7A.9 STRONG AND VIOLENT TORNADO OUTBREAKS: COMPARISONS IN THERMODYNAMIC AND WIND PARAMETERS BETWEEN LARGE HAIL AND NON-LARGE HAIL EVENTS

Michael P. Seaman *
NOAA National Weather Service Weather Forecast Office
Salt Lake City, UT

Robert H. Johns
Norman, OK

1. INTRODUCTION

A popular misconception in the past has been that storms with associated mesocyclones (supercells) always produce large hail at the surface. However, there have been instances, primarily in the southeastern U.S., where strong and violent tornado outbreaks have occurred without the associated supercells producing large hail. Previous work in this area has focused on the frequency and distribution of these "no large hail" events (Johns and Hart, 1998, hereafter referred to as JH98).

This study focuses primarily on thermodynamic and instability parameters associated with both "large hail" (LH) and "no large hail" (NLH) cases, in an attempt to identify differences between LH and NLH environments. We focus this study on extratropical tornado cases, since it is known that tornado events resulting from tropical systems are typically not associated with large hail at the surface (JH98). The parameters investigated in this study are listed in table 1.

The methodology used to obtain data for this study is presented in Section 2. Thermodynamic and wind variables that appear to differentiate between NLH and LH environments are discussed in Section 3, and Section 4 summarizes the findings of the study.

2. METHODOLOGY

For tornado events JH98 identified cases in which multiple F2 tornadoes or an F3 or greater intensity tornado occurred. This criterion was employed in order to assure that most cases in the data set involved mesocyclones (supercells). JH98 defined LH cases as those having one or more reports of large hail ($\geq$ ¾ inch) within 200 statute miles of any tornadoes within the episode. Events not meeting this definition were classified as NLH events. Using Severe Plot v2.0, this study expands the JH98 database using the above methodology to cover the 30 year time period 1975-2004.

To study the environments in which both LH and NLH storms were occurring, proximity sounding data was gathered from radiosonde sites located within the same airmass as the tornadoes. Proximity soundings were defined to be those convectively uncontaminated soundings taken within 1 hour and 125 miles of a storm producing a tornado. Tornadoes reported within one hour of sounding times were retrieved, and the distance from the tornado location to the sounding site was calculated using the respective latitude and longitude points.

For each proximity sounding, instability parameters were generated using both a) a most unstable parcel within the lowest 300mb, and b) a 100mb mean layer parcel. Soundings which appeared convectively contaminated, or otherwise unrepresentative (i.e. no CAPE, deep surface stable layer, etc…), were thrown out. Additionally, because this study focused on events associated with extratropical cyclones, those events which resulted from a named tropical system were removed from the study, in order to avoid contaminating the NLH dataset. All NLH cases in the dataset were checked for proximity soundings. Proximity soundings for 30 cases

*Corresponding author address: Mike Seaman, National Weather Service, 2242 West North Temple, Salt Lake City UT, 84116; e-mail: Mike.Seaman@noaa.gov

Parameters		
Thermodynamic	Instability	Shear
700-500mb Lapse Rate Wet Bulb Zero Level Freezing Level Mean RH	CAPE -10°C to -30°C Layer CAPE 0-3km CAPE Equilibrium Height LCL Height LFC Height Lifted Parcel Level	0-6km Shear 0-3km SRH 0-1km SRH BRN Shear

Table 1 – Parameters investigated in this study. Instability parameters for both a most unstable parcel in the lowest 300mb, as well as a mean layer parcel within the lowest 100mb

from the LH dataset were then selected, with an attempt to identify cases which occurred in similar regions to those within the NLH dataset.

3. RESULTS

Using this expanded dataset, a total of 762 cases were identified: 649 LH cases and 112 NLH cases, including tropical cases. The geographical and temporal distribution of NLH cases for the expanded dataset was very similar to what was presented in JH98, and will not be presented here.

A total of 30 NLH proximity soundings were identified. Subsequently, 30 LH proximity soundings were then chosen from similar geographical regions to the NLH cases. The majority of these proximity soundings for both the LH and NLH were from the Southeastern United States, with additional proximity soundings taken from the Great Lakes region, as well as the Mid-Atlantic and Northeast. Examination of the data from these soundings reveals some noticeable differences between LH and NLH environments.

3.1 *Thermodynamic Parameters*

Differences in several different thermodynamic parameters were noted between the LH and NLH cases. For the LH proximity soundings, the mean lapse rates within the 700-500mb layer (Fig. 1) were somewhat steeper (6.1° C km^{-1}) than what was observed in the NLH proximity soundings (5.9° C km^{-1}). Steeper lapse rates within the 700-500mb layer would seem to imply colder mid level temperatures, as well as the potential for stronger instability within the hail growth zone (-10°C to -30°C). Stronger instability within this zone would support the production of larger hail stones within an updraft, with larger stones having a better chance of reaching the surface. This will be further discussed in Section 3.2.

Significant differences between LH and NLH episodes were also noted in the wet bulb zero level (Fig. 2) and freezing level (Fig. 3). For the selected cases, the mean wet-bulb zero level for NLH cases (3674m) was higher, by approximately 13%, than what is observed for LH cases (3215m). Additionally, the mean freezing level for NLH cases (4198m) was nearly 10% higher than the LH cases (3837m). Higher freezing levels associated with a warmer temperature profile would support greater melting of hail stones within the sub-cloud layer (Rasmussen and Heymsfield, 1987, hereafter RH87). This is particularly true for smaller hail stones, and would potentially keep these hail stones from reaching the surface before melting.

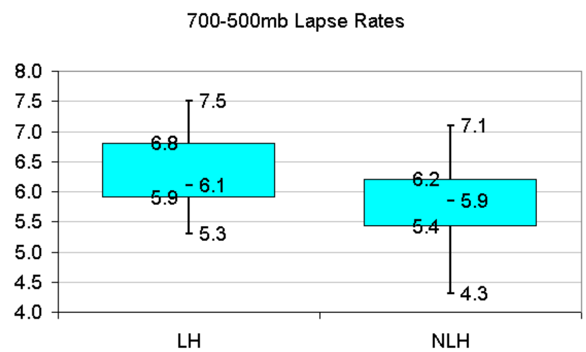

Figure 1. Box and whiskers plot of 700-500mb Lapse Rates for Large Hail (LH) and Non-Large Hail (NLH) events, in C km^{-1}. The top and bottom of the shaded boxes represent the 75th and 25th percentile, respectively. The median is denoted within each box. The whiskers extend up to the maximum, and down to the minimum.

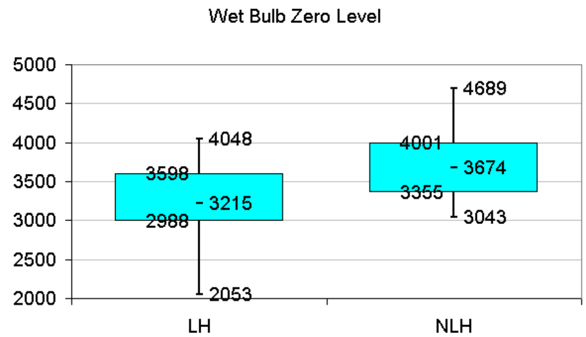

Figure 2. Box and whiskers plot of Wet Bulb Zero Level, in meters. The plotting conventions are as in Fig. 1.

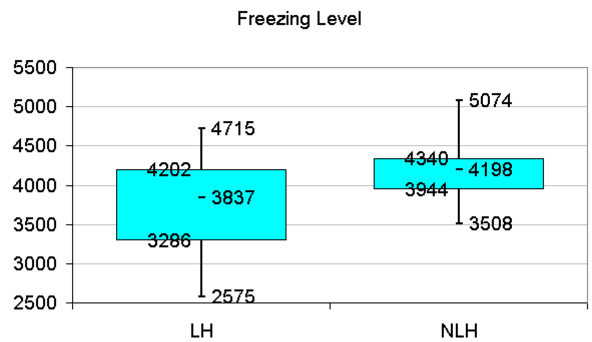

Figure 3. Box and whiskers plot of freezing level, in meters. The plotting conventions are as in Fig. 1.

3.2 Instability Parameters

CAPE values were calculated for both the most unstable parcel (MU) within the lowest 300mb, as well as the lowest 100mb mean layer (ML) parcel (Fig. 4). A virtual temperature correction was applied to for both parcels. For both MU CAPE and ML CAPE, instability was substantially greater for LH cases as opposed to NLH cases. In fact, the median ML CAPE was approximately 40% greater for LH cases (1423 J kg^{-1}) than what was observed for NLH cases (865 J kg^{-1}). Similar differences were noted for MU CAPE (not shown). The larger CAPE values within the LH soundings would seem to support stronger updrafts which could support larger hailstones. However, CAPE distribution is also important for the strength of an updraft, and thus, larger CAPE values alone may not necessarily be significant.

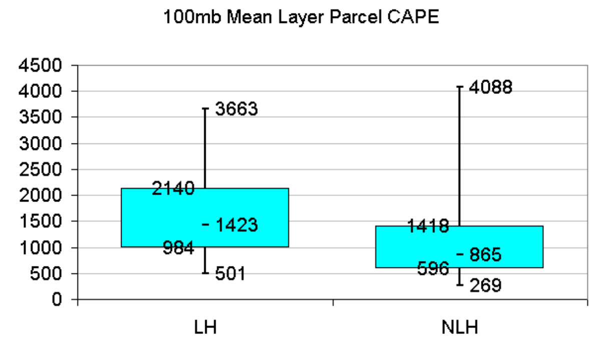

Figure 4. Box and whiskers plot of 100mb mean layer CAPE, in J kg^{-1}. The plotting conventions are as in Fig. 1.

CAPE was also calculated within the favorable hail growth zone (HCAPE) between -10°C and -30°C (Knight and Knight, 2001) for both MU and ML parcels (Fig 5). This shows perhaps the most pronounced difference between NLH and LH cases. For an ML parcel, mean HCAPE for LH cases (534 J kg^{-1}) was more than 40% larger than for NLH cases (306 J kg^{-1}). Similar differences (35%) were noted for MU parcels as well (not shown). Much larger HCAPE within an LH environment would tend to support the idea that larger hailstones are generated within these environments, as opposed to what is observed in the NLH environments. This stronger HCAPE seems likely to favor stronger updraft currents within the favorable hail growth zone, resulting in larger hailstones. Larger hailstones are less likely to be impacted by melting effects within the sub-cloud layer (RH87), and thus would be more likely to reach the surface before melting.

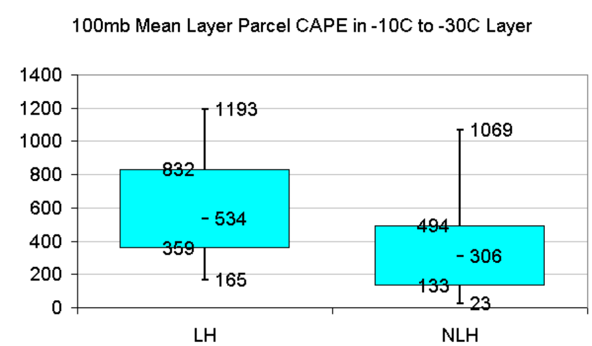

Figure 5. Box and whiskers plot of 100mb mean layer CAPE (J kg^{-1}) within the -10°C to -30°C layer. The plotting conventions are as in Fig. 1.

3.3 Shear Parameters

Deep layer shear (0-6km) also shows a significant difference between LH and NLH cases (Fig 6). For LH cases, 0-6km shear was substantially stronger (52 kts) than what was observed for NLH cases (42 kts). In order to better understand why deep layer shear might be stronger for LH cases, scatter plots of monthly distribution were created for freezing level (Fig 7) and 0-6km shear (Fig 8).

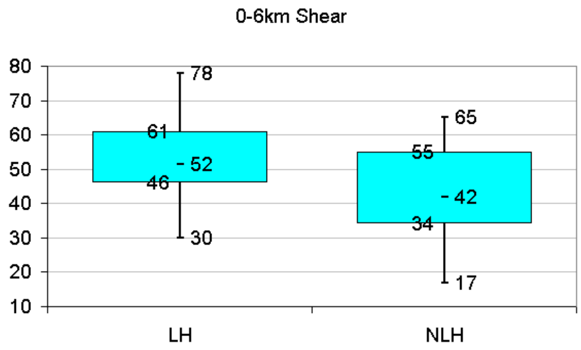

Figure 6. Box and whiskers plot of 0-6km shear, in knots. The plotting conventions are as in Fig. 1.

Many of the NLH proximity soundings used in this study were observed during the late spring through early fall, when shear is weaker and freezing levels are higher. Very few if any LH events meeting the JH98 tornado criteria occurred across the Southeastern U.S. during the late spring, although there were many NLH cases across that region during the same time frame. LH cases during the late spring through early fall were only available for locations further north such as the Great Lakes region. It seems entirely plausible that the differences observed in the 0-6km shear profiles is more a result of seasonal distribution, and less from any impact of strong to extreme deep layer shear on hail production.

Low level shear parameters such as 0-1km and 0-3km storm relative helicity (SRH) are highly dependent on mesoscale features such as outflow boundaries. Markowski et. al, (1998) suggested significant tornadoes often develop in close proximity to surface boundaries, and that the

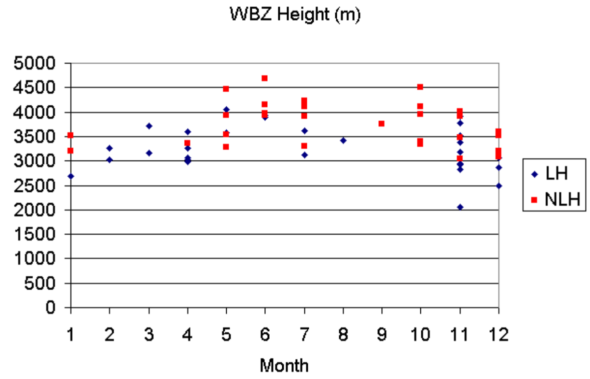

Figure 7 Scatter plot of wet bulb zero heights, in meters, verses month.

distribution of SRH varies greatly on small scales near a boundary. As a result, calculation of representative low level shear would likely require significant modification of the winds within the observed soundings, and was not included in this study.

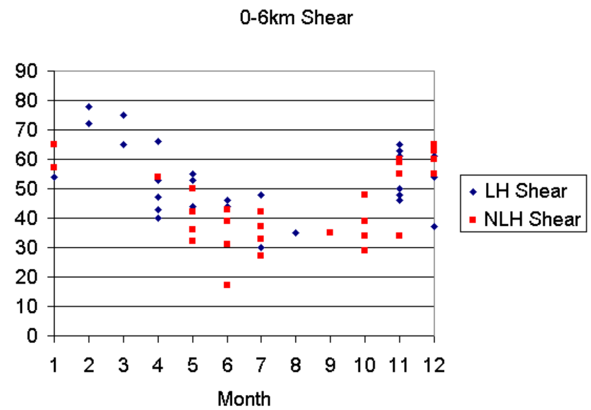

Figure 8. Scatter plot of 0-6km Shear, in knots, vs month.

3.4 Additional Observations and Results

There were only small differences noted in the other observed parameters listed in Table 1. Minor differences were noted in both LCL and LFC heights. However in both LH and NLH cases these values fell well below 1500m. These low values indicate high boundary layer moisture is present in both types of cases, which would support an increased melting rate. Since these low heights were noted for both types of events, they were deemed insignificant. Additionally, only minor differences were noted for equilibrium heights for both LH and NLH cases.

Box and whisker diagrams (not shown) were also created using only those soundings in which a significant tornado (F2 or greater intensity) occurred within close proximity, as opposed to a tornado of any intensity occurring within close proximity. There were no noted differences in any of the aforementioned parameters between those soundings associated with significant tornadoes, and those associated with any type of tornado.

4. CONCLUSIONS

Significant differences between LH and NLH environments were identified. The most significant differences appear to be substantially higher freezing and wet-bulb zero levels associated with NLH events, as well as higher CAPE values associated with LH cases. The higher CAPE values were most significant within the hail growth zone between -10°C and -30°C in the LH cases. These results would seem to suggest that larger hailstones are typically generated from updrafts within a LH environment as opposed to a NLH environment. Because of their larger size, these stones would be far less impacted by melting effects as opposed to the smaller stones generated within a typical NLH environment. Additionally, the substantially higher freezing levels within the NLH environment promote melting of these smaller hailstones, which would significantly reduce their odds of reaching the surface.

5. REFERENCES

Johns, R. H. and John A. Hart, 1998: The Occurrence and Non-Occurrence of Large Hail with Strong and Violent Tornado Episodes: Frequency Distributions. Preprints, 19th Conf. Severe Local Storms, Minneapolis, Amer. Meteor. Soc., 283-286

Knight, C. M. and N. C. Knight, 2001: Hailstorms. Severe Convective Storms, C. A. Doswell, Ed., Amer. Meteor. Soc., 223-254.

Markowski, P. M., E.N. Rasmussen, and J. M. Straka, 1998: The Occurrence of Tornadoes in Supercells Interacting with Boundaries during VORTEX-95. Wea. Forecasting, 13, 852-859.

Rasmussen, R.M. and A. J. Heymsfield, 1987: Melting and Shedding of Graupel and Hail. Part II: Sensitivity Study. J. Atmos. Sci., 44, 2764-2782.