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ON THE NATURE OF THE WSR-88D BUILD 9 HAIL DETECTION ALGORITHM

PART I: REVIEW OF THE ALGORITHM AND OPERATIONAL CONSIDERATIONS

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Introduction

Estimating the probability and size of hail from a particular thunderstorm is complicated by several factors. The morphology of the storm, the sub-cloud atmospheric conditions, and uncertainties in the nature of the radar-observed hydrometeors can all affect the determination of the size of hail which eventually falls to the surface. The difficulty in estimating hailfall from thunderstorms is further complicated by the spatially erratic and temporally brief nature of many hail storms, which makes verifying such events problematic at best.

The WSR-88D Build 9 hail detection algorithm (HDA) was implemented to help radar operators determine the severity of hail within thunderstorms. Three products are produced by the algorithm: the probability of hail of any size (POH), probability of severe hail (POSH), and maximum expected hail size (MEHS). The purpose of this Technical Attachment (Part I) is to investigate the nature and sensitivities of the HDA in an operational setting. Part II describes the performance of the HDA in the western U.S.

Description of the WSR-88D Build 9 Hail Detection Algorithm (HDA)

The WSR-88D Build 9 HDA (also referred to as the Hail Core Aloft Algorithm - HCAA) was added to the suite of 88D generated products as replacement for the existing hail algorithm. The HDA provides estimates of the probability of any sized hail (POH), the probability of severe hail (≥3/4"; POSH), and the maximum expected hail size (MEHS) for each identified storm cell. The algorithm is based primarily on empirical studies, but is grounded in the mechanics of hail formation. That is, regions of high reflectivity at high altitudes (well above the freezing level), are most likely to produce hail. The freezing (and -20C) levels are parameters which are entered at the WSR-88D Unit Control Position.

a) The Probability of Hail (POH)

To determine the POH of any size in a particular storm cell, the top of 45 dBZ echo is compared to the freezing level. The greater the distance between the height of 45 dBZ echo top and the height of the freezing level, the greater the POH. Figure 1 demonstrates the relationship between these two values, and the calculated values of POH. Note that when the top of the 45 dBZ echo is greater than 18,000 ft, the POH is 100%.

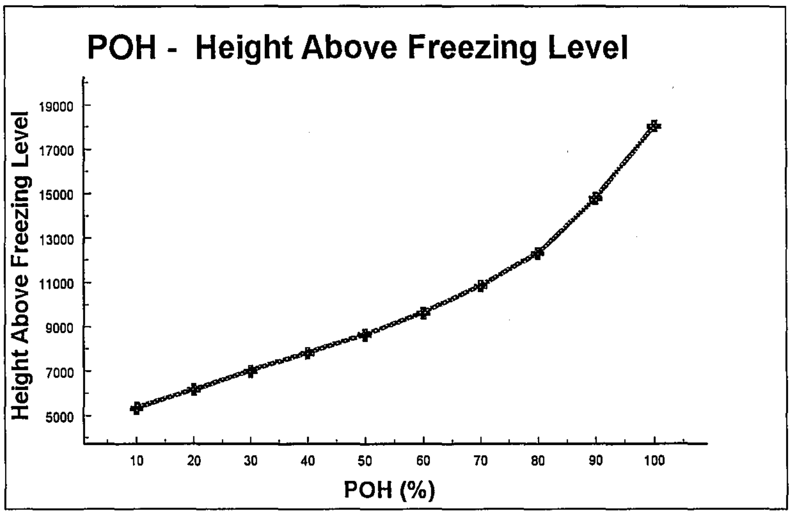

Figure 1. *Relationship between POH (%), and the distance of the top of a 45 dBZ echo above the freezing level (feet).*

b) Probability of Severe Hail (POSH), and Maximum Expected Hail Size (MEHS)

To determine POSH and MEHS for each storm cell, an approach similar to that of calculating VIL is performed. However, as noted in the WATADS software HCAA documentation by Arthur Witt, there are several significant differences. First, a cell-based algorithm, rather than a grid-based algorithm is used. Cell-based means that integrated quantities follow a cell with height while a vertically-stacked grid may not fully sample a tilted cell. Secondly, a reflectivity-hail relationship is adopted (hailfall kinetic energy, HKE), rather than a reflectivity-liquid water relationship. HKE is calculated from the reflectivity from the following relationship:

$$\mathbf{HKE = 5\times10^{-6}W(Z)10^{0.084Z}}$$

where

$$W(Z) = \begin{cases} 0 & \text{for } Z \le 40 \\ 0.1\,(Z-40) & \text{for } 40 < Z < 50 \\ 1 & \text{for } Z \ge 50 \end{cases}$$

and Z is the reflectivity in dBZ.

The Z-HKE relationship differs markedly from the Z-LWC (liquid water content) relationship used in calculating VIL (which filters out the high reflectivities associated with hail and establishes an upper limit of 55 dBZ). HKE, on the other hand, is very sensitive to the highest reflectivities (there is no upper limit), and filters out the lower values of reflectivity (below 40 dBZ). Figure 2 illustrates the nature of the Z-HKE and Z-LWC relationship.

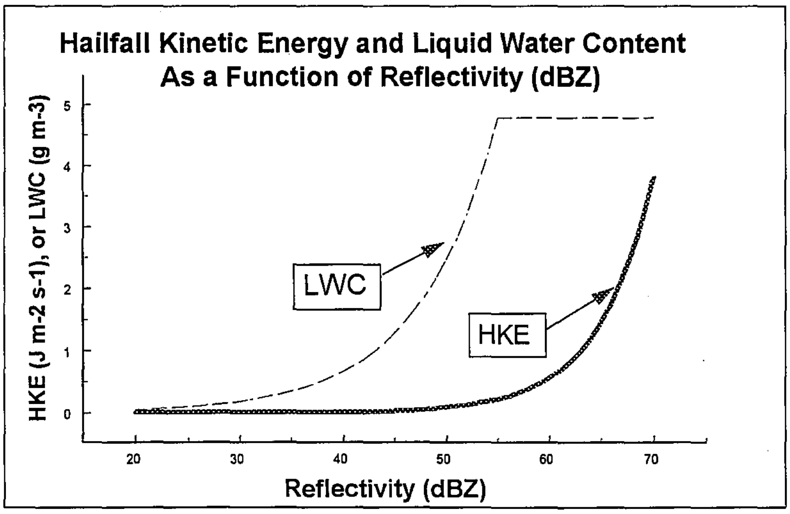

Figure 2. Relationship between Liquid Water Content (LWC; used in VIL calculations) and Hailfall Kinetic Energy (HKE), to radar reflectivity (dBZ).

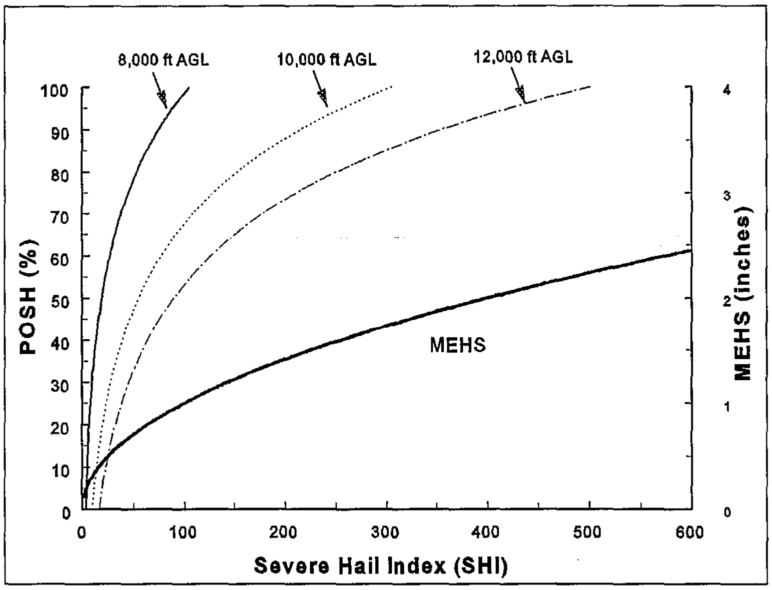

Figure 3. *POSH as a function of the Severe Hail Index (SHI), for different values of the freezing level height (8,000 ft, 10,000 ft, 12,000 ft AGL). Also included is MEHS as a function of the SHI.*

Conclusions: Some operational observations of the Build 9 HDA.

The purpose of this Technical Attachment is to better explain the basic functionality of the WSR-88D Build 9 Hail Detection Algorithm. How usage of the algorithm impacts severe weather operations and warning decisions depends on how well the users understand the inherent strengths and limitations of the HDA, and how to interpret the output in light of their local conditions. One can not stress this point enough. Below are some conclusions based on the observed nature of the HDA.

a) The new HDA may increase warning lead time on some events.

Being as the new hail algorithm looks specifically for elevated hail cores, the algorithm can 'catch' on to a severe storm well before VIL (for example) and may indicate a severe event prior to any hydrometeors reaching the ground. If the radar operator is too busy to make a judgment about a storm's severity based solely on the base data, then the POSH/MEHS algorithms may significantly increase the lead time on severe hail events if an appropriate threshold has been determined.

b) The new HDA may narrow the severe/non-severe threshold.

The interactive nature of the Build 9 HDA (i.e. the input of the 0C and -20C levels) removes much of the seasonal variability which is inherent in using some other severe weather parameters. Additionally, being as the algorithm uses only elevated data, storms at greater distances can be evaluated with more confidence.

c) Dependance of POSH on the height of the freezing level

The additional dependance of POSH on the freezing level makes it particularly sensitive when the freezing level is low (say, below 8,500 ft AGL). Under these conditions, minor changes in the freezing level can cause the POSH values to vary considerably. When freezing levels are low, POSH should be treated with caution.

d) Sensitivity of the algorithm to 'incorrect' values of input freezing level.

Several tests have been performed where the freezing (and -20C) levels were input with errors of up to 3000 ft. It was found that the MEHS varied ±.5", and POSH varied up to 40%. Therefore, it is recommended that one judiciously pick the 0C and -20C levels for input into the hail algorithm, and update when necessary to insure their appropriateness. For most situations, variations of 500 ft in the input levels should not adversely affect values of POH, POSH, and MEHS.

e) Be careful when a storm trends downward, to 'non-severe' levels

As a hail core descends to the surface, the SHI (and thus the POSH and MEHS) will decrease as the core approaches and passes below the freezing level. By the time that the hail reaches the surface, the POH, POSH, and MEHS may very well indicate that no severe hail is likely from the storm. In such cases, it is recommended that the user watch the maximum reflectivity very closely...it should not change significantly until the hail core has dropped to the surface. In practice, it may be wise to continue a warning based on large hail at least 15 to 20 minutes past the time of the last indication of severe hail from the HDA.

f) Behavior of the HDA in regions of complex terrain

The Build 9 HDA estimates the probability and size of hail at the elevation of the radar. When hail falls over areas which are at elevations significantly different from that of the radar, the HDA estimates will likely be somewhat inaccurate. For example, when hail falls over mountainous terrain which is well above the elevation of the radar, the HDA will underestimate the size of the hail (all things being equal), as the hail stones will not have as much time to melt below the freezing level. When hail falls over an area which is at an elevation significantly lower than that of the radar, the HDA will likely overestimate the size of the hail. Part II of this article gives a more detailed discussion of terrain effects.

Acknowledgments

For the most part, this paper is simply an appropriate regurgitation of the excellent Build 9 HDA documentation available, much of it written by Arthur Witt and Mark Fresch. This paper is, in part, a reproduction of an article written by the lead author for the Workshop on Northern High Plains Convective Storms held in Rapid City, SD.

References

Witt, A., 1997: NSSL Hail Core Aloft Algorithm. WATADS software documentation, Chapter 9.