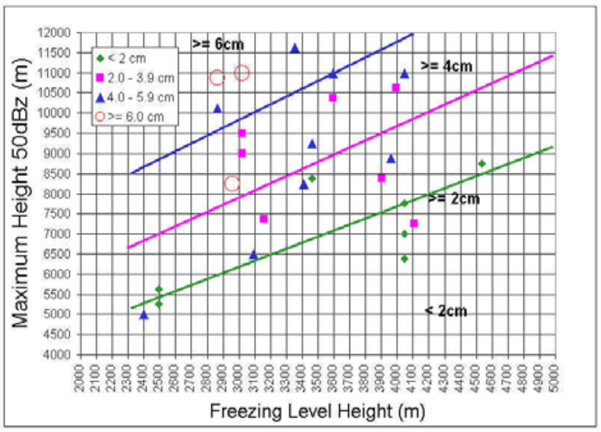


Fig. 9: The "50 dBZ hail nomogram" based on a local hail climatology for the Sydney area, freezing levels from the Sydney airport sounding and reflectivities from the S-band Sydney radar. The sloping straight lines are a subjective fit through the data with the intent of identifying an approximate 50 dBZ height threshold beyond which hail sizes greater than 2/4/6 cm are a significant warning consideration.

Given a continually supportive storm environment for severe convection, once a storm in or near the Metro Warning Area has been assessed as severe or is expected to be severe on the next scan, a metropolitan severe thunderstorm warning is

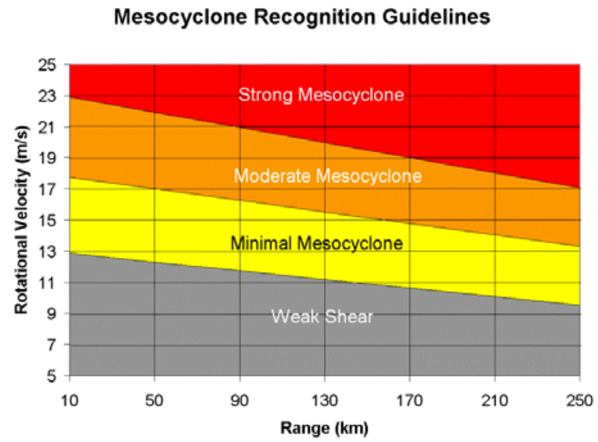
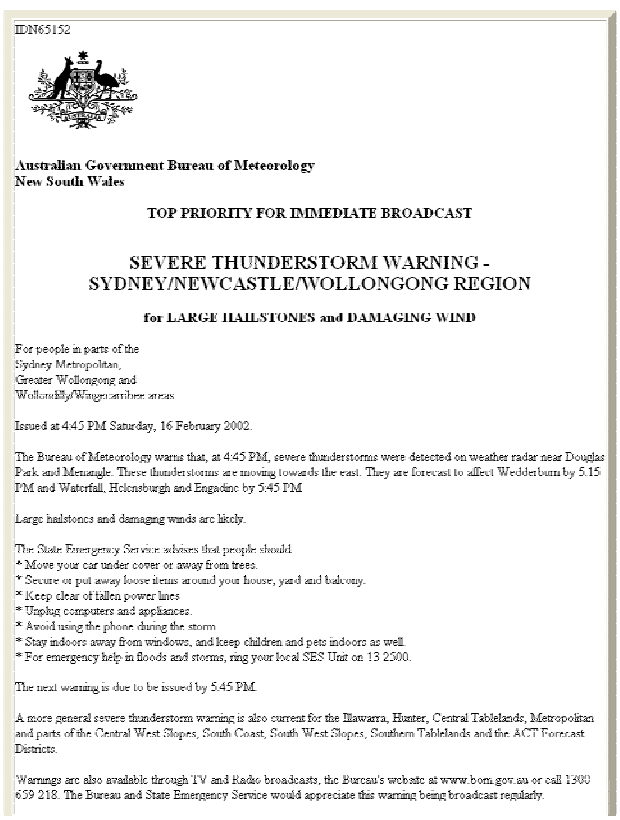


Fig. 10: Mesocyclone nomogram relating the strength of a rotational signature to the range from the radar.

issued using TIFS (Fig. 11). Explicit Tornado Warnings have not been issued by Australian RFCs, primarily due to the lack of velocity data of sufficient quality and an absence of realtime spotter reports. On rare occasions, tornadoes have been added as a severe convective phenomenon to a Severe Thunderstorm Warning if strong realtime evidence of a tornado (e.g., a credible realtime spotter report) was available.



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Australian Government Bureau of Meteorology
New South Wales

TOP PRIORITY FOR IMMEDIATE BROADCAST

SEVERE THUNDERSTORM WARNING - SYDNEY/NEWCASTLE/WOLLONGONG REGION

for LARGE HAILSTONES and DAMAGING WIND

For people in parts of the
Sydney Metropolitan,
Greater Wollongong and
Wollondilly/Wingecarribee areas.

Issued at 4:45 PM Saturday, 16 February 2002.

The Bureau of Meteorology warns that, at 4:45 PM, severe thunderstorms were detected on weather radar near Douglas Park and Menangle. These thunderstorms are moving towards the east. They are forecast to affect Wedderburn by 5:15 PM and Waterfall, Helensburgh and Engadine by 5:45 PM .

Large hailstones and damaging winds are likely.

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

The next warning is due to be issued by 5:45 PM.

A more general severe thunderstorm warning is also current for the Illawarra, Hunter, Central Tablelands, Metropolitan and parts of the Central West Slopes, South Coast, South West Slopes, Southern Tablelands and the ACT Forecast Districts.

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

Fig. 11: Sample of a NSW Metropolitan severe thunderstorm warning. The right panel shows the cell-based graphical part of the warning, identifying cell position and motion (in ten minute increments). The cell is surrounded by an immediate threat area (hashed) and a broad-scale shaded background which denotes the area where a state warning for severe thunderstorms is active. The text part of the Metro warning (left panel) is largely automatically generated, but allows for forecaster editing to convey the warning intent more accurately.

The individual storm cells in the graphical part of the Metro warning are either cells ingested into TIFS from the Thunderstorm Identification, Tracking, Analysis and Nowcasting (TITAN) algorithm (Dixon and Wiener 1993), or they are cells inserted manually by the warning forecaster. Automatically ingested cells and their associated cell motion vector in TIFS are generally modified by the forecaster. The text in Fig. 10 is automatically generated from the graphics and presented to the forecaster for review and, if necessary, minor editing before the warning is issued.

5. REFERENCES

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Appendix A

	Duration			Strength			Depth (vert.)			Size (horiz.)			Comments
	Brief	Mod	Long	Weak	Mod	Strong	Shallow	Mod	deep	Small	Med.	Large	
BREF Signature													
50 dBZ echo top height													
Echo top displacement													
WER													
BWER													
Tight low-level BREF gradient on inflow side													
Hook echo or/pendant on rear flank													
Single echo top													
Forward flank notch													
Max(dBZ) values													
Bowing segments (low levels)													
BVEL Signature													
Storm summit divergence													
Low-level convergence below the updraft													
Mid-level rotation													
Low-level rotation													
Low-level divergence													
Strong near-surface ground-relative winds													
Strong rear inflow jet													

Table 1: Conceptual checklist listing radar-based signatures that are useful in diagnosing storm severity. Beyond the mere identification of such signatures, warning forecasters are expected to make an assessment of the significance of that signature to arrive at a more informed warning decision.