Applied Meteorology Unit **Memorandum**

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SUBJECT: Exploit NEXRAD: Extended Evaluation of Core Aspect Ratio

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INTRODUCTION

This memorandum documents the findings of the Applied Meteorology Unit (AMU) analysis and evaluation of the capabilities of Core Aspect Ratio (CAR) information for predicting hail and damaging winds. Data were obtained from the 1998 AMU Cell Trends study (Wheeler 1998). Results and recommendations are provided for the benefit of forecast operations by the 45th Weather Squadron (45WS), the Spaceflight Meteorology Group (SMG) and the National Weather Service Office at Melbourne (NWS/MLB).

CAR is defined as the ratio of storm depth to storm width, where storm depth is the height difference between the storm top and storm base, and storm width is the width of the 2D component containing the maximum reflectivity. A reflectivity threshold of 30 dBZ was used to determine storm height and storm width. CAR is a measure of storm cell intensification and dissipation. For instance, as a storm intensifies CAR increases and the shape is more like a column; as a storm dissipates CAR decreases and its shape is more like a mushroom (WATADS, 1998). CAR information may be useful for improving short-term forecasts of damaging winds and hail from convective storms. The data sets used in this analysis were from the AMU Cell Trends Study of 4 case days and 52 total cells. The average CAR value for the dataset was 3.2. Statistical analyses were done on the CAR information using standard measures of performance, such as the Probability of Detection (POD), False Alarm Rate (FAR), Critical Skill Index (CSI), and Heidke Skill Score (HSS).

This paper is divided into three sections. Section 1 describes previously performed work and Section 2 contains an overview on the statistical analysis of the CAR database. Finally, Section 3 highlights the potential development of tools to monitor and identify cell signatures that can be incorporated into the Weather Surveillance Radar (WSR) model 74C (WSR-74C) Exploitation Task – Phase II.

1.0 Background

The AMU report "WSR-88D Cell Trends Final Report" (Wheeler, 1998) documents the evaluation of the WSR-88D Cell Trends display as a tool for radar operators to use in their evaluation of

storm cell strength. The objective of the evaluation was to determine the utility of the WSR-88D Cell Trends display for local storm cell interpretation in assessing operational requirements.

Four case days were selected for evaluation: 29 March and 23 April 1997 (cool season) and 11 July 1995 and 13 August 1996 (warm season). The WSR-88D Level II data from the National Weather Service office in Melbourne, Florida (NWS MLB) was analyzed using the WSR-88D Algorithm Testing and Display (WATADS) Build 9.0, developed at the National Severe Storm Laboratory (NSSL). The analysis procedure was to identify each cell and track the Maximum Reflectivity (MAX), Height of Maximum Reflectivity (HMAX), Storm Top (ST), Storm Base (SB), Hail Probability (H), Severe Hail Probability (SH), Cell-based, vertically integrated liquid (CVIL) and Core Aspect Ratio (CAR) using WATADS cell trends information. Wheeler (1998) includes detailed information on cell locations and a discussion of the effects of radar scan strategies on cell trends.

The analysis revealed that most cells associated with significant weather, such as hail or wind gusts, had consistent trends in certain cell attributes. Hail was classified as an event if it was observed with a diameter of 0.5 inches or greater in the vicinity of a cell. Wind cases were classified as an event if there was reported wind damage or if a microburst signature (gust > 35 kt) was observed on the CCAFS wind tower network. Cells that exhibited a rapid increase or decrease in their HMAX and CVIL over the same time period could be associated with significant weather. Those cells that did not show these changes were typically not associated with significant weather events.

The investigation found that most cells producing large hail or damaging microburst events had discernable Cell Trends signatures. For microburst events, consecutive observations taken at 5 minute intervals showed, in general,

- A rapid 8000 ft or greater decrease in HMAX initially at 18000 ft or greater, and
- A rapid decrease in CVIL by 10 kg/m^2 or greater prior to the wind event.

For the hail events, consecutive observations taken at 5 minute intervals showed, in general,

- A rapid increase in HMAX by 8000 ft or greater to 18000 ft or greater, and
- A rapid increase in the CVIL by 10 kg/m^2 or greater prior to the hail events.

On the basis of these findings the following decision tree has been constructed and used to evaluate forecasts based on observations of HMAX, CVIL and CAR, as explained in Section 2. One objective was to restrict the decision tree to three or four pieces of information, to assure the capability of forecasters to rapidly and accurately reach a decision in a dynamically evolving environment with a multiplicity of cells to evaluate.

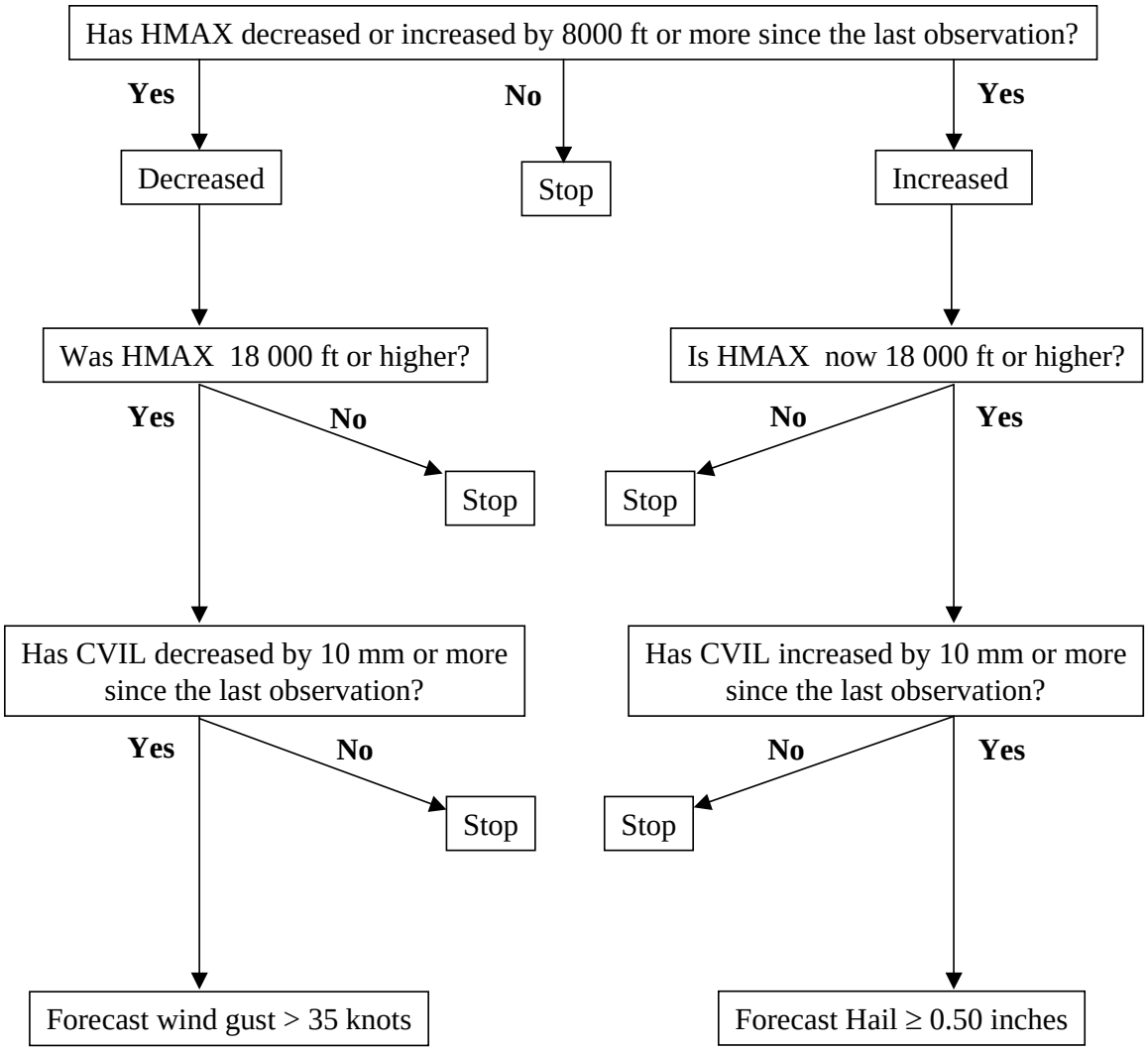

Figure 1. A decision tree for forecasting wind gust and hail events, adapted from the cell trends algorithm using HMAX and VIL, as reported by Wheeler (1998).

It is important to note that these results are based on a very limited data set (four case days). Fifty-two (52) storm cells were analyzed during those four days. Lead times ranged from 0 to 20 minutes. The POD was 88% for both event types. The FAR was 36% for hail events and 25% for microburst events. In addition the HSS was 0.65 for hail events and 0.67 for microburst events. For a random forecast, the HSS is 0 and for a perfect forecast, the score is 1.

2.0 Evaluation of the Core Aspect Ratio

The goal of the AMU's analysis of the cell trends database is to determine if there were any signatures for microburst or hail prediction in the CAR for each cell's life cycle. Previous empirical studies of the dynamical processes responsible for producing severe weather in convective cells have shown that the processes depend on physical characteristics of the cloud that can be characterized by radar observations (Kessenger et al., 1988; Parsons and Kropfli, 1990). The database used in the present study consisted of each cell's attributes of MAX, HMAX, ST, SB, H, SH, CVIL and CAR.

In the cell trends database the time resolution of a cell's trend, as determined by the WSR-88D volume scans, varied from 5 to 9 minutes. To create a homogeneous database for statistical modeling the time history of each of the 52 cells was linearly interpolated to 0.5 minutes. This will also facilitate the possible transition of signatures and tools over to the WSR-74C phase II effort, as the WSR-74C data is updated every 2.5 minutes.

The analysis procedure was to identify all cells and track the trend in CAR, MAX, HMAX, ST and CVIL. A composite cell trend was obtained for wind gust and hail events by first defining an initial time (T_0) for each event. This technique in time series analysis is often referred to as the superposed epoch method (Panofsky and Brier, 1968). T_0 for each wind gust event was defined as the time at which simultaneous decreases in HMAX and CVIL were observed, according to the criteria established by Wheeler (1998) and those specified above. Similarly, T_0 for each hail event was defined as the time at which simultaneous increases in HMAX and CVIL were observed according to the criteria established by Wheeler (1998). The composite cell trends of MAX, HMAX, ST, CVIL and CAR for 15 wind gust events are shown in Figure 2a. The composite cell trends of MAX, HMAX, ST, CVIL and CAR for 6 hail events are shown in Figure 2b. Several of the hail events had time histories of only 10 minutes before T_0.

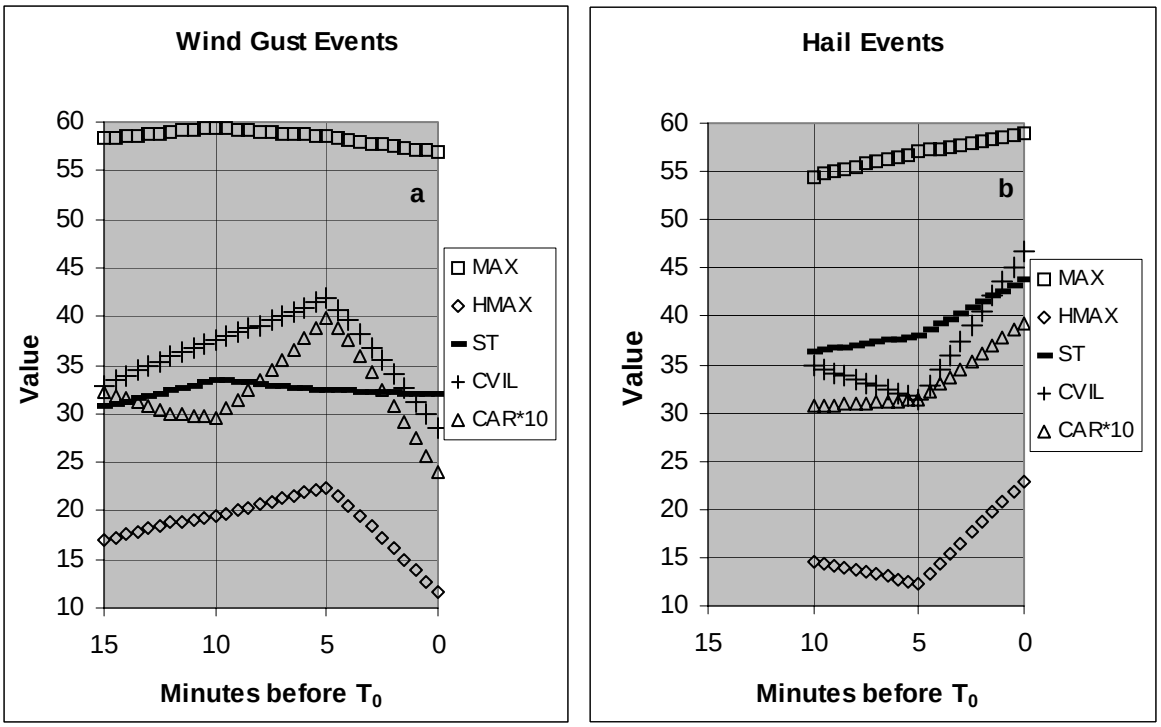

Figure 2. Composite cell trends for a) Wind gust events and b) Hail events. Maximum reflectivity (MAX; dBZ), height of maximum reflectivity (HMAX; kilo-feet), storm top (ST; kilo-feet), cell-based vertically integrated liquid (CVIL; kg/m^2) and core aspect ratio (CAR; x 10) are shown.

Figure 2a shows that the average trends of HMAX, CVIL and CAR are sharply downward prior to wind gust events. Weak downward trends are also observed in the average MAX and ST parameters. These signatures are all consistent with a descending mass of hydrometeors, the causative mechanism of downbursts (Fujita 1985). Figure 2b shows that the average trends of HMAX, CVIL and CAR are upward prior to hail events. Upward trends are also observed in the average MAX and ST parameters. These signatures are all consistent with the presence of a strong updraft, required for the growth of hail.

Given the consistent signatures of HMAX, CVIL and CAR shown in Figures 2a and 2b, it seems reasonable to examine the value of CAR information for improving predictions of wind gust and hail

events. The database used in Wheeler (1998) was re-examined to determine the predictive potential of CAR information when combined with CVIL and HMAX information. The basic structure of the original algorithm, shown in Figure 1, was adopted and tested using four standard measures of performance: FAR, POD, CSI, HSS. Table 1 gives definitions of these measures in terms of the number of successful and unsuccessful forecasts.

Table 1. A four-cell contingency table used for verification.

Standard Contingency Table		Observed Event	
		Yes	No
Forecast	Yes	a	b
Event	No	c	d

N = a + b + c + d

False Alarm Rate (FAR) = b/(a+b)

Probability of Detection (POD) = a/(a+c)

Critical Success Index (CSI) = a/(a+b+c)

Heidke Skill Score (HSS) = [(a+d) - E]/(N-E)

E = [(a+c)(a+b)+(b+d)(c+d)]/N

Tests of individual predictors for forecasts of wind gust events indicated that HMAX had the greatest skill, followed by CVIL and then CAR. However, false alarm rates for these predictors were as follows: HMAX (0.33), CVIL (0.59) and CAR (0.61). Lower FARs and higher skill scores were obtained by combining predictors as described below.

The approach used in testing the value of CAR information was to combine it with HMAX and CVIL, the successful predictors identified by Wheeler (1998). The decision tree shown in Figure 1 was used for the algorithm and modifications described below were made to test the impact of CAR information. However, in an effort to restrict the algorithm to three or four pieces of information, CAR was used to replace first one and then the other proven predictor.

Table 2 shows performance characteristics of various combinations of HMAX, CVIL and CAR cell trends when used to predict wind gust events. The original algorithm of Wheeler (1998) has excellent performance, as evidenced in the FAR, POD, CSI and HSS numbers. A slight improvement in performance can be obtained by combining HMAX, CVIL, CAR and their cell trends. One false alarm can be eliminated, however, this level of complexity exceeds the restrictions noted above.

The combination of HMAX and CAR information was used by substituting CAR for CVIL in Figure 1 and requiring that the trend in CAR was negative. When CAR information is combined with HMAX, the FAR improves slightly, but the POD decreases slightly. Given the relatively small sample size and excellent performance of the Wheeler (1998) algorithm, it may be difficult to determine if the changes in performance have arisen statistically, through sampling variations, or if they indicate an improved

physical characterization of the event-producing cells. Nevertheless, this objective test does indicate that CAR information has predictive value when used in combination with HMAX for these events.

The combination of CVIL and CAR was used by substituting CAR for HMAX in Figure 1, requiring that the trend of CAR was negative with an initial value > 3.0, and requiring that the initial CVIL value was > 30. When CAR is used in combination with CVIL the performance measures all decrease, relative to the original algorithm.

Table 2. Comparison of Cell Trends Attribute Statistics for Microbursts

Microburst Signature (original algorithm; HMAX & CVIL)						
		Observed		FAR	=	0.12
		Yes	No	POD	=	0.94
Forecast	Yes	**15**	**2**	CSI	=	0.83
Microburst	No	**1**	**35**	HSS	=	0.86
Microburst Signature (HMAX & CAR)						
		Observed		FAR	=	0.07
		Yes	No	POD	=	0.87
Forecast	Yes	**14**	**1**	CSI	=	0.82
Microburst	No	**2**	**36**	HSS	=	0.87
Microburst Signature (CVIL & CAR)						
		Observed		FAR	=	0.39
		Yes	No	POD	=	0.87
Forecast	Yes	**14**	**9**	CSI	=	0.56
Microburst	No	**2**	**28**	HSS	=	0.56

Table 3 shows the performance characteristics of various combinations of HMAX, CVIL and CAR cell trends when used to predict hail events. The original algorithm of Wheeler (1998) has good performance, as evidenced in the FAR, POD, CSI and HSS values. The combination of HMAX and CAR was used buy substituting CAR for CVIL in Figure 1, requiring that the trend in CAR was negative and that its initial value was > 3.0. When CAR information is combined with HMAX, the FAR decreases, but the POD decreases. Because of the small sample size it is not known if this degradation is statistically significant.

The combination of CVIL and CAR was used by substituting CAR for HMAX in Figure 1 and by requiring that the trend in CAR be negative. When CAR is used in combination with CVIL the performance measures all decrease, relative to the original algorithm. These results are similar to what is shown in Table 2, suggesting a common explanation for the relative weakness of the CAR and CVIL combination, when compared to the CAR and HMAX combination.

Table 3. Comparison of Cell Trends Attribute Statistics for Hail

Hail Signature (original algorithm; HMAX & CVIL)						
		Observed		FAR	=	0.40
		Yes	No	POD	=	1.00
Forecast	Yes	**6**	**4**	CSI	=	0.60
Hail	No	**0**	**43**	HSS	=	0.71
Hail Signature (HMAX & CAR)						
		Observed		FAR	=	0.20
		Yes	No	POD	=	0.67
Forecast	Yes	**4**	**1**	CSI	=	0.57
Hail	No	**2**	**46**	HSS	=	0.70
Hail Signature (CVIL & CAR)						
		Observed		FAR	=	0.55
		Yes	No	POD	=	0.67
Forecast	Yes	**4**	**5**	CSI	=	0.36
Hail	No	**2**	**42**	HSS	=	0.46

In order to obtain some insight into the relative weakness of the CAR and CVIL combination, changes in CAR, CVIL and HMAX were examined for all cells and times in the database. Figure 3 shows scatter diagrams of changes in CVIL versus CAR (a) and HMAX versus CAR (b). The correlation between changes in CVIL and CAR is + 0.33, whereas the correlation between changes in HMAX and CAR is + 0.12. The positive correlation between CVIL and CAR makes physical sense because when a cell's CAR decreases (increases), it becomes relatively shallower (deeper), compared to its width and the CVIL can also be expected to decrease (increase). These results indicate that CVIL and CAR changes are not independent and thus may tend to give the forecaster information on only one aspect of the cell's tendency. Therefore, performance of the CVIL and CAR combination is inferior to the original algorithm. On the other hand the changes in HMAX and CAR are less dependent, providing the forecaster with insight into both internal (HMAX) and external (CAR) characteristics of the cell.

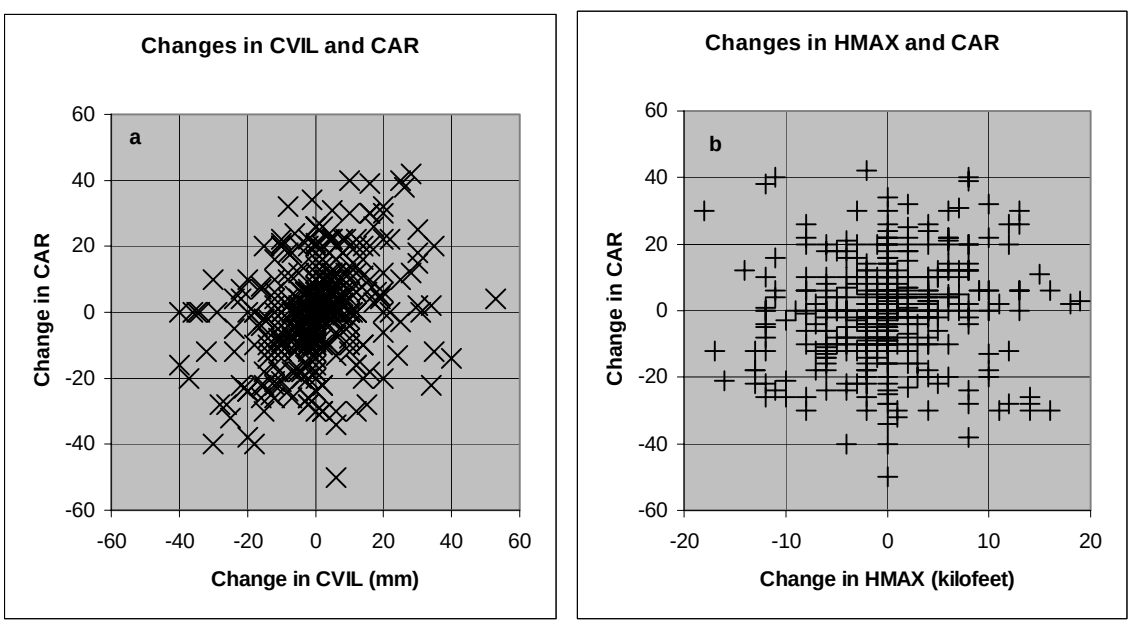

Figure 3. Five-minute changes in all cells and times in the database, a) for CVIL and CAR x 10, and b) HMAX and CAR x 10.

3. Cross-Feed into the WSR-74C Exploitation Task

The results from Section 2 suggest that CAR information can be combined with HMAX information to predict wind gust and hail events with no significant change of skill as compared to the combination of CVIL and HMAX information. This may be important for the WSR-74C exploitation task because of the potentially high computational cost of producing a cell based VIL product on the SIGMET Integrated Radar Information System (IRIS). A cell-based VIL product requires determination of the vertical tilt of a cell at a number of closely spaced vertical levels. Core aspect ratio may take less processing time to compute than cell-based VIL because IRIS already has a storm top product, a cell-tracking product and a maximum reflectivity product. These can be used locate a cell, assign a maximum reflectivity, assign the height of its top, and determine the height of the maximum reflectivity by an intelligent search of the reflectivity database.

An additional factor to consider is the cell trend of ST. The WSR-74C exploitation task includes generation of a cell trend product displaying ST. Figure 2a shows that the average cell trend of ST is weakly downward for wind gust events. Incorporation of ST information into the wind gust algorithm does not increase its skill. On the other hand, Figure 2b shows that the average cell trend of ST for hail events is positive. Incorporation of ST information into the hail algorithm can eliminate one false alarm in the database used in this study, during an event in which HMAX and CVIL both rapidly increased while ST rapidly decreased. However, the sample size of hail events available for this study may be insufficient to warrant a recommendation that a cell trend product for ST be generated for the WSR-74C exploitation task.

4. References

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