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RELATIONSHIPS OF VARIOUS SOUNDING PARAMETERS DURING HAIL EVENTS IN THE CHICAGO COUNTY WARNING AREA

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1. Introduction

Between 1990 and 1999, there were nine days per year, on average, with reports of hail (0.75 in diameter or greater) within the County Warning Area (CWA) of the National Weather Service's Chicago office. When making warning decisions it is critical that forecasters are able to recognize pre-storm environments that favor hail production. One of the more common variables forecasters tend to use when diagnosing pre-storm environment is the height of the wet bulb zero. In general, when the height of the wet bulb zero is high (greater than 12,000 ft, for instance), the threat of severe hail is significantly lower as the hail will have more time to melt as it descends toward the surface.

Previous studies have found that more than 90% of reported hail events in the Midwest occur when the wet bulb zero height is between 5,000 and 12,000 ft (Miller 1972). The initial intent of this study was to develop a local climatology of wet bulb zero heights during severe hail occurrences in the NWS Chicago's CWA. The results led to more questions than answers. With more than 40% of the severe hail events in the CWA having occurred in environments with wet bulb zero heights above 12,000 ft, it appears that wet bulb zero heights are a poor indicator, at best, for anticipating hail producing thunderstorms.

Given the inconclusive nature of wet bulb zero heights as a predictor of hail, other sounding parameters were examined in an attempt to locate other variables that may be more useful than wet bulb zero in assessing pre storm environment and the threat of severe hail. Parameters such as environmental freezing level, lapse rates, and 500mb wind speed were created to look for possible connections with hail events. The results in this study were very much in line with what Edwards and Thompson (1998) found on a national basis, that is, singular parameters tend to be poor predictors of severe hail.

2. Data and Methodology

a. Hail Reports

For the period 1971-1995, using the Storm Prediction Center's Severe Plot Software (Hart 1999), reports of hail equal to or greater than 0.75 in were gathered. These reports were then broken down into separate events. For the purpose of this study, an event is defined as any six hour period when at least two reports of severe hail were received. If more than six hours elapsed with no severe hail reports then it was considered to be separate events.

b. Soundings

For each of the observed hail events wet-bulb zero heights, lapse rates, and 500 mb wind speeds were determined using radiosonde data provided by Forecast Systems Laboratory, Boulder, Colorado. Soundings taken before and after each hail event were carefully examined to determine, subjectively, which sounding was most likely representative of the environment in which the severe hail was produced. Soundings examined in this study were primarily taken at Peoria, Illinois. However in 1995 the radiosonde site was moved from Peoria to Lincoln, Il and for that year Lincoln's soundings were used. In the majority of cases the Peoria site proved to be ideal since it is located approximately 80 miles southwest of the center of the Chicago CWA, and in general should be fairly representative of the upstream environment.

c. Event Classification

Once 77 events were identified, they were broken up into separate categories based on severity of the event and the time of year. In order to distinguish between a *marginal* hail event and one of greater importance, a second category was created for significant events. For the purpose of this study an event is classified as significant if there were two or more reports of hail *greater than* one inch received within a six hour period. In addition, events that occurred between June 15 and September 15 were classified as summer events, with all others considered spring events. There were a few events that occurred toward the end of September and one event that occurred in November. For the sake of simplicity these were lumped together with the spring events.

3. Results

a. Height of the Environmental Freezing Level

The first parameter investigated was the environmental freezing level. Higher freezing levels would yield a lower frequency of hail occurrences as they would tend to be more indicative of a tropical air mass, and the hail stones would fall through a deeper depth of above freezing temperatures. Comparing the frequency of hail events during various freezing levels for all events (Fig. 1), it is clear that the freezing level most favored fell between 14,000 and 15,000 ft.

In Fig 1, a minimum in marginal events is evident around 13,000 ft, while maxima of marginal events are around 14,000 ft and around 12,000 ft. This suggests there are two types of cool season events. Early and colder cool season events occur with a local maximum between 11,000 and 13,000 ft. A secondary maximum appears in the 14,000 ft, range likely being indicative of the warmer, near summertime events. This conclusion appears to be somewhat supported in Fig. 2, as two distinct maxima appear during spring, both above and below 13,000 ft.

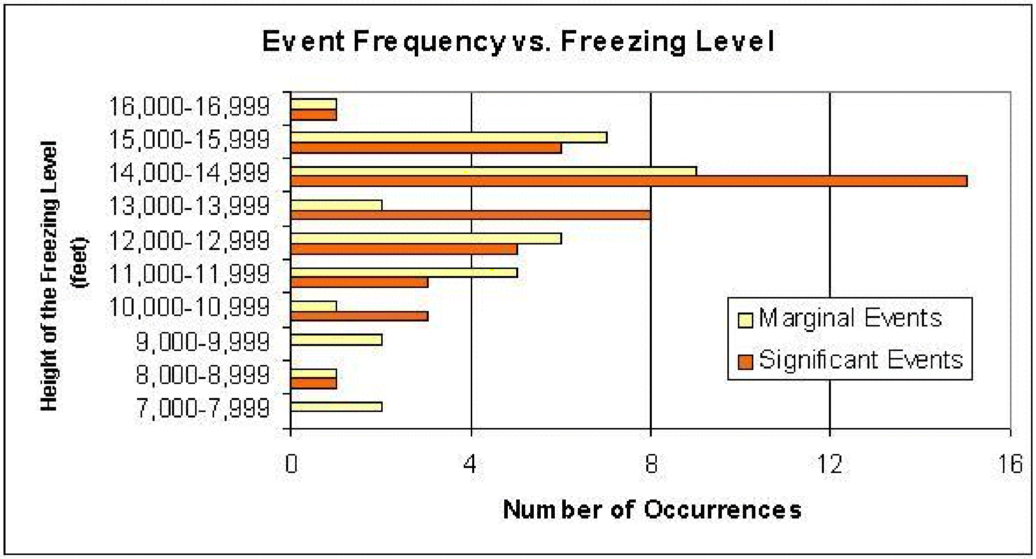

Figure 1. Chart comparing the significant and marginal hail event frequency with the various freezing levels.

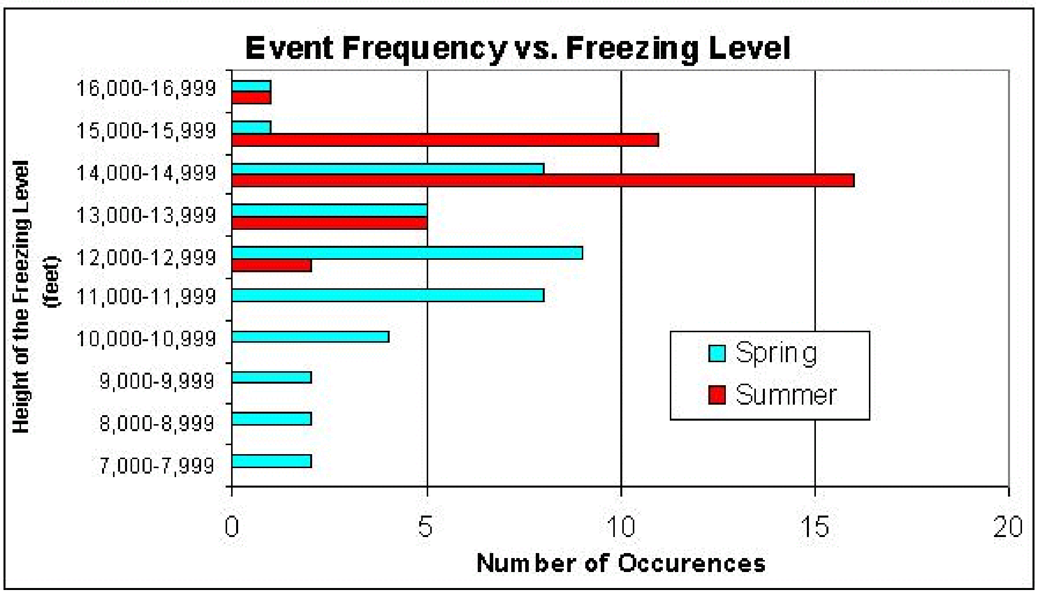

Figure 2. Chart comparing the warm season and cool season event frequency with the various freezing levels.

2. Height of the Wet Bulb Zero

One of the potential downfalls of using the freezing level when diagnosing hail potential is that the freezing level often lowers during convection as the atmosphere becomes saturated. In order to avoid this problem, forecasters often look at the wet bulb temperature, which is the temperature at which a parcel would become saturated if water is evaporated into it at a constant volume and constant pressure (Byers 1974). By using the wet bulb temperature, and looking for the height of the wet bulb zero, forecasters get a better handle on what height the freezing may be once the atmosphere is saturated.

When examining the frequency of hail events during various wet bulb zero heights in the Chicago CWA, a few rather surprising results appeared. Figure 3 suggests that the most frequent wet bulb zero heights during hail events in the Chicago CWA are between 11,000 and 14,000 ft, which is substantially higher than what previous studies had suggested (Miller 1972). For significant hail events there is an obvious peak between 11,000 and 12,000 ft, while in marginal events the most frequent occurrences were between 13,000 and 14,000 ft.

As one would likely expect, comparing frequencies by season (Fig. 4), the wet bulb zero heights tend to be lower during the spring. However, there have been several severe hail events with wet bulb zeros above 13,000 ft during spring. So even during the cool season, high wet bulb zeros do not necessarily preclude the development of severe hail producing thunderstorms. During the warm season, the most frequent wet bulb zero heights during hail events are between 13,000 and 14,000 ft, which are often considered too high to support severe hail.

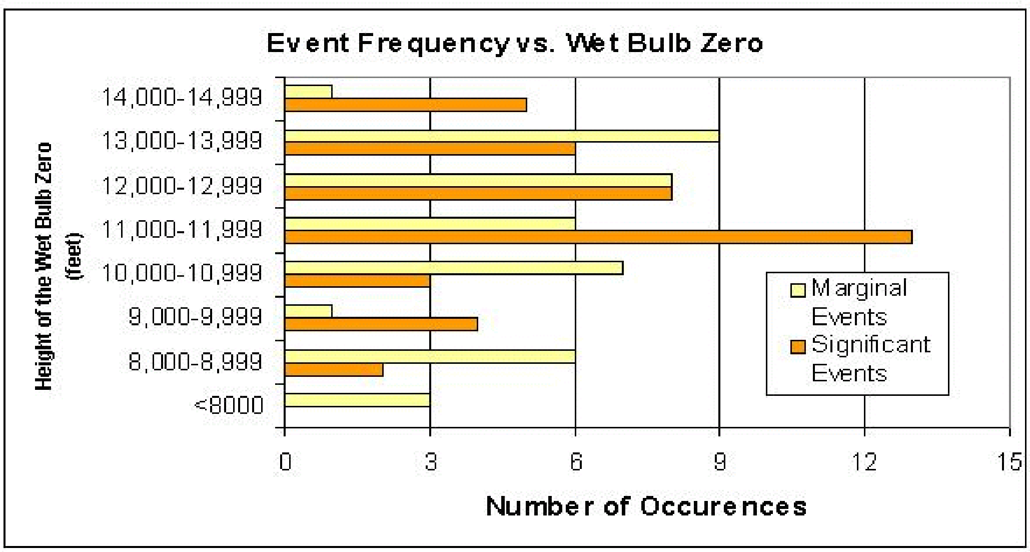

Figure 3. Chart comparing the significant and marginal hail event frequency with the various wet bulb zero heights.

3. Wind Speeds at 500 mb

In order to attempt to get a better understanding of the amount of dynamics involved in the development of hail producing thunderstorms 500 mb wind speeds were examined. The assumption is that the stronger 500 mb winds would tend to indicate a more vigorous synoptic system. A stronger 500 mb wind might also be indicative of

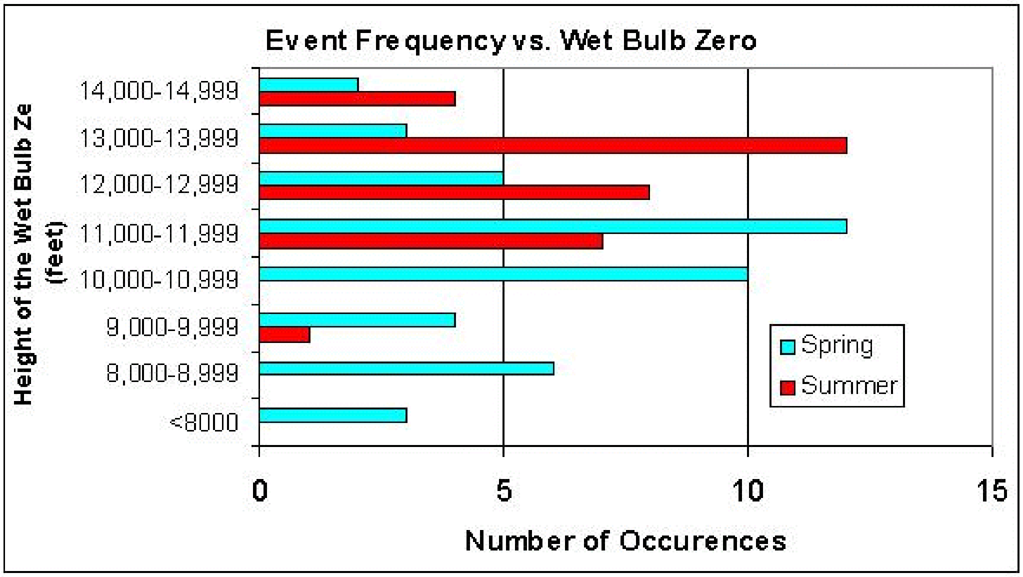

Figure 4. A comparison of warm season and cool season event frequency with the various wet bulb zero heights.

a more strongly sheared environment where thunderstorm updrafts may be more sustained. One would expect to find the stronger 500 mb winds associated with more severe hail events than a with a weak flow at 500 mb.

The majority of all hail events occurred when the 500 mb wind speed was between twenty and forty knots. However breaking that down further, Figure 5 shows that marginal hail events tend to occur with twenty to thirty knot winds and as the wind speeds increase to between thirty and forty knots the frequency of significant events nearly triples. It is worth noting that substantial number of events have been observed with 500 mb wind speeds less than 30 knots.

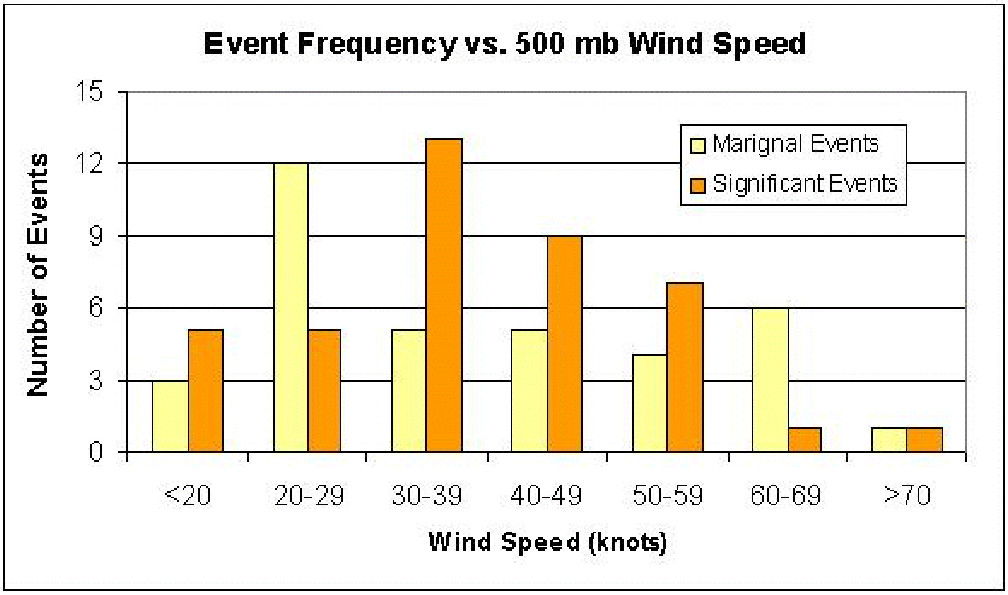

Figure 5. A comparison of number of hail events and wind speeds at 500 mb.

4. 700-500 mb Lapse Rates

Mid level lapse rates were examined to obtain a better understanding of the amount of instability present during the various hail events. Another benefit to looking at lapse rates is that the steeper lapse rates tend to be indicative of some combination of either cold air advection in the mid levels and/or low level warm air advection, either of which would act to decrease the overall stability of the atmosphere. So it would be logical to expect that a greater number of hail events, especially significant one would occur during times of steep lapse rates in the 700-500 mb layer.

A seasonal distribution of hail frequency during various lapse rates (Fig. 6) shows that the majority of summer hail events occurred with relatively weak lapse rates, with more than two thirds of the events occurring with lapse rates less than 7°C/km. Lapse rates between 850-500 mb were also examined (not shown), but the 700-500 mb lapse rates generally offered a better correlation to hail occurrences. For a point of reference, the moist adiabatic lapse rate is generally around 6°C/km, while the dry adiabatic lapse rate is 9.8°C/km.

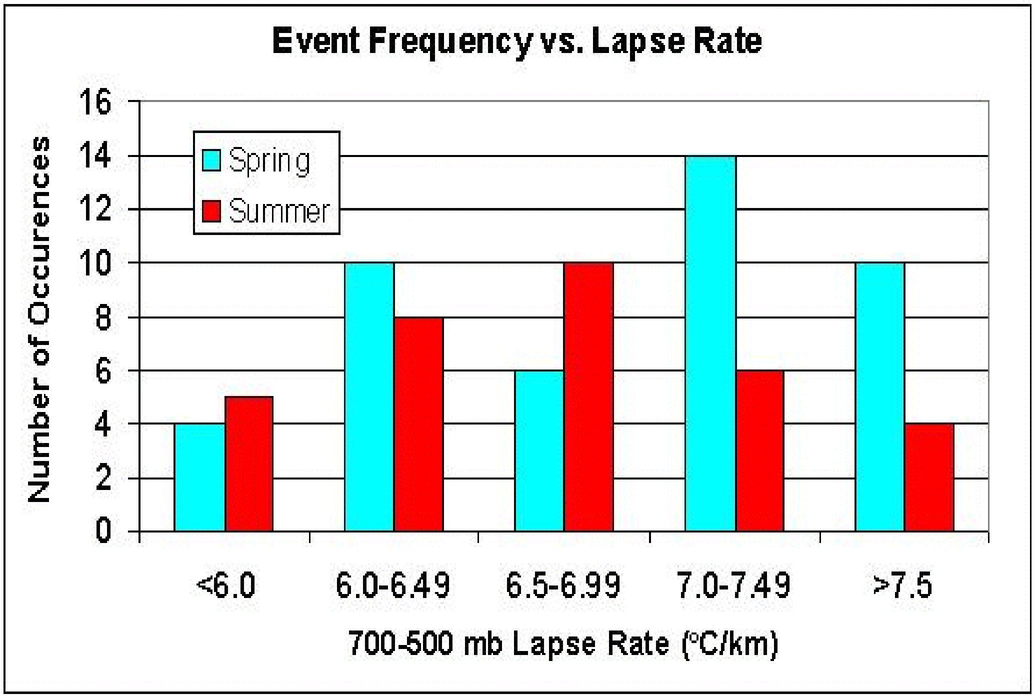

Figure 6. Distribution of hail events by season and lapse rate.

It would be expected that the significant hail events would favor steeper lapse rate environments and that the more marginal hail events will tend to be clustered in the weaker lapse rate range. While this is the case, the extent to which it is true is not as much as expected. The distribution of significant events leans heavily to the side of steeper lapse rates (Fig. 7), with nearly three fourths of all significant hail events occurring when the environmental lapse rate was at 6.5°C/km or steeper. For marginal hail events the distribution varies greatly with no appreciable pattern evident. This indicated that the range of environments or instabilities in which a marginal hail event can occur is much broader than that for a significant hail event.

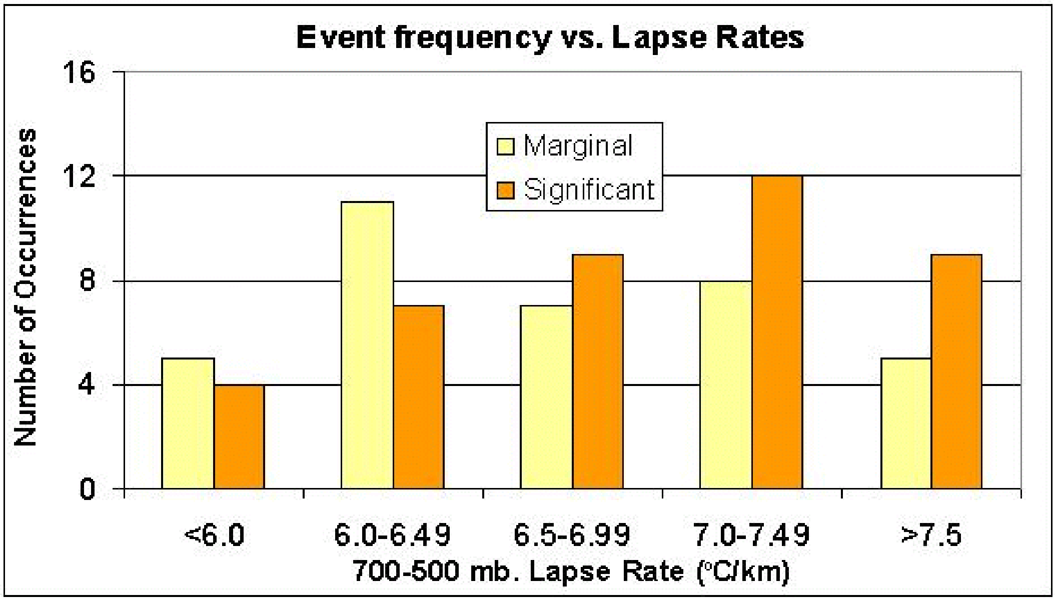

Figure 7. Distribution of hail events by severity of event and lapse rate.

5. Combining Instability with Wet Bulb Zero Height

Making a clear determination of any relationships between hail events and wet bulb zero heights or lapse rates is difficult because hail events have occurred over such a large range of both instabilities and wet bulb zero heights. In an attempt to find a better correlation the relationship between wet bulb zero height and lapse rates during hail events were examined.

A scatter plot of the height of the wet bulb zero and the lapse rate for each hail event (Fig. 8), both significant and marginal, reveals no apparent strong positive correlations. The correlation coefficient for spring events was 0.17, while summer was only 0.01. Despite the fact the correlation coefficients are so low, the trend line for spring events clearly shows that there is some relationship between wet bulb zero height and mid level lapse rates for all events. The trend line for summer events is nearly horizontal, which is likely a result of (1) less variability of the wet bulb zero height during the summer, and (2) a few marginal hail events that occurred with very weak lapse rates (less that 6.0°C/km) and wet bulb zero heights above 13,000 ft.

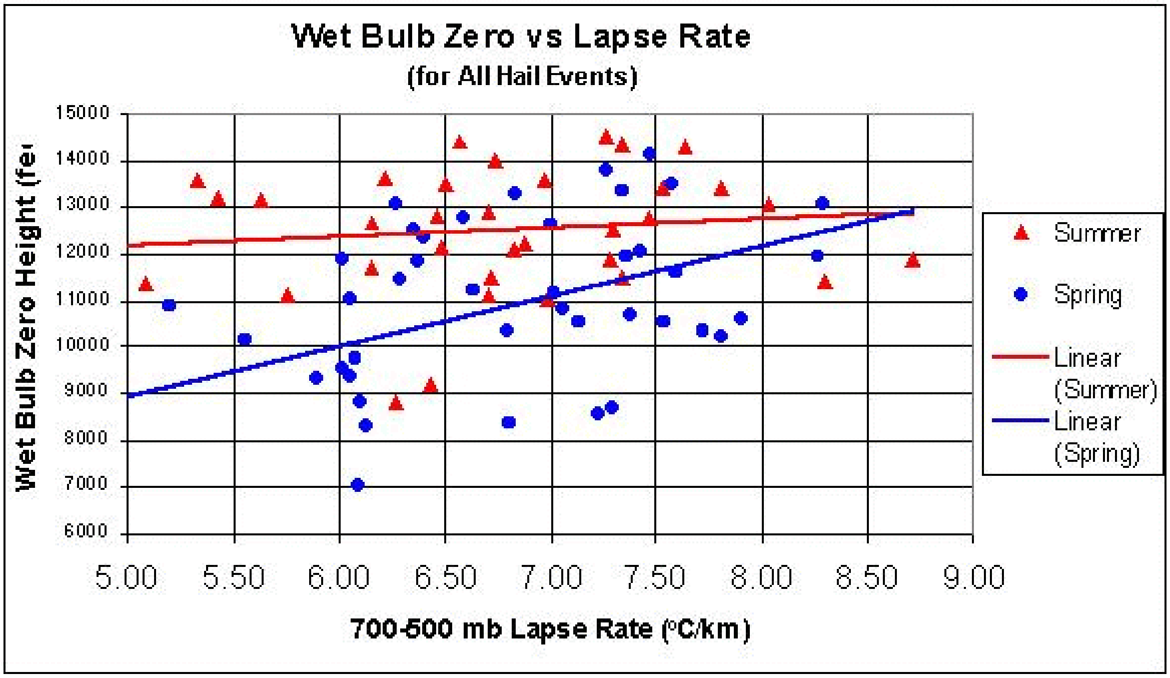

Figure 8. Scatter plot diagram comparing the wet bulb zero height with the lapse rate during hail events in the Chicago CWA.

When eliminating the marginal hail events and just examining significant hail events (Fig. 9), a few things stand out. First, the threesummer time hail events that occurred with very weak lapse rates and with very high wet bulb zeros disappear. Second, the trend line for summer events is no longer horizontal, in fact it becomes nearly parallel with the spring trend line. While the correlation coefficient for spring remains nearly identical, the coefficients for summer increases from 0.01 to 0.22, so a much stronger relationship exists between wet bulb zeros and lapse rates for significant events during the summer than for marginal events. So while hail events can occur with wet bulb zeros over 14,000 ft in the Chicago CWA, no significant hail events have occurred with wet bulb zeros above 13,000 ft. and with lapse rates weaker than 6.5 °C/km. In fact, on days with wet bulb zeros above 12,500 ft. more than three out of every four events occurs when the lapse rate is steeper than 6.5°C/km (Fig. 10). During the spring, only once in the 25 year period of this study was there a hail event with a high wet bulb zero (>12,500 ft.) and a weak lapse rate (<6.5°C/km). When diagnosing the hail threat in a pre storm environment, examining instability or lapse rates in conjunction with wet bulb zero heights seems to be a more effective way of anticipating the hail threat for the Chicago CWA.

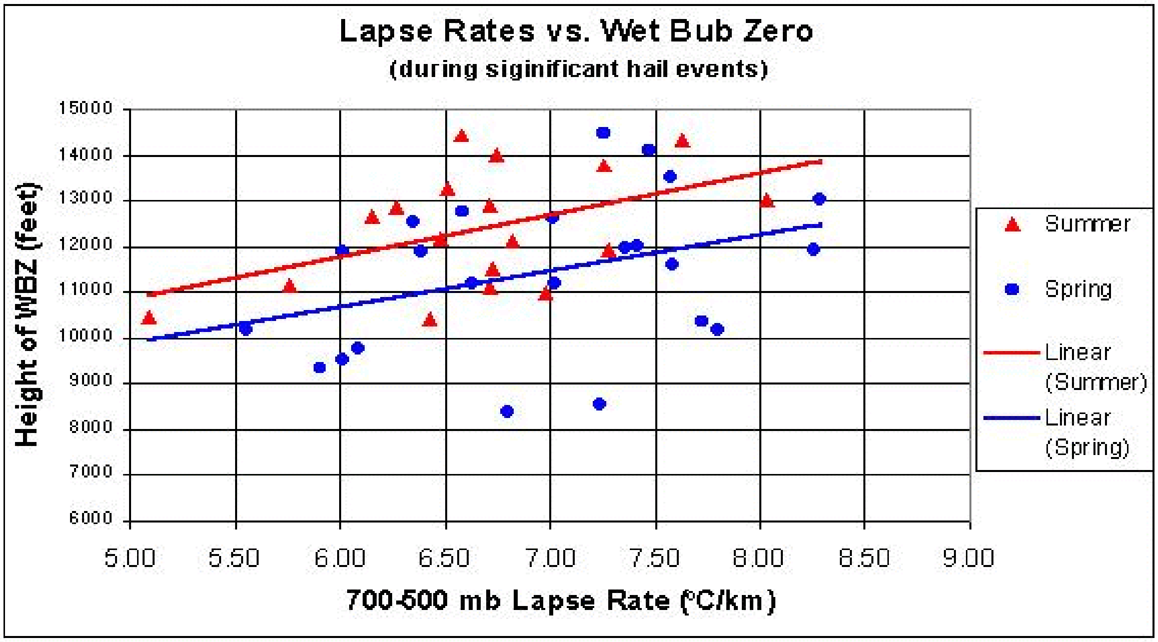

Figure 9. Scatter plot diagram comparing the wet bulb zero height with the lapse rate during *significant* hail events in the Chicago CWA.

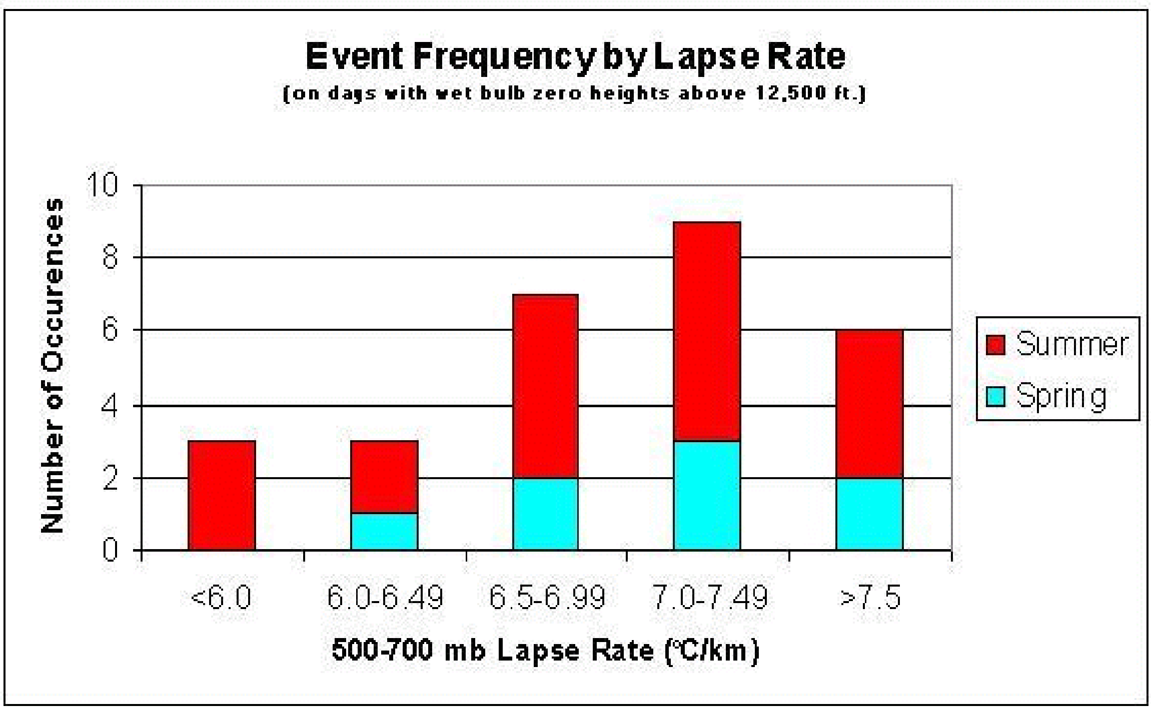

Figure 10. Histogram showing the hail frequency during various lapse rates for high wet bulb zero events.

4. Conclusions

The individual parameters examined in this study suggest that any of them individually are ineffective in diagnosing the severe hail threat for the Chicago CWA. For example, even traditional techniques such as examining the wet bulb zero height to assess the hail threat, are inconclusive. While previous studies had shown that hail events are associated with wet bulb zero heights at or below 10,500 ft (Miller 1972), this climatology clearly shows that not to be the case in the Chicago CWA. In fact nearly 50% of all hail events in the Chicago area occur with wet bulb zeros above 12,000 ft. It was found however that there is a relationship, albeit not an overly strong one, between the wet bulb zero height and environmental lapse rates. This relationship is strongest for significant hail events, but exists to a lesser extent for marginal events during the spring as well. So discounting the threat of large hail because wet bulb zeros are too high will lead to an erroneous assessment in the Chicago CWA. Using a combination of variables such as instability along with wet bulb zero height may lead to more insight into the hail threat.

While national studies correlating WSR-88D data with various sounding and thermodynamic properties have yielded less than promising results (Edwards and Thompson 1998), there have been some local studies that have found some positive correlation between sounding parameters and WSR-88D data for anticipating severe hail (Hart and Frantz 1998; Tardy 2001). So in order to improve the forecasters warning capabilities in the Chicago CWA, a more comprehensive study including WSR-88D data, soundings, and possibly even surface data should be conducted.

Acknowledgements

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