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

PART II: PERFORMANCE OF THE ALGORITHM OVER UTAH

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Introduction

This is the second of a two-part Technical Attachment (TA) focusing on the WSR-88D Hail Detection Algorithm (HDA). Part I (Klimowski et al, 1997) discussed the nature of the HDA in terms of how the Probability of Hail (POH), Probability of Severe Hail (POSH), and Maximum Expected Hail Size (MEHS) are derived. In this TA, examples of the HDA performance in northern Utah are illustrated and summarized. For the most part, the HDA did a good job. However, it produced erratic results with tall, narrow storms at longer ranges.

There are three aspects of the HDA that stand out.

- <u>Since the HDA keys off of cores aloft, the primary benefit is increased warning lead time</u>.

- POSH may be over-done on long-range storms (beyond ~80 nm).

- Different hailstone size distributions, which are a function of varying storm environments, can produce the same reflectivity and the HDA may false alarm as a result. The HDA seems to work better in moderately-to highly sheared environment.

Analysis Methodology

The key component in the assessment of the HDA is ground truth - accurate reports of hail. Unfortunately, these reports are often erroneous in time and space and are rarely representative of the true distribution of hail. Witt (1997) describes such errors and the scoring method that has been used for years at the National Severe Storms Laboratory (NSSL). Essentially, if a hail report is within 5 nm and 15-45 min of a cell location and time, it is associated with the cell. A strong effort is made to analyze only those storms that move over populated areas. Wyatt and Witt (1997) discusses the role of population density in scoring the HDA.

For the analyses herein, values of POH, POSH, and MEHS were compared to the reported hail sizes. Analyses such as these are sensitive to many factors, and have several inherent assumptions. For example, it is assumed that the observed hail is representative of the maximum expected hail size. It is also assumed that the reported hail size is accurate. As can be seen, the assumptions inherent in these analyses render quantitative statistical analyses of limited use. However, qualitatively, there is much use in observing the behavior of the algorithms for specific case studies and for the group of observations as a whole.

Data Analysis

Table 1 lists the hail events which were used for this study. Data are from four moderate shear cases (30 May 1996, 21 June 1996, 28 June 1996, and 18 June 1997) and one weak shear case (15 June 1997). All of the cases are from northern Utah using the KMTX WSR-88D on Promontory Point. Furthermore, NSSL's WSR-88D Algorithm Testing and Display System (WATADS) was used to analyze the data.

Table 1. Various parameters associated with the 5 hail days analyzed in this study. The maximum speed difference is the speed at 400 mb minus the speed at 850 mb.

Date	Volume Coverage Pattern	No. of cells examined	No. of sev. hail reports	Mean/Max obs. Size (in)	0°C level (ft, MSL)	-20°C level (ft, MSL)	Max. speed diff (knots)
21 June 1996	21	11	3	.7/1.0	14,600	22,000	40
28 June 1996	21	6	1	..69/.75	11,900	20,500	35
30 May 1996	21	4	2	.88/1.0	11,400	19,780	35
15 June 1997	11	2	0	.5/.5	12,000	21,000	5
18 June 1997	11	2	1	.75/.75	14,000	23,000	25

Table 2. Summary of hail detection algorithm output and verification for 28 June 1996, 30 May 1996, 15 June 1997, and 18 June 1997. An * indicates that the cell moved over somewhat highly-populated areas. Lead time is the time between the first POSH of 60% or greater and the severe hail report. Severe reports are in bold type.

Cell	MAX POH	MAX POSH	MEHS (in)	MAX VIL	MAX dBZ	MAX REPORT	RANGE (nm)	LEAD TIME (min)
21 June 1996 cells								
12	**100**	**100**	**1**	**36**	**60**	**3/4"***	**75**	**29**
36	**100**	**100**	**1**	**47**	**59**	**3/4"**	**65**	**17**
7	100	70	<1	27	54	1/2"	70	
91	100	70	<1	23	53	None	45	
8	100	80	<1	32	55	None	65	
94	40	20	<1	12	49	None*	70	
21	100	90	1	26	56	1/2"	35	
24	90	70	<1	24	63	None	45	
63	0	0	-	5	50	None*	30	
7	100	90	<1	33	58	None	70	
7	**100**	**100**	**1**	**43**	**62**	**1"**	**50**	**31**
28 June 1996 cells								
3	80	50	<1	13	50	None	70	
36	80	20	<1	10	52	None*	60	

46	**90**	**30**	**<1**	**11**	**47**	**3/4"**	**60**	**miss**
58	0	0	-	5	45	None*	60	
3	90	60	<1	18	55	None	40	
12	90	80	<1	31	58	5/8"	70	
<u>30 May 1996 cells</u>								
29	**100**	**100**	**1**	**34**	**59**	**1"***	**60**	**27**
40	**90**	**80**	**<1**	**28**	**56**	**3/4" ***	**80**	**28**
59	90	60	<1	10	53	None	100	
16	90	60	<1	14	51	None	80	
<u>15 June 1997 cells</u>								
27	100	60	<1	20	43	None	85	
20	80	30	<1	14	54	1/2"*	45	
<u>18 June 1997 cells</u>								
9	**100**	**100**	**1.5**	**60**	**61**	**3/4"***	**60**	**49**
40	100	80	<1	21	52	None	115	false alarm?

Table 2 shows the attributes of all the cells in the study. There were three cells that were not well handled by the HDA. Cell 46 on 28 June 1996 had a maximum POSH of 30% with a 3/4" report. This is considered a miss. A possible false alarm occurred with cell 91 on 21 June but it passed over the edge of a small town bringing into question the accuracy of the ground truth.

The HDA also issued an apparent false alarm for Cell 40 on 18 June 1997. Even though the cell was over a sparsely-populated area and reports are not expected, the 80% POSH appears to be a false alarm due to range effects. A vertical cross-section through the cell (Fig. 1) shows that the bottom of the 0.5 deg beam is 14,000 ft above the radar. There is a narrow vertical column of 45-47 dBZ. The upper part of the echo appears to be an artifact of the large beam width (~9000 ft at this range) where the top of the cell was probably near 21,000 ft, partially filling the 1.4 deg tilt just above. This beam filling effectively raised the top of the storm resulting in what appears to be unrealistically-large values of POSH.

Even if Cell 40 did produce significant hail, it is very odd that its POSH was only 20% lower than the 100% POSH for a much larger cell much closer to the radar (Fig. 2). <u>The fact that two such different cells had very similar POSH values indicates that the HDA responds simply to the height of high reflectivity echoes but not other aspects of the cell structure such as width. Thus, there is a tendency for the HDA to over-warn for narrow high-reflectivity storms with large gradients of reflectivity at storm top.</u>

Conclusions

Hail storms on five days in northern Utah were analyzed and the performance of the WSR-88D Build 9 hail detection algorithm was assessed. There were specific situations when the POH/POSH/MEHS were quite accurate, and other situations in which they did not perform as well.

a) The HDA appears to over-warn for storms far from the radar.

At large distances from the radar (~ 100 nm), the radar beam is ~10,000 feet above the radar. This is at or above the freezing level for most severe hail events. Since the integration of HKE does not extend below the freezing level, the storm area not sampled under the beam is not a concern. However, at these distances from the radar, one must be aware of the affects of beam broadening, which will tend to decrease the peak values of reflectivity, but broaden the vertical extent of the reflectivity components. This will likely cause the Build 9 HDA to overestimate the severe hail potential in these locations. <u>The radar operator must assess storm structure to identify possible false alarms.</u>

b) Dependence of POSH on the low-level atmospheric conditions

POSH is particularly sensitive to low freezing levels (say below ~8,500 ft). A problem may arise if the Western storms have substantially different sub-cloud humidity and temperature profiles than those storms the HDA was developed with. This may affect hail melt, and in turn, affect the size of the hail which falls to the surface.

A second phenomenon particular to the mountainous West (as well as portions of the Eastern U.S.) is the radar's elevation relative to the vertical temperature and moisture profile. As seen in Fig. 3, locations close to the freezing level (e.g., mountains) are more likely to experience hail while locations at lower altitudes may receive no precipitation at all!. Thus, a freezing level height relative to a mountain-top radar will over-warn for areas far below the freezing level. An extreme example of these effects can be seen in Vasiloff (1997) where a 68 dBZ echo near Reno, Nevada initially produced no precipitation at the ground.

Additional work is being done to counteract the above problem by adjusting the HDA's Warning Threshold Selection Model (used to calculate POSH) so that a more representative melting height is used. Sensitivity studies are being done and recommendations will be made in a future TA.

c) POH was near 100% for most hail reports.

The POH was 100% for four out of six observations of severe hail and at least 80% for all hail reports. While it's usefulness in predicting *severe* hail may be limited, it could serve to act as an indicator of storms which are approaching severe levels. Further research needs to be performed in this area.

d) POSH was near 100% for most severe hail reports.

Although the lead-time that POSH gives for severe hail is suspect due to the erratic nature of the reports, a POSH of 100% was <u>always</u> associated with severe hail. Thus, for these cases, it appears that the elevated radar height of 2300 ft above the sounding point has minimal affect on the algorithm's performance.

e) MEHS over-predicts hail size by 30% to 50%.

This is one of the weakest conclusions since it is not known if the maximum hail size has actually been observed. However, there is a high bias in the MEHS that is inherent in the algorithm design as it predicts the maximum hail size <u>anywhere in the storm.</u> In this study, the over-estimates of MEHS were on the order of 30% to 50%.

f) This HDA performance evaluation is biased toward reports.

Most of the hail reports were from areas with low population density. These reports may or may not be the results of special effort by the WFO to call the spotter network. There are several problems with this technique. First, it is assumed that the largest hail was reported. Secondly, if there were no reports, then it is assumed that there was no hail. Thirdly, it is not known if, in the case of a strong cell over sparsely-populated areas, hail actually fell. This can result in not properly measuring the true false alarm rate.

References

Klimowski, B. A., 1997: On the nature and performance of the Build 9 hail algorithm. *Preprints,* Workshop on Northern High Plains Convective Storms, Rapid City, SD.

Witt, A., 1997: An enhanced hail detection algorithm for the WSR-88D. Submitted to *Wea. and Forecasting.*

Wyatt, A., and A. Witt, 1997: The effects of population density on ground-truth verification of reports used to score a hail detection algorithm. *Preprints*, 28th Conf. On Radar Meteorology, AMS.

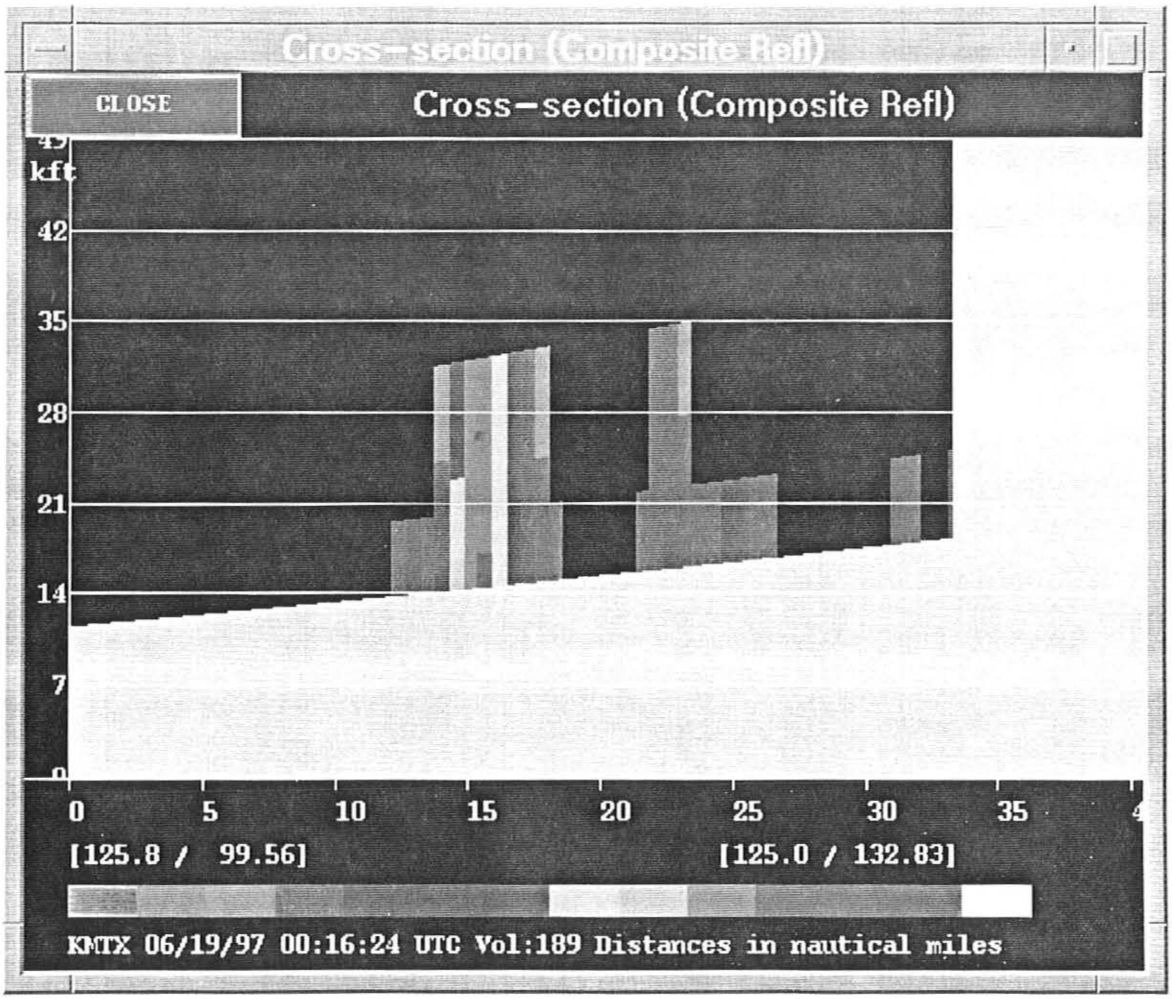


Figure 1. Vertical cross-section of reflectivity (dBZ) at 0016 UTC along the 125 deg azimuth through Cell 40 on 19 June 1997. Data shown in the cross-section are from only the 0.5 deg and 1.4 deg tilts. The program that generates the sections smears the data point vertically over the full diameter of the beam; the center of the 1.4 deg beam at 115 nm range is ~ 27,000 ft above the radar.

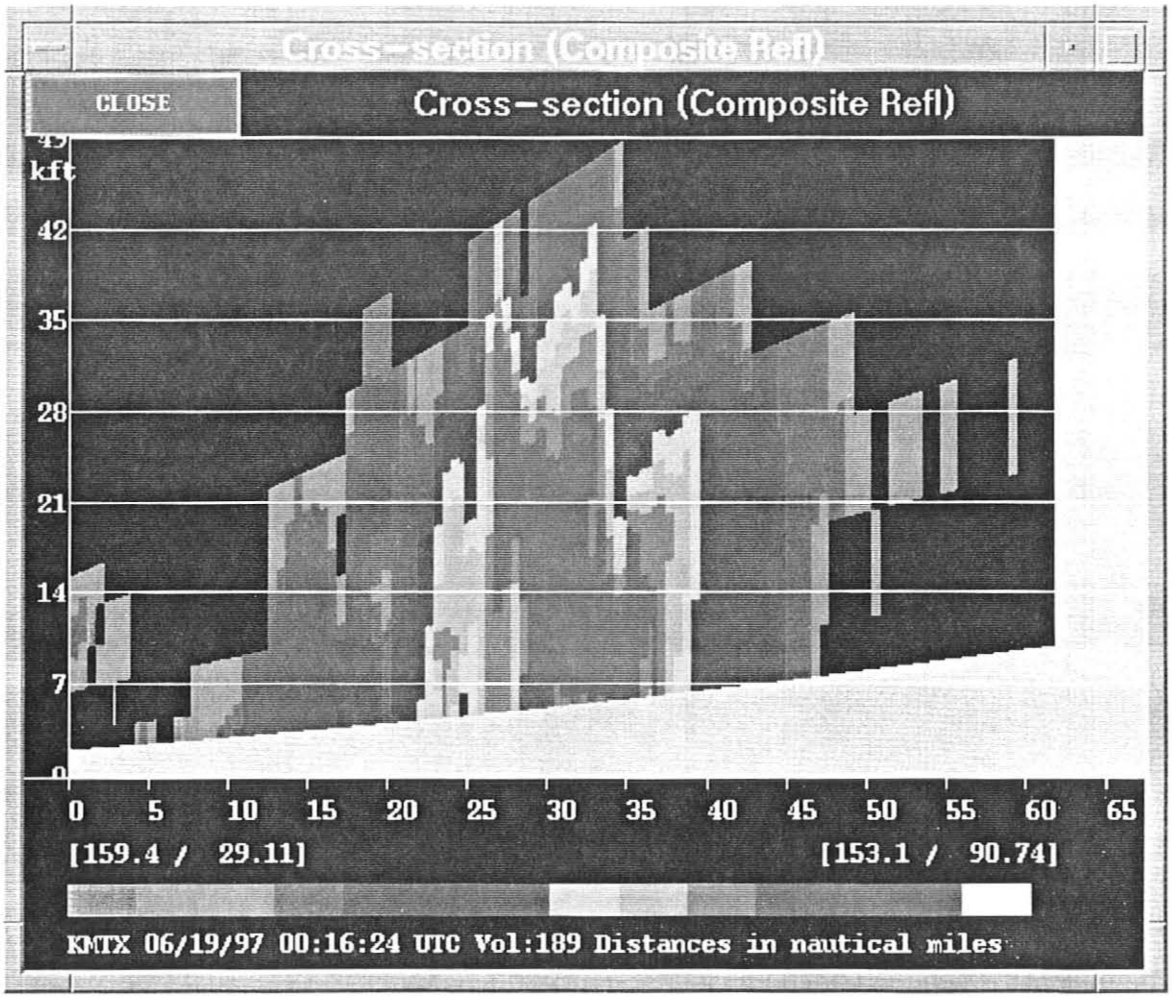


Figure 2. As in Fig. 1 except for a cell closer to the radar along ~155 deg. Many more tilts are represented in the plot.

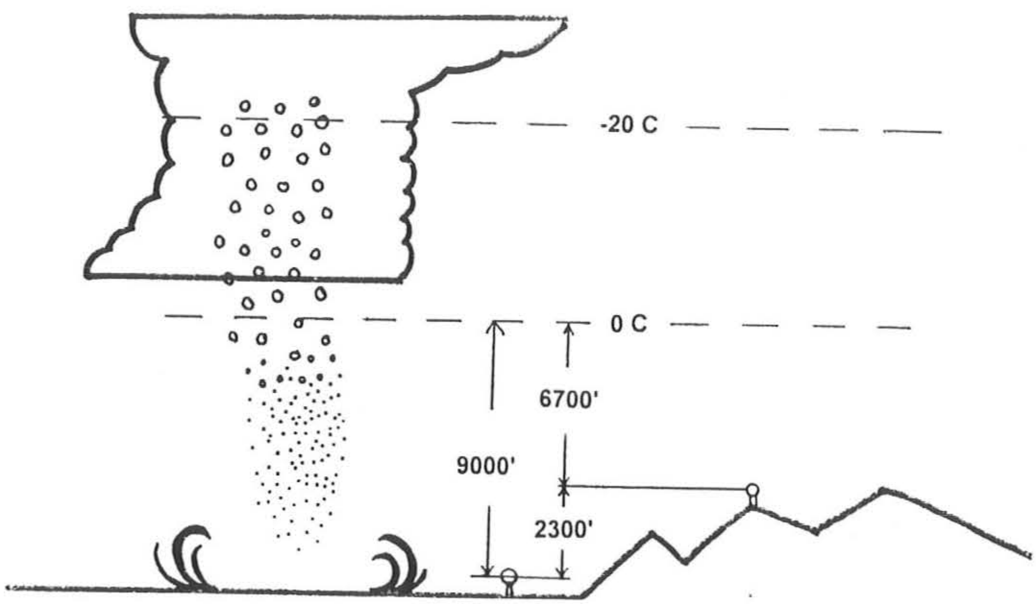
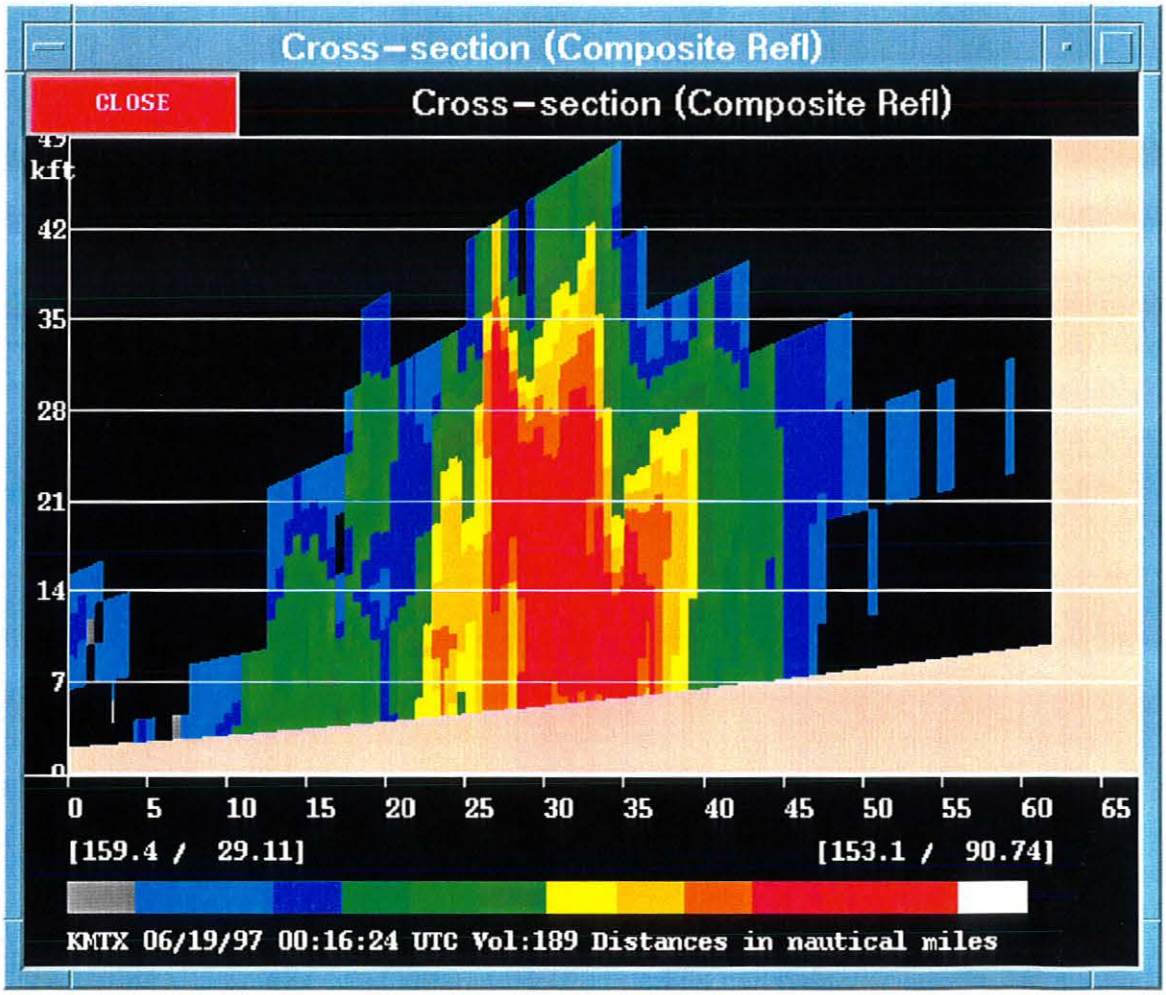


Figure 3. Schematic diagram showing the effects of complex terrain on the interpretation of output from the hail detection algorithm. Circles in and just below the cloud represent hail and the dots represent rain. Note, in this example, no rain is reaching the ground. Distances shown pertain to the KMTX WSR-88D on Promontory Point north of Salt Lake City. The radar depicted at the base of the mountain is for illustration purposes only.



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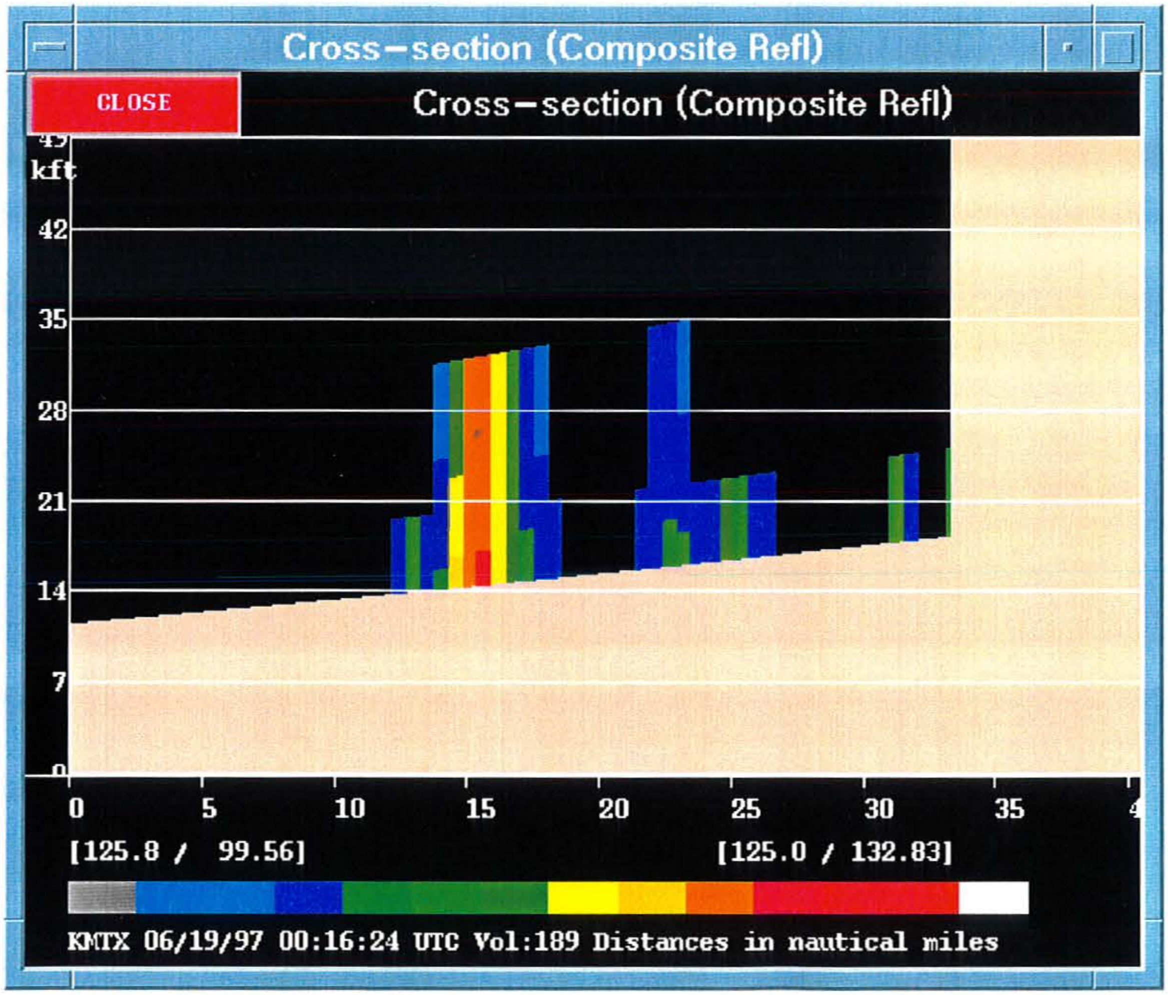

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Another difference between VIL and the HCA parameters is that a *temperature-weighted* vertical integration is used in the derivation of POSH and MEHS. Temperature-weighting is preferred because all hail growth will occur above the freezing level, and most large hail growth occurs near or above the -20C level. In light of this, a weighting function was implemented which assigns a weight of 1.0 to reflectivity components above the -20C level, a weighting of 0.0 to components below the freezing level, and a value between 0.0 and 1.0 for intermediate levels. The result of the temperature-weighted vertical integration of HKE yields the Severe Hail Index (SHI).

POSH and MEHS are both derived from SHI:

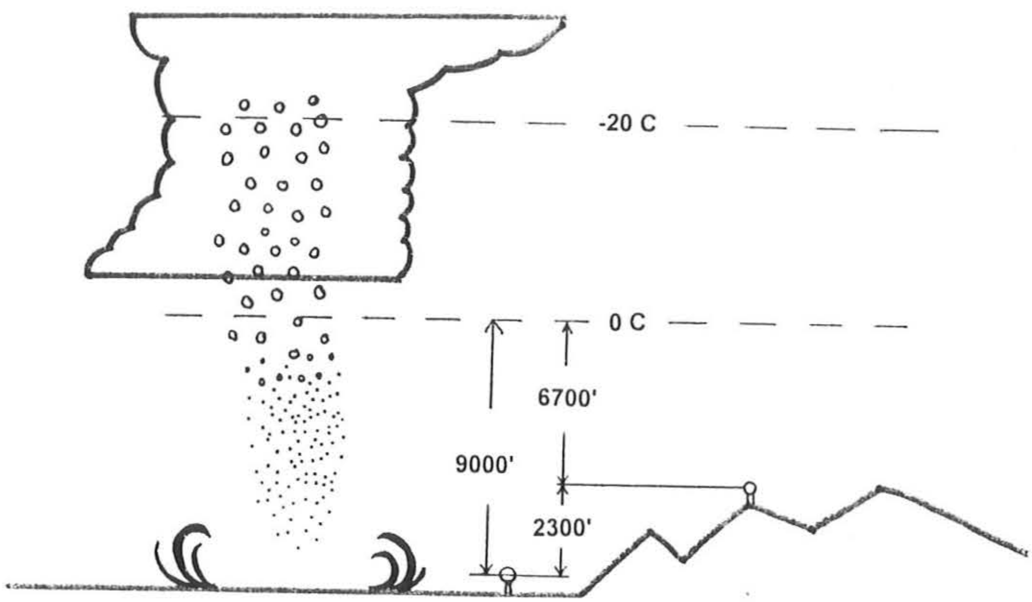
$$\mathbf{MEHS = .1\,(SHI)^{0.5}}$$

$$\mathbf{POSH = 29[\ln(SHI / WTSM)] + 50\%}$$

where

$$\mathbf{WTSM = 57.5\,(H0) - 121.0.}$$

For a given reflectivity profile, the value of SHI is dependant, of course, on the values input at the radar for the 0C and -20C levels; the higher (lower) the input values, the lower (higher) the output values of SHI (and therefore, the lower (higher) the POSH and MEHS). However, for a given SHI, only POSH is additionally dependant on the height of the freezing level, i.e., it is additionally sensitive to melting effects. Figure 3 illustrates this dependence of this relationship on the height of the freezing level, and the affect on the POSH values for a given value of SHI. Note how sensitive the POSH values are in cases where the freezing level is relatively low (say 8,000 ft AGL). Relatively small changes in the SHI can lead to very large changes in the output values of POSH when the freezing levels are low.



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