Correlations between updraft strength and tornado intensity using Gibson Ridge Level 2 Analyst Edition software

JUSTIN T. SCHULTZ

Iowa State University

Mentors: Karl Jungbluth[1], and Dr. Tsing-Chang Chen[2]

Johnston, Iowa: National Weather Service[1], and Iowa State University[2]

ABSTRACT

The updraft is the most important determinant of the strength of the severe thunderstorm, and determining its strength is vital to estimate the strength of the storm itself. For this study, Gibson Ridge Level 2 Analyst Edition radar software was used to imply the strength of the updraft in 150 cases of severe weather and tornado activity. Using Gibson Ridge, several parameters were observed, such as 50 dBZ Height, Echo Top Height, Vertically Integrated Liquid, and Vertically Integrated Liquid Density. These parameters were then observed for the six different categories of tornado strength, by the Fujita Scale and were observed to see how much they varied with different tornado intensities to imply the strength of the updraft.

1. Introduction

Severe thunderstorms have an interesting structure. Many people are usually concerned about how the winds are blowing in the horizontal directions. However, the updraft within the thunderstorm is usually overlooked. Even though this is the case, the updraft is the most important aspect of the thunderstorm, and understanding its strength is vital to understanding the behavior and structure of the severe thunderstorm.

According to Marwitz (1972), and Matejka and Bartels (1998), the updraft is one of the most important aspects to understand regarding severe thunderstorm strength. Marwitz claims, "The severe thunderstorm is driven by a continuous source of warm, moist low-level air. This is normally fed into the storm through an organized updraft area. To understand the kinematics and dynamics of storms…it is valuable to be able to determine the location of the updraft area…" Matejka and Bartels also claim that "…knowing the vertical air motion is so important to studies of cloud and mesoscale dynamics, precipitation production, and vertical transports of mass, momentum, and energy that, in much research, the vertical air motion must be derived from Doppler radar data somehow even if the estimates might be poorer than desired."

It is important to be able to determine the severity of tornadoes due to their violent nature. Some tornadoes only blow branches off of trees, as some tornadoes destroy entire buildings. Understanding the structure of the tornadic thunderstorm is crucial to determining the overall strength of the tornado itself.

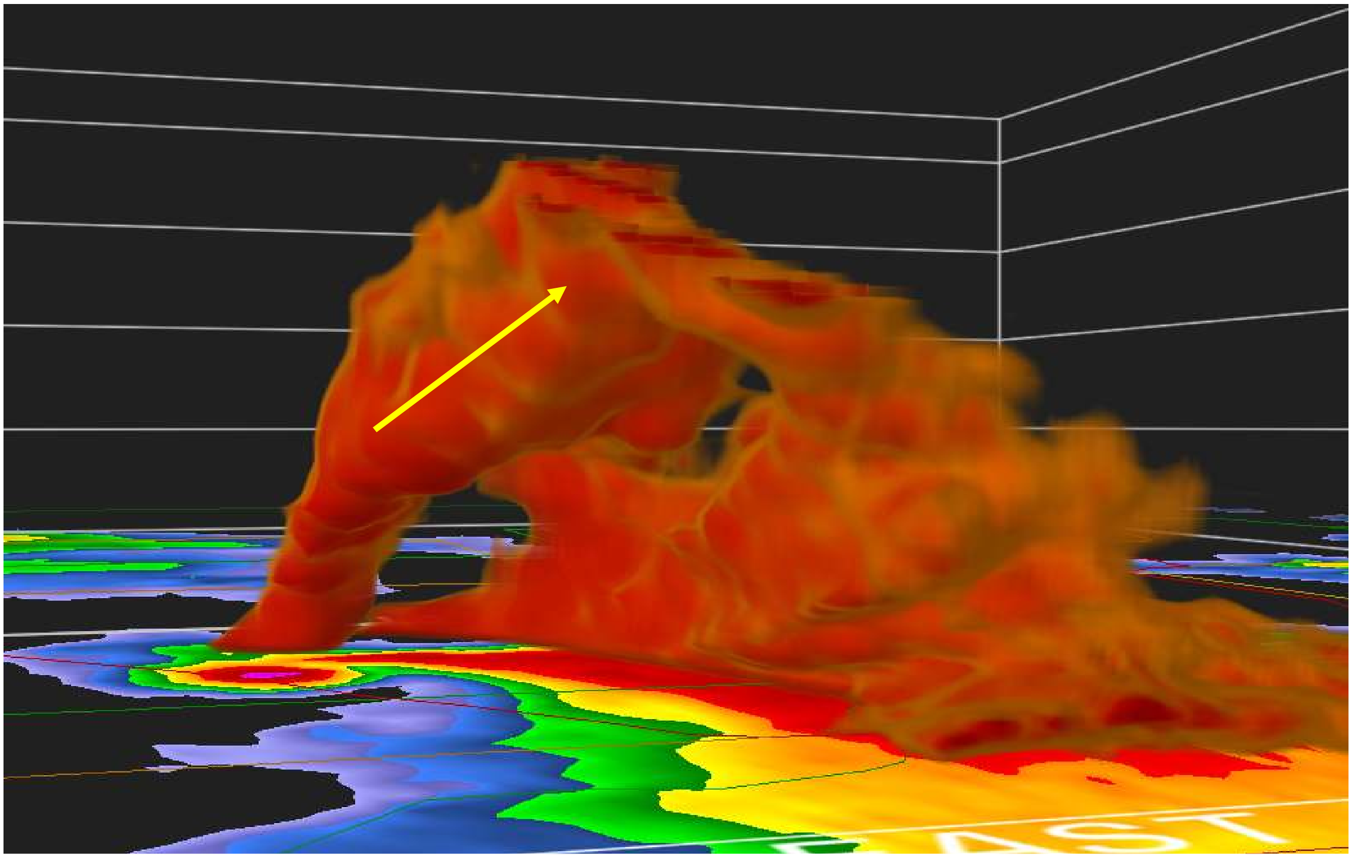

Figure 1: A 3-Dimensional cross-section of the May 3, 1999 Moore, OK F5 tornado. Notice how the user is able to see how the thunderstorm is structured with height. The yellow arrow indicates the updraft location in the mesocyclone. Image was taken by the author using Gibson Ridge Level 2 software. The red object is the 50 dBZ isosurface.

When trying to understand the dynamics of the severe thunderstorm, one should try to determine ways to quantify the strength of the updraft. However, since updraft strength cannot be found explicitly other than by flying an airplane or releasing a weather balloon into the mesocyclone, one would have to imply the updraft strength by other means. Doppler radar is a great way to do this as it can, by remote sensing, pierce into the storm and view its turbulent nature.

The purpose of this study is to determine a correlation between four radar-calculated parameters to use to imply the strength of the updraft in the mesocyclone.

I would hypothesize that there will be a correlation between these four parameters, more specifically, their means and linear trends, and hence, they will help to imply the updraft strength. My reasoning is that if these four parameters are dependent how high they are forced up, then they are dependent on the updraft strength.

2. Methods and Analysis

Since updraft strength cannot be found explicitly by Doppler radar, one would have to imply its strength using these parameters. It is possible to imply the updraft strength of these tornadic storms by determining a correlation of these parameters to the tornado strength. These are the parameters observed in this study: 50 dBZ Contour Height, Echo Top Height, VIL, and VILD.

The method of analyzing these parameters is by WSR-88D Level 2 radar through Gibson Ridge Level 2 Analyst Edition (GR2AE). This software was created by Michael Gibson, from Gibson Ridge Software, LLC, for the purpose of pulling Level 2 radar data from National Weather Service radars from across the United States of America. This radar data can be bisected to give a 2-Dimensional view of the storm, giving its reflectivity and general vertical structure, or even a 3-Dimensional view. Figure 1 shows a 3-Dimensional cross-section of the May 3, 1999 Moore, Oklahoma F5.

a. VIL and VILD

VIL (Vertically Integrated Liquid) and VILD (Vertically Integrated Liquid Density) are defined as measurements of "atmospheric water content that can be measured by (C or S band) weather radars and stands for the precipitation water content" by Boudevillian and Andrieu (2003).

According to Jeff Haby from www.theweatherprediction.com, "The higher an updraft penetrates through the troposphere then it is more likely significant moisture has been funneled and suspended in that vertical column. Higher VIL values occur with suspended hail, heavy rain and precipitation extending through a deep vertical depth of the troposphere. VIL is defined by Eq. 1.

$$\mathrm{VIL} = \sum 3.44 \times 10^{-6}[(Z_i + Z_{i+1})/2]^{4/7}\Delta h \quad (1)$$

The units of VIL are kilograms per square meter (kg m^{-2}), Z_i and Z_{i+1} are radar reflectivity values (mm^6 m^{-3}) at the lower and upper portions of the layer being observed by radar, and Δh is the vertical thickness of that layer in meters. For the WSR-88D radar, VIL is based on reflectivity over the vertical thickness. These values are then summed together to calculate the total amount of liquid water within the vertical structure of the storm. (Amburn, 1997)

VILD is simply defined by Amburn and Wolf (1997) as "…the VIL (kg/m^2) divided by the echo top height (m). The quotient is multiplied by 1000 to yield units of g/m^3." In other words, VILD is mathematically defined in Eq. 2 as:

VIL density = VIL/echo top height (2).

VILD is a normalized parameter by Echo Top Height, and it is independent of topography since it is a measure of liquid water within the storm core itself. Greene and Clark (1972) claimed, "Another advantage of vertically integrated values is that vertical integration will filter out strong radar returns that may be due to terrain features or nonstandard propagation. Although these returns may be very strong at low elevation angles, thus adversely affecting present Z-R relationships, they become insignificant when integrated over the vertical extent of the storm."

Amburn and Wolf (1997) stated, "As VIL density increases, the hail cores tend to be deeper and more intense, and reported hail sizes tend to be larger." With this being said, and acknowledging the fact that a stronger updraft brings larger hail size, it can be assumed that the larger the VIL and VILD values, the stronger the updraft strength is.

b. dBZ Height

In the vault area of the severe thunderstorm, one can locate the WER (Weak Echo Region). This region of the thunderstorm is also the location of the main updraft. It can simply be implied that the updraft strength is correlated to dBZ height, more specifically the 50 dBZ height contour, since the forcing from the updraft would propel the liquid water droplets upward. According to Browning (1965), the maximum dBZ height location is also the location of the main updraft in the severe thunderstorm. Thus, dBZ height is a useful parameter in locating and identifying the strength of the thunderstorm updraft.

The 50 dBZ Height location was found over the location of the mesocyclone, which is given by evidence of the weak echo region. Using the 2-Dimensional splicing tool on GR2AE, it is possible to determine the location and height of the tallest extent of the 50 dBZ Height reflectivity.

50 dBZ Height was used as it is the last reflectivity threshold passed before the 60 dBZ regime, which is more associated with hail than intense precipitation. If the 60 dBZ Height were used instead of the 50 dBZ Height line, it would be difficult to observe the 60 dBZ Height isosurface since not every supercell thunderstorm has hail in it.

c. Echo Top Height

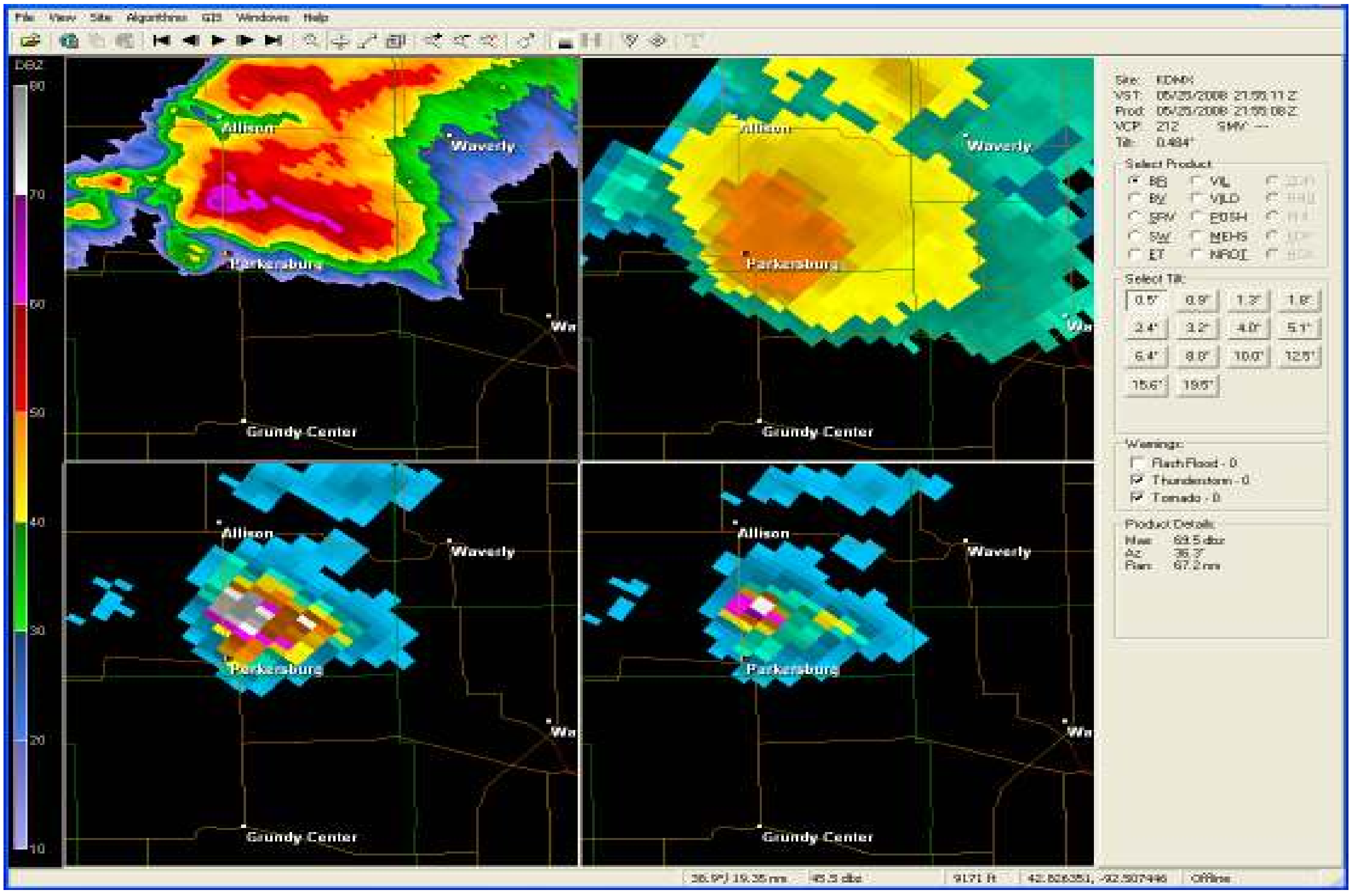

Figure 2: The four-panel view of the May 25, 2008 Parkersburg, IA EF5 at the moment of the tornado occurrence. Notice the different parameters that are being shown: upper left is Base Reflectivity, upper right is Echo Top Height, lower left is Vertically Integrated Liquid, and lower right Vertically Integrated Liquid Density.

Echo Top Height is the highest extent that precipitation within the storm reaches. According to www.theweatherprediction.com, "Once the precipitation intensity drops below a threshold value as the radar beam samples higher elevations of a storm of precipitation region then the echo top is located." In other words, once the precipitation intensity becomes too low for the radar beam to distinguish its reflectivity value, the Echo Top Height is located. Figure 2 shows a four-panel view of the May 25, 2008 Parkersburg, IA tornado. Three of the parameters observed in this study are plotted in the figure.

In the same sense as dBZ height, Echo Top Height can be used to imply the strength of the updraft due to the transportation of mass of the water droplets within the storm. The updraft will give a thunderstorm its vertical structure inside the core, making its way upward due to the positive buoyancy force that a lifted parcel of air would have in a colder environment. This would imply the higher the Echo Top Height, the stronger the updraft.

Thus, due to the upward transport of the mass (reflectivity) in the updraft, one can imply the strength of the updraft due to how high the Echo Top Height is reached. When observing several severe storms on radar, the storm with the highest echo top height would most likely be the storm that would produce the strongest convective winds and largest hail.

3. Procedure

For this study, 25 cases of each Fujita tornado intensity category were observed (i.e. F0/EF0, F1/EF1, etc.). However, for the F5/EF5 category, due to a deficiency of Fujita Category 5 cases, F5/EF5 cases were combined with F4/EF4 cases to avoid any statistical anomalies. A null case category (NT—"No Tornadoes") of severe weather reports, but no tornado reports was also considered for the study to compare the statistical analysis.

This study has a total of 150 cases to compare with—25 cases for each category and six total categories. The cases were mostly of American Midwestern tornadoes and severe weather, but some were of some special locations such as Florida, the East United States Coast, and Utah. The cases were spread mostly over the American Midwest over all states from Minnesota, south to Texas. The data for the study was found in between the time periods of May 1995 to July 2008.

The Level 2 radar data was found at several locations on the web. These locations include: The Iowa Environmental Mesonet (www.mesonet.agron.iastate.edu), National Climatic Data Center's HDSS Access System of NEXRAD Level 2 Data (http://hurricane.ncdc.noaa.gov/pls/plhas/HAS.FileAppSelect?datasetname=6500), and Unidata's six month data cache (http://lead.unidata.ucar.edu:8080/thredds/idd/radars12.html).

All cases considered in this study were observed for the parameters stated above during the time of the tornado. For example, if an F2/EF2 tornado struck a certain location at 2154 UTC, then the parameters were observed for the storm at 2154 UTC.

Once all of the data was collected, the parameters were broken up into a spreadsheet. Afterward, the data was entered into the statistical analysis program known as SAS's JMP. Through JMP, quartile box plots, the means and standard deviations were calculated. These plots are to be used for the purpose of finding any correlations and/or statistical trends within the parameters observed.

4. Results

a. Box plots

The box plots show the 75%, 50%, and 25% quartiles. The blue line that connects each box plot shows the mean of each parameter for each category of the Fujita Scale. Note that the box plots for the 50 dBZ Height, and Echo Top Height are plotted in feet since the GR2AE algorithm does as such.

1) 50 DBZ HEIGHT

Figure 3 shows the box plots for the 50 dBZ Height. There is a distinct mean trend present in the chart, most specifically an increase from the F1/EF1 cases to the F3/EF3 cases. However, there was a decrease in the mean from the F0/EF0 category to the F1/EF1 category, and the mean trend leveled off from the F3/EF3 to the F4/EF4 and F5/EF5.

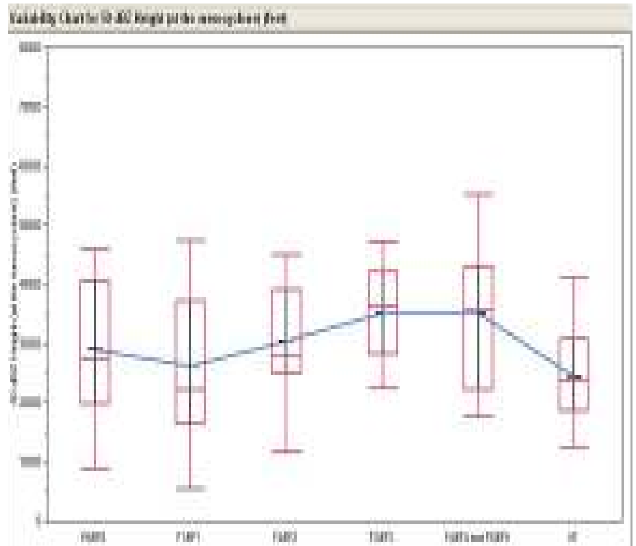

Figure 3: Box plots for the 50 dBZ parameter. The blue line represents the trend in the mean of each Fujita Scale category.

Another category to notice is the null cases. The mean for the null case was 24497.6 feet (7466.9 meters). Clearly, the null cases show a tendency to have a very low 50 dBZ Height compared to all of the tornado categories.

A probable reason for the trend to level off at the F4/EF4 and F5/EF5 category might be due to vertical wind shear. Sometimes wind shear could tilt the thunderstorm so much that the updraft doesn't extend the storm straight up, but instead, propagates at an angle. Figure 4 shows a storm that is tilted at an angle, prohibiting it to propagate along the vertical axis.

2) ECHO TOP HEIGHT

Figure 5 shows the box plots for the Echo Top Height. The mean trend of the Echo Top Height is similar to that of the 50 dBZ Height. There is a clearly visible increase in the mean Echo Top Height from the F1/EF1

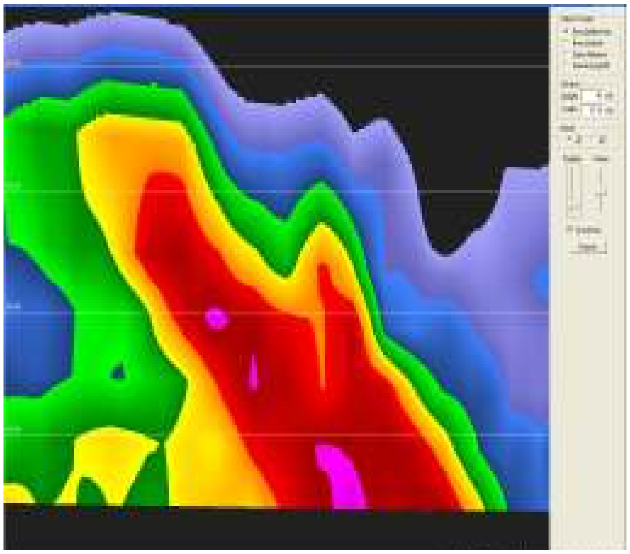

Figure 4: An example of how vertical wind shear can tilt a storm so the updraft doesn't reach its highest potential height.

category to the F3/EF3 category. However, once again, there is a visible decrease in the mean Echo Top Height from the F0/EF0 category to the F1/EF1 by 1780 feet (542.6 meters). The only way the Echo Top Height box plots are different than the 50 dBZ Height box plots are the fact that there is a slight increase in the mean from the F3/EF3 category to the F4/EF4 and F5/EF5 category.

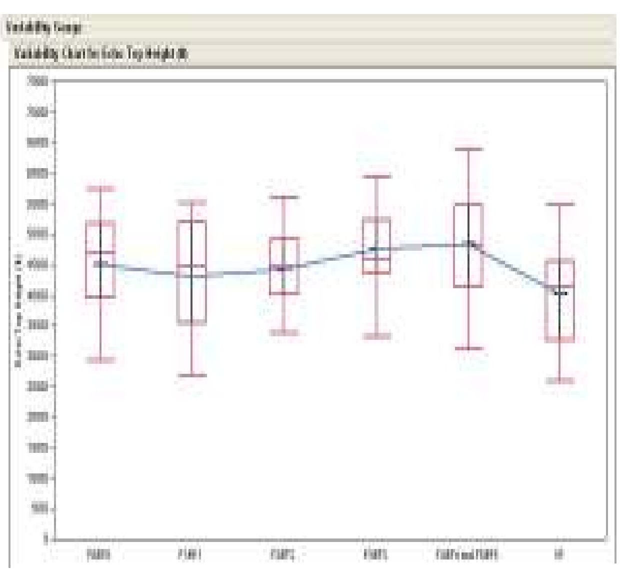

Figure 5: Box plots for the Echo Top Height parameter. The blue line represents the mean of each Fujita Scale category.

Again, the mean of the null case category is the lowest of the plot, with a mean of 40047.9 feet (12,206.6 meters).

3) VIL

Figure 6 shows the box plots for Vertically Integrated Liquid. There is a visible increase in the mean trend from F1/EF1 to F3/EF3, much like the 50 dBZ Height. There is also a level trend from the F0/EF1 category to the F1/EF1 category, and a decrease in the mean trend from the F3/EF3 category to the F4/EF4 and F5/EF5 category.

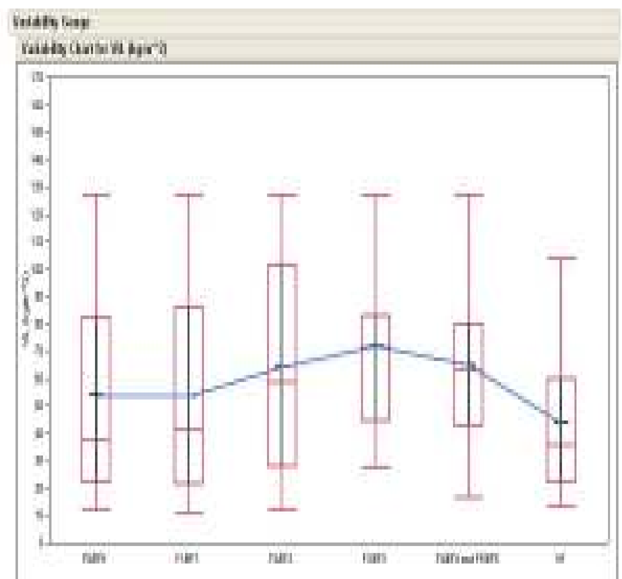

Figure 6: Box plots for VIL parameter. The blue line links the mean of each category.

The highest outlier for the VIL parameter box plots, which occurs for all of the Fujita Scale cases, was 127 kg/m².

The mean for the null case category was, once again, the lowest mean, which was 43.6 kg/m², of the entire box plot, and it had the lowest 75% quartile of the entire box plot.

4) VILD

Figure 7 shows the box plots for Vertically Integrated Liquid Density. There is a gradual increase in the mean trend from the F0/EF0 category to the F3/EF3 category, although the trend tended to level off from the category F2/EF2 to the category F3/EF3. Also, there was a decreasing mean trend from the F3/EF3 category to the F4/EF4 and F5/EF5 category.

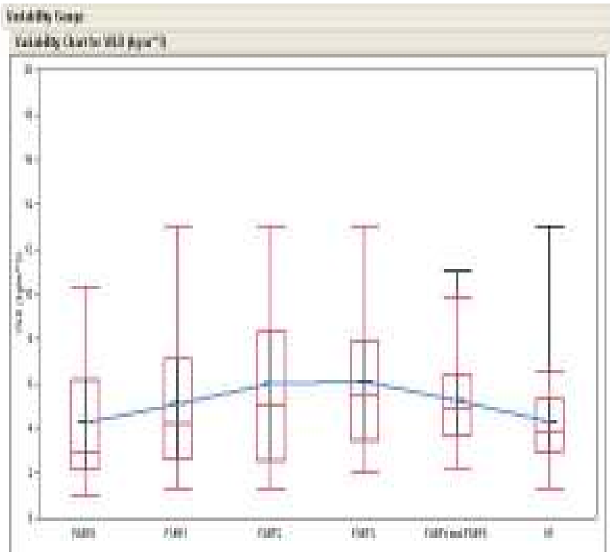

Figure 7: Box plots for VILD. The blue line connects the means of each box plot.

Again, the null cases' mean was the lowest in the entire box plot with a mean of 4.25 kg/m³.

b. Means and Std. Dev.

Figure 8 below shows the means for all of the parameters and all of the Fujita Scale categories.

MEANS

Categories	50 dBZ Height (meters)	Echo Top Height (meters)	VIL (kg/m²)	VILD (kg/m³)
NT	7466.9	12206.6	43.65	4.29
F0/EF0	8855.9	13689.2	53.89	4.25
F1/EF1	7963.9	13146.6	53.38	5.08
F2/EF2	9255.2	13503.9	64.24	6.0
F3/EF3	10721.2	14523.1	71.81	6.09
F4/EF4 and F5/EF5	10703.9	14729.2	65.02	5.27

Figure 8: The means of each Fujita Scale category and for each parameter.

Figure 9 shows the standard deviations for all of the parameters and all of the Fujita Scale categories.

STANDARD DEVIATIONS

Categories	50 dBZ Height (meters)	Echo Top Height (meters)	VIL (kg/m²)	VILD (kg/m³)
NT	2365.6	2302.3	26.17	2.32
F0/EF0	3457.8	2572.5	37.99	2.66
F1/EF1	3744.8	2641.7	40.65	3.35
F2/EF2	2720.1	1858.5	39.49	3.99
F3/EF3	2373.1	1994.9	30.65	3.27
F4/EF4 and F5/EF5	3484.9	2680.6	32.48	2.12

Figure 9: The standard deviations of each Fujita Scale category and for each parameter.

From observing Figure 8, there is a definite trend in the data for each parameter in the means chart as the means of the 50 dBZ Height, Echo Top Height, VIL and VILD parameters all show an increase from the NT cases to the F4/EF4 and F5/EF5 cases.

Figure 9 suggests that there is a lot of overlap in the parameters for each category, and the box plots in Figures 4, 5, 6, and 7 suggest that this is true by overlapping the box plots of the upper, middle, and lower quartiles. However, the general trends in the data do show a visible increase in the trends of the means.

The increasing trend in the data would suggest that indeed the updraft strength is increasing with increasing tornado intensity.

5. Conclusions

The general trends in the box plots and the means show that there is an increasing trend in the means. This would ultimately imply that the strength of the updraft is increasing as the tornado intensity increases. Since these four parameters are dependent on the strength of the updraft as was stated in the **Methods and Analysis** section, it can be conclusively said that there is an increase in supercell updraft strength.

Even though there is a correlation in these parameters with respect to the tornado intensity, this still isn't mathematically sound. Further research is needed to be able to decisively quantify the updraft strength. Since the method used for this study is only an implication, it is still not a concrete method of gauging the updraft strength.

There is a clear decrease in the trends of the means of the 50 dBZ Height, Echo Top Height, and VIL, from the category F0/EF0 to category F1/EF1. This decrease is a fascinating find. Additional research is needed to understand why this decreasing trend occurs.

In summary, additional research is needed to quantify the updraft strength to explicitly correlate the updraft strength and tornado intensity, instead of implying the updraft strength by parameterization.

6) References

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