79. THE UTILITY OF VERTICALLY INTEGRATED GRAUPEL AS A MAX HAIL SIZE PREDICTOR

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1. Introduction

High-resolution, convection-allowing models (CAMs) have demonstrated success simulating supercells and other types of convective storms over the last several years. As a result, interest continues to grow in incorporating CAM output into National Weather Service convective warning operations through programs like FACETs and Warn-on-Forecast (WoF). However, most studies focus on the presence of tornado-like vortices and general supercell structure, not individual severe hazards like wind speed and hail size. Hazard-specific information will be necessary for next-generation warning systems, and will therefore need to be derived from CAM output.

A majority of supercells produce significant hail (diameter ≥ 2.00 in [5.1 cm]; Blair et al. 2014), making the presence of supercell characteristics in CAM output a decent indicator of significant hail; however, the distribution and specific size of hail in supercells depends on a number of factors. Hail has recently been represented in CAM data via vertically integrated graupel (VIG; Kain et al. 2010, Clark et al. 2012), but verification has thus far been very limited. This study examines maximum VIG in seven simulated storms, and compares these values to maximum hail sizes sampled by the field project HailSTONE (Blair et al. 2012), in order to begin evaluating the ability of VIG to predict maximum hail size in simulated storms.

2. Data and Methodology

The WRF-ARW was used to model the seven simulations presented in this study, and all cases were run at a horizontal grid spacing of 1 km. Simulations were warm started using the 13 km Rapid Refresh, and parameterizations used were the ACM2 planetary boundary layer scheme, the Thompson double-moment microphysics scheme, Goddard long-wave and short-wave radiation, and the Noah land surface model. All cases selected for this study were sampled by HailSTONE, and had maximum hail sizes ranging from 1.25 in (3.2 cm) to 6.00 in (15.2 in) in diameter.

HailSTONE cases were chosen for verification due to the high resolution nature of the hail reports. The density and resolution of reports in *Storm Data* are rarely sufficient for scientific studies, and a significant low bias in maximum reported hail size in *Storm Data* was observed when compared to the true maximum size observed by HailSTONE (Blair et al. 2014). As a result, a high spatial and temporal resolution of hail reports is necessary for verification of high-resolution CAM data.

The seven case studies presented herein and their locations are: 1) 23 May 2011 in western OK; 2) 31 May 2014 in north central WY; 3) 1 Jun 2014 in southwest KS; 4) 3 Jun 2014 in western NE; 5) 7 Jun 2014 in the TX panhandle; 6) 14 Jun 2014 in south central NE; and 7) 2 Aug 2014 in south central SD (Figure 1).

3. Results and Discussion

The relationship between VIG and maximum hail size can be seen both in Table 1 and Figure 2, and generally shows a slight increase in maximum hail size with increasing VIG, with a moderate but not significant correlation (r^2 = 0.564). However, there are a few exceptions to this increasing relationship — especially 2 Aug 2014, denoted by a light blue dot in Figure 2. Additionally, without the extreme values from 23 May 2011 the relationship between hail size and VIG is much less apparent (r^2 = 0.169).

Since significant and giant (diameter ≥ 4.00 in [10.2 cm]) hail sizes have been related to the peak magnitude of rotational velocity in radar-based studies (Blair et al. 2011), maximum hail size was also compared to maximum updraft helicity (UH) in the 2 km to 5 km layer (Table 1 and Figure 3). The relationship between hail size and UH is even muddier, with no clear relationship between maximum hail size and UH (r^2 = 0.028). Once again, 2 Aug 2014 stands out with abnormally low UH values for the observed 3.75 in (9.5 cm) hail, but even without the inclusion of this case, no clear trend emerges.

It is worth noting that significant hail was not well-anticipated on 2 Aug 2014, and occurred in a "see text" severe weather outlook from the Storm Prediction Center where a five percent probability

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of severe hail was indicated. Large scale forcing for convection was not particularly strong on this day; a situation where CAMs tend to perform poorly (Weisman et al. 2008) — which may also have resulted in a less robust than observed storm in this simulation. These weakly forced scenarios may continue to present a challenge for both the anticipation of severe convective weather and for any hazard-specific information derived from CAM output, and will require specific consideration in future work.

Finally, a stronger relationship between UH and VIG than between either of those parameters and hail size has been observed in CAM output (Correia et al. 2014), so this relationship was also tested for the seven case studies (Figure 4). In this study, a positive relationship existed between VIG and UH as had been previously observed, but the correlation was still not significant ($r^2 = 0.478$) and was actually lower than the correlation between hail size and VIG ($r^2 = 0.564$). This observed relationship seems reasonable since higher UH likely indicates a stronger updraft and thus more potential for graupel to be lofted, but VIG will also depend on a few different environmental factors than those that help determine UH.

4. Summary and Future Work

There appears to be some potential for using VIG as a proxy for maximum hail size, but so far no significant relationship has been identified between maximum hail size and VIG. Additionally, no threshold value for significant hail, giant hail, or severe hail (diameter ≥ 1.00 in [2.5 cm]) can be defined, although more cases are needed to determine such a threshold value. Updraft helicity does not appear to have value as an indicator of hail size despite its relationship to VIG, and based on these results, UH is not recommended as a hail size forecast parameter.

Future work will involve simulating the remainder of the HailSTONE cases (62 in total at the time of this study) and re-running the statistics presented herein. Additionally, the authors plan to utilize the HAILCAST model (Adams-Selin et al. 2014) that has been recently implemented into the WRF-ARW to test its ability to forecast maximum hail size for all HailSTONE cases. Once the ability of CAMs to provide hail size information has been evaluated, the authors also plan to study the accuracy of the hail swath locations relative to the updraft, and compare these results to observations in cases with varied amounts of hydrometeor size sorting. All of the results and future work discussed in this study will also be tested with radar data assimilation using WRF-DART, to determine whether or not any improvement occurs when radar data are assimilated — especially for the weakly forced, poorly predicted cases.

5. References

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6. Figures and Tables

Date	Hail	Max VIG	Max UH
23-May 2011	6.00 in	72.9 kg m^{-2}	360 m^2 s^{-2}
31-May 2014	2.25 in	40.3 kg m^{-2}	141 m^2 s^{-2}
01-Jun 2014	1.25 in	36.1 kg m^{-2}	291 m^2 s^{-2}
03-Jun 2014	3.50 in	49.5 kg m^{-2}	186 m^2 s^{-2}
07-Jun 2014	3.50 in	62.0 kg m^{-2}	351 m^2 s^{-2}
14-Jun 2014	2.00 in	55.6 kg m^{-2}	304 m^2 s^{-2}
02-Aug 2014	3.75 in	41.4 kg m^{-2}	59 m^2 s^{-2}

Table 1. Maximum hail size, maximum VIG, and maximum UH for each simulated storm.

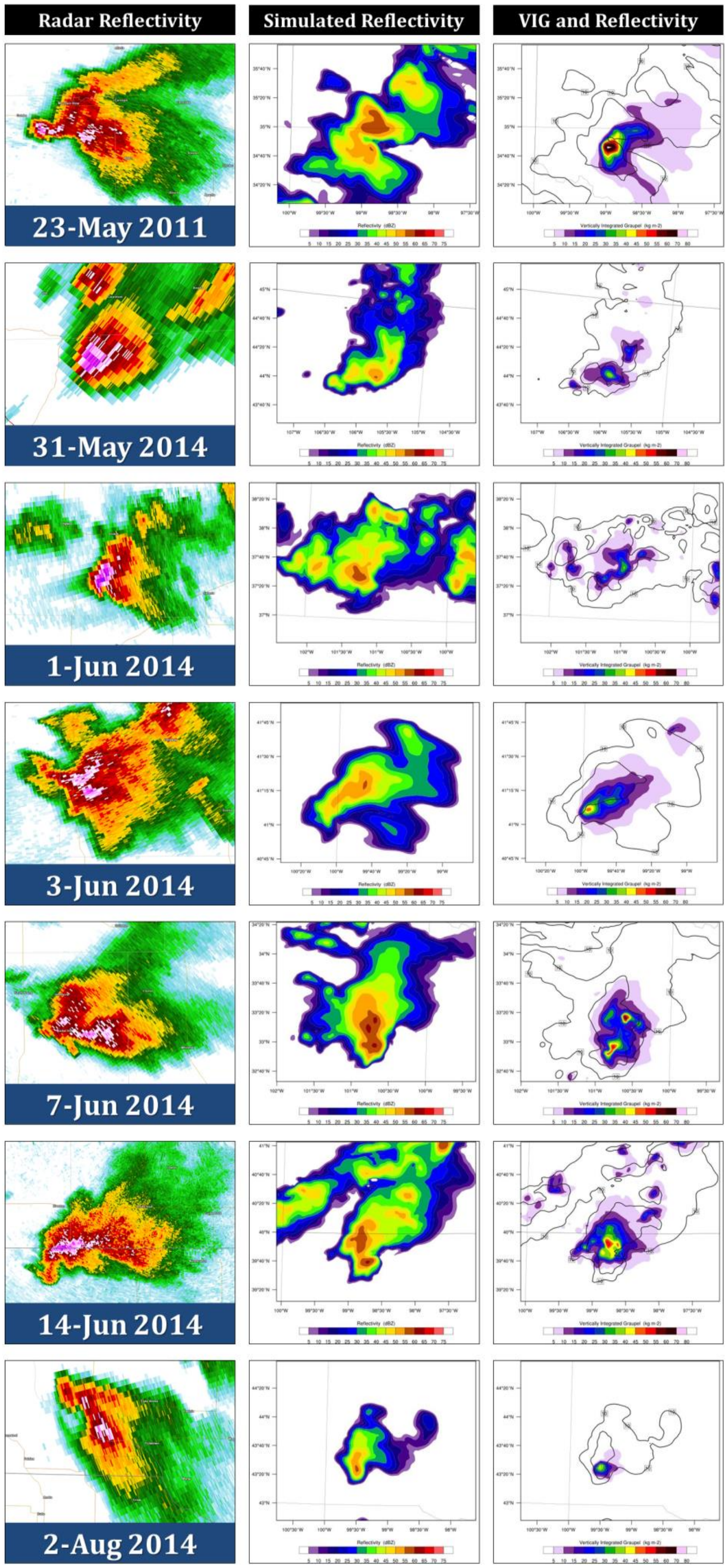

Figure 1. Observed radar reflectivity (left panel), simulated radar reflectivity (center panel), and VIG (shaded, right panel) and simulated radar reflectivity contoured at 10 dBZ and 40 dBZ (black contours, right panel) for all case studies.

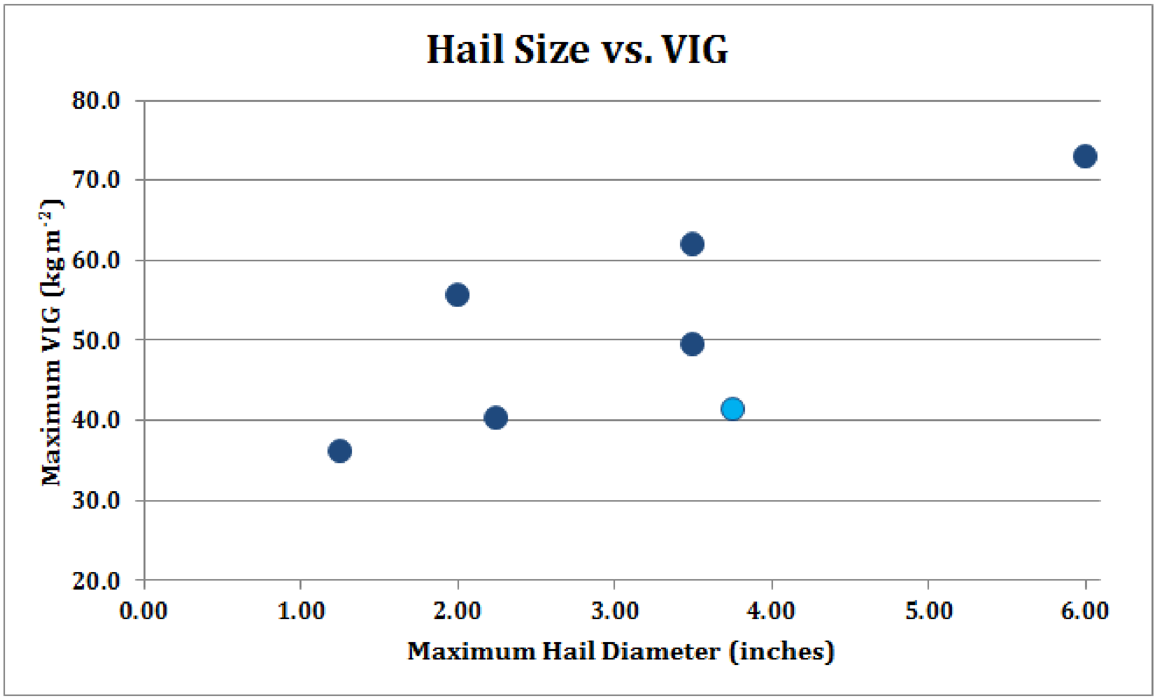

Figure 2. Scatter plot of maximum VIG (kg m^{-2}, y-axis) and maximum hail diameter (inches; x-axis). The 2 Aug 2014 case is denoted by the light blue icon.

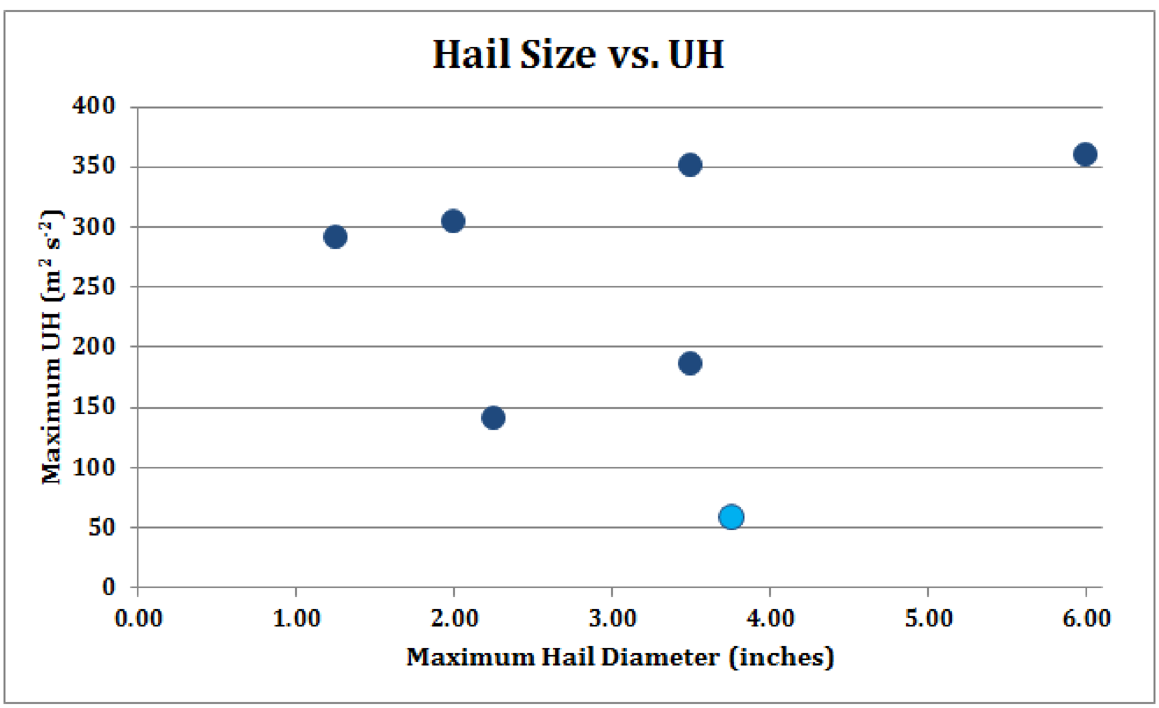

Figure 3. Scatter plot of maximum UH (m^2 s^{-2}; y-axis) and maximum hail diameter (inches; x-axis). The 2 Aug 2014 case is denoted by the light blue icon.

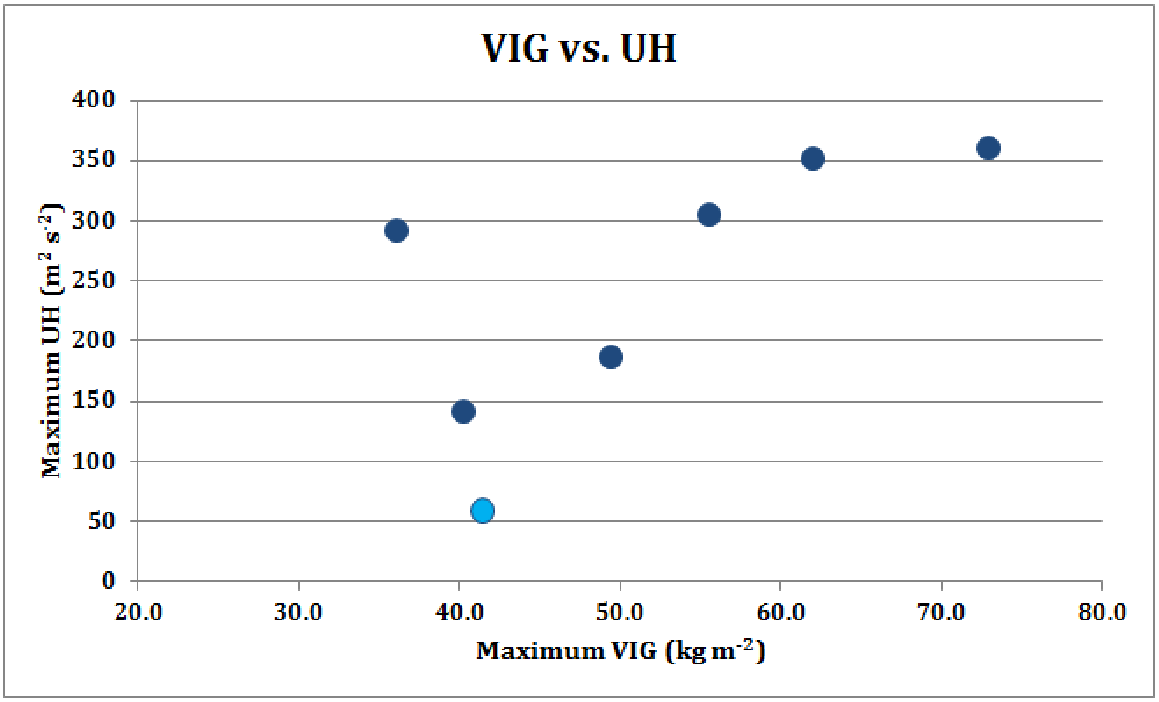

Figure 4. Scatter plot of maximum UH (m^2 s^{-2}; y-axis) and maximum VIG (kg m^{-2}; x-axis). The 2 Aug 2014 case is denoted by the light blue icon.