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THE FOUR LARGE HAIL ASSESSMENT TECHNIQUES IN SEVERE THUNDERSTORM WARNING OPERATIONS IN AUSTRALIA

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1. INTRODUCTION

In Australia, severe thunderstorms are defined by the occurrence of one or more of the following four phenomena: 1. hail greater than 2 cm in diameter, 2. wind gusts in excess of 48 knots, 3. tornadoes and 4. heavy rainfall conducive to flash flooding. This paper will focus on the severe hail criterion and the associated demand on warning forecasters to diagnose whether a given thunderstorm is likely to produce hail in excess of 2 cm in diameter.

Conventional radar base reflectivity and base velocity signatures do generally not correspond well with the occurrence of large hail, especially near the 2 cm hail size severity threshold. The Australian Bureau of Meteorology (ABoM) has therefore adopted a "preponderance of evidence" approach based on four hail recognition techniques: 1. the hail nomogram, 2. the three-body scatter spike (TBSS) from an S-band radar, 3. storm structure and 4. the Warning Decision Support System (WDSS) hail detection algorithm (HDA). Especially in marginal hail cases, all four techniques should be employed by the forecaster and the resulting evidence weighed up in favor of a warn/no-warn decision (based on hail only).

The formation of large hail is underpinned by complex microphysical and storm-scale processes. In an operational setting, all individual hail assessment techniques are linked to a simplified conceptual understanding of the qualitative ingredients contributing to the growth of hail to large sizes. The occurrence of large hailstones at ground level requires long residence times of the initial hail embryos in regions of high supercooled liquid water content followed by minimal melting on the way to the ground. This conceptual idea can be expanded upon by introducing a hail growth layer between -10°C and -30°C in which the primary hail growth occurs, and by associating the melting potential with the height of some downdraft-representing freezing level. We will refer some of the hail diagnosis techniques to follow back to the conceptual underpinnings we just outlined.

In sections 2-5 this paper will step through brief descriptions of the four individual hail assessment techniques.

2. HAIL NOMOGRAM

The first severe hail assessment tool in Australia is based on a hail climatology for the Sydney region where hail size reports are plotted as a function of two parameters: the corresponding 50 dBZ echo top heights as seen by the 2° beam width Sydney S-band radar and the corresponding freezing level height from the Sydney airport (proximity) sounding (Fig. 1; Treloar 1998).

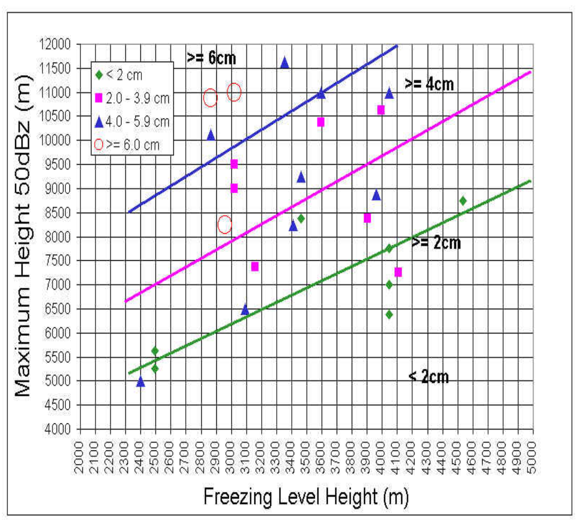

Fig. 1: The "50 dBZ hail nomogram" based on a local hail climatology for the Sydney area, freezing levels from the Sydney airport sounding and reflectivities from the S-band Sydney radar. The sloping straight lines are a subjective fit through the data with the intent of identifying an approximate 50 dBZ height threshold beyond which hail sizes greater than 2/4/6 cm are a significant warning consideration.

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The resultant hail nomogram in Fig. 1 has found wide 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 when viewing volumetric radar data. Although the nomogram technique is based on a climatological rather than conceptual approach, it turns out that CAPPI levels set according to the threshold lines in Fig. 1 are generally close to the -20^{o}C level and therefore incidentally display base reflectivities in the center of the hail growth layer.

3. TBSS

For S-band radars studies by Zrnić (1987), Wilson and Reum (1988) and Lemon (1998) have identified a close connection between a radar signature known as the three-body scatter spike (TBSS) and a hail core containing severe hail.

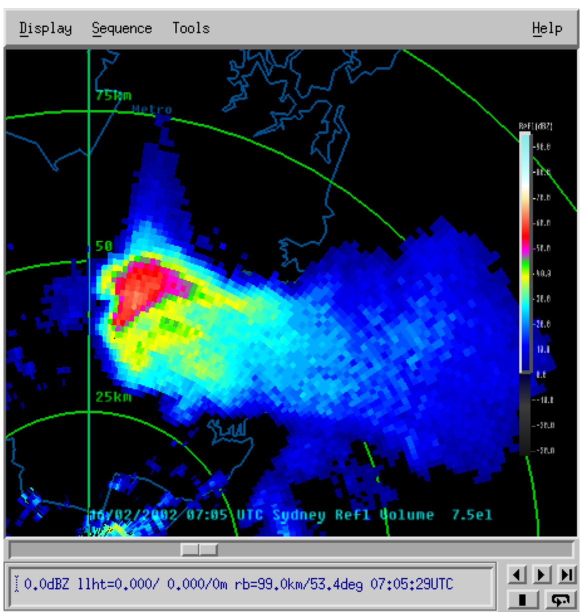

Fig. 2: A TBSS associated with a left-moving supercell over Sydney during 16 February 2002 (around 0705 UTC) as seen from the S-band Sydney radar.

Also known as a “hail flare” or “flare echo,” the TBSS is a 10-30 km long low reflectivity (< 20 dBZ) mid-level echo “spike” aligned radially downrange from a high reflectivity (usually 63 dBZ+) core (Fig. 2). During its generation, the radar beam strikes an intense hail core and energy is scattered forward towards the ground in a Mie scattering regime. Some of that energy is then scattered back from the often wet ground to the same hail core where it is forward-scattered back to radar antenna.

On C-band radars the TBSS can be related to large raindrops rather than hail, so the TBSS application in large hail diagnosis is confined to S-band weather radars only. The TBSS is a sufficient (but *not* a necessary) condition for large hail detection. Surface hail of at least 2.5 cm in diameter should be expected when a TBSS is observed on an S-band radar, often with a warning lead time (for the largest surface hail) of 10-30 minutes (Lemon 1998 and personal communication).

4. STORM STRUCTURE

The least specific but also most comprehensive interrogation technique for diagnosing large hail in radar data is to use storm structural elements as a proxy for a storm’s capacity to support the growth of large hail.

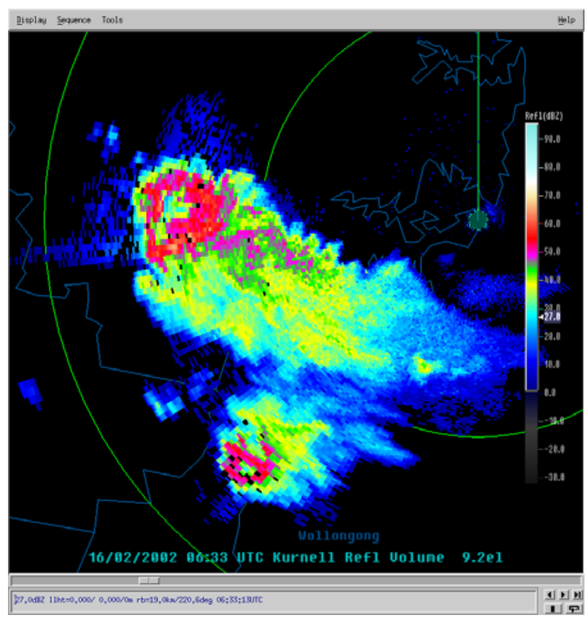

Fig. 3: A pair of left- and right-moving supercells over Sydney on 16 February 2002 shortly after the preceeding split. Both storms feature a long-lived, deep and sizeable BWER.

A trivial example of how storm structural elements feed into a severe thunderstorm warning decision based on hail is depicted in Fig.3. A split pair of left- and right-moving supercells exhibited a long-lived, deep and large bounded weak echo region (BWER) suggesting a high probability of consistently rotating updrafts which in turn serves as a good proxy for prolonged residence times of hail embryos in regions of high supercooled liquid water content aloft and thus increased large hail potential with both storms.

Additional "severe indicators" could be tested for (Table 1) to collect further evidence that the storm is severe, such as a sizeable echo top displacement or persistent mid-level rotation. While the interrogation of these storm severity indicators might only support a foregone warning conclusion in the example of Fig. 3, in more marginal situations it might sometimes be necessary to test for a large range of indicators before the balance of evidence tips one way or the other.

	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.

5. WDSS HDA

The most convenient way of receiving hail size information is the utilization of radar-based hail size algorithms such as the Hail Detection Algorithm (HDA) within the Warning Decision Support System (WDSS) as described by Witt et al. (1998). The resulting output on the radar display directly yields an estimate of the algorithm-estimated hail size given an earlier input of the height of the freezing and the -20^{o}C levels (Fig. 4).

Qualitatively, the determination of large hail ties in closely with the generic conceptual model for hail growth outlined in the first section of this paper. Fig. 5 shows that the HDA, in its determination of the Maximum Expected Hail Size (MEHS), gives full weights to strong radar reflectivity returns that are situated in and above the hail growth layer (around -20^{o}C and above). The MEHS ignores cores of any size and intensity below the freezing level, a property that distinguishes itself from any VIL-based approach to hail size determination (Edwards and Thompson 1998).

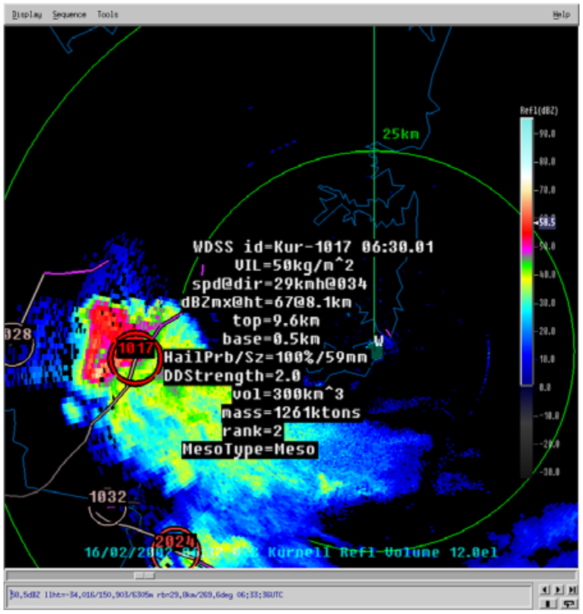

Fig. 4: Example of the WDSS overlay on base reflectivity data including a list of cell properties as determined by a variety of algorithms within the Warning Decision Support System (WDSS). Note the explicit listing of a 59 mm MEHS as determined by the Hail Detection Algorithm (HDA).

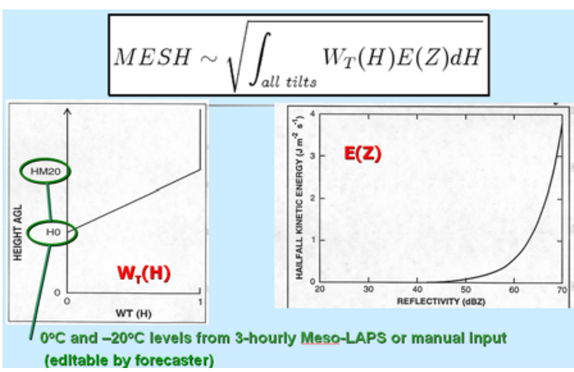

Fig.5: Determination of the Maximum Expected Hail Size (MEHS) within the Hail Detection Algorithm (HDA).

6. SUMMARY

This paper outlined the four primarily radar-based hail size interrogation techniques currently employed by severe thunderstorm warning forecasters at the Australian Bureau of Meteorology. The four techniques, 1. the hail nomogram, 2. the three-body scatter spike (TBSS) from an S-band radar, 3. storm structure and 4. the warning decision support system (WDSS) hail detection algorithm (HDA) are meant to be used in a "preponderance of evidence" approach. Warning decisions that incorporate the threat of severe hail should not be made on the basis of one technique alone unless the storm is very clearly non-severe or very clearly severe. In all marginal situations, in Australia these would include the majority of severe thunderstorm warning decisions, enough warning decision evidence should be collected so that the balance of evidence clearly favors one decision, to warn or not to warn.

Near storm environmental (NSE) considerations naturally feed into the warning decision process through expectations regarding the temporal evolution of severity indicators outlined in Table 1. NSE assessments therefore may strongly modulate the outcome from the radar-based preponderance of evidence approach proposed in this paper. For example, if it becomes clear that the left-moving supercell in Fig. 4 is about to ingest persistently very cold and dry inflow, it can be expected that even this presently potent storm will not require a severe thunderstorm warning for much longer.

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