P1.1 Examining Preconvective Heavy Rainfall Environments Utilizing Observational and Model Analysis Proximity Soundings

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Cooperative Institute for Precipitation Systems CIPS A Tribute to James T. Moore

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Heavy Rainfall Forecast Problems

Extreme weather has an enormous impact on all facets of transportation. According to the Weather Information for Surface Transportation (WIST; 2005), there are:

1) Approximately 3.9 million miles of public roadways.

2) 122,000 miles of major railroad tracks.

3) Over 26,000 miles of commercially navigable waterways.

4) Nearly 5,300 public-use airports.

5) 28% of all highway crashes and 19% of all fatalities are directly or indirectly related to adverse weather conditions.

6) Weather-related crashes have an estimated annual economic impact of nearly 42 billion USD.

Heavy rainfall is just one type of treacherous weather event, but has the potential to cause a variety of socioeconomical problems:

1) Loss of or reduced visibility.

2) Flooding or flash flooding.

Both occur quickly on small time scales and are potentially deadly. According to WIST (2002), as visibility decreases the speed of traffic also decreases, especially when traffic flow increases (e.g., during the local rush hours). The faster the reduction of visibility, the quicker traffic must slow to prevent accidents. According to the National Oceanic and Atmospheric Administration (2006), every year flooding costs an average of over 2 billion USD in damages and causes over 100 fatalities. As areas become more populated and are covered with impermeable structures and surfaces, such as buildings and roads, the amount of strom-water runoff increases (Kelsch 2002). Consequently, modest rainfall episodes can become potentially dangerous flash flood situations.

Research Objective

The objective of the present study is to investigate proximity soundings (observation and model analysis) that sampled the environment within which a heavy rainfall event initiated or developed to better understand critical parameters (moisture, instability, wind shear, etc) and how those particular parameters are associated with differing rainfall amounts.

Heavy rainfall is defined as rainfall accumulations of 4 inches or more in a 24-h period from one precipitation system. The event must have occurred in the central United States from March through September for the years 2003 through 2005. This totaled 46 observed and 33 model analysis soundings.

The 4-inch dataset is compared to a dataset comprised of days where 1-2 inches of rainfall occurred, following the same guidelines as the 4-inch dataset. Totaling 73 observed and 47 model analysis soundings.

The Rapid Update Cycle Version 2 (RUC-2) was utilized with the following resolutions:

Horizontal Resolution:	40 km
Vertical Resolution:	40 layers

Overall, it is anticipated that forecasters will have the opportunity to recognize a potential heavy rainfall situation utilizing key sounding parameters rather than a light rainfall episode before it becomes a surprise storm for the community.

Domain and Definition of Proximity

Area within the black outline illustrates the domain for this study.

Spatial Criteria:

Soundings must be within 250 km of the region that received the greatest rainfall accumulation.

Temporal Criteria:

Soundings must be within 6 hours prior to convection affecting the region that received the greatest accumulation of rainfall.

Quality Control:

No major boundaries must exist between the soundings and the area of heavy precipitation within the 250 km spatial region.

Contaminated (i.e., outflow, precipitation) soundings were removed.

Suspect soundings with CAPE values greater than 5000 Jkg^{-1} were removed.

Justification of Proximity Criteria:

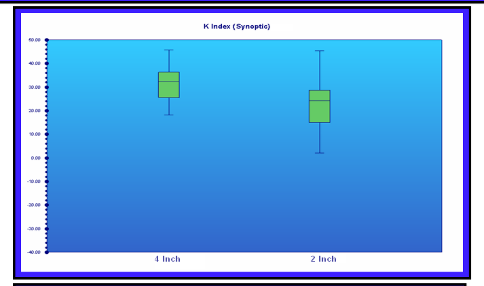
Beyond 250 km, there are numerous large-scale boundaries and potential contamination sources that limit the availability of other soundings.

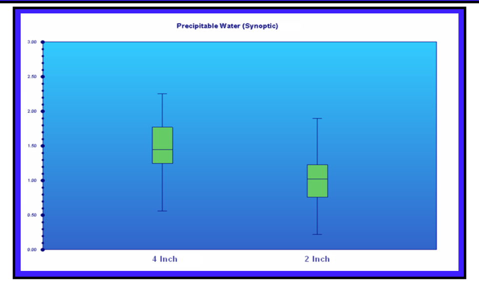
Cutting the spatial criteria in half drastically reduces the dataset, which would question the statistical significance of the results. 20 years would be needed to obtain the same number of soundings in the current dataset.

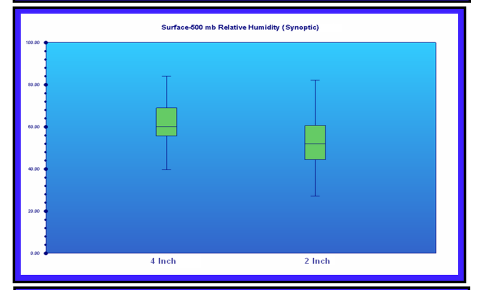
Beyond 6 hours, there are very few cases (12) that could be considered for this particular study. These 12 cases add no significant difference between categories.

Cutting the temporal criteria reduces the dataset by 40-50%.

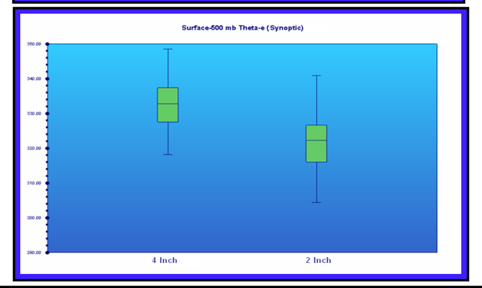
Four Inch vs Two Inch Synoptic-Type Events

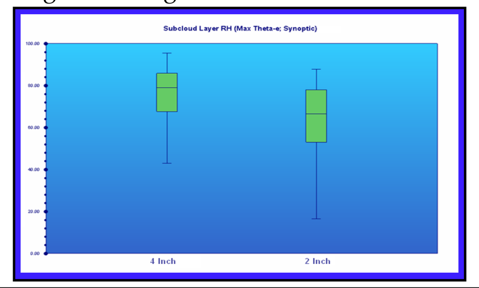


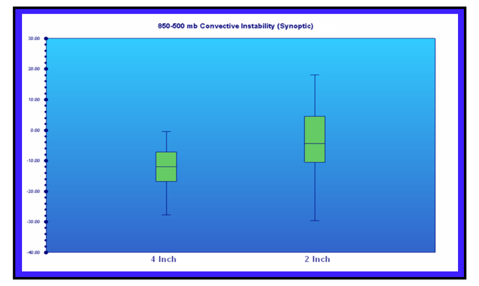




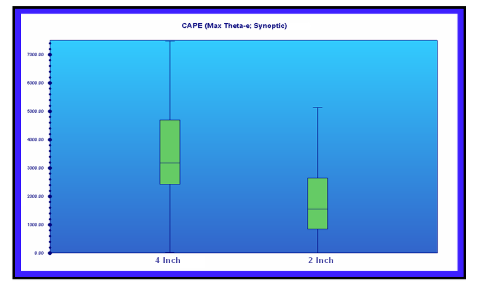
Moisture parameters depict a noticeable difference between 4-inch and 2-inch rainfall categories. These parameters illustrate an increase in moisture content in the atmosphere for the 4-inch rainfall days. Using the Mann-Whitney test statistic, all moisture parameters, even those not shown, depicted a less than one percent chance of the two rainfall categories being from the same distribution.



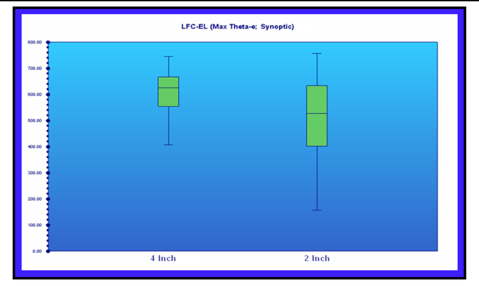


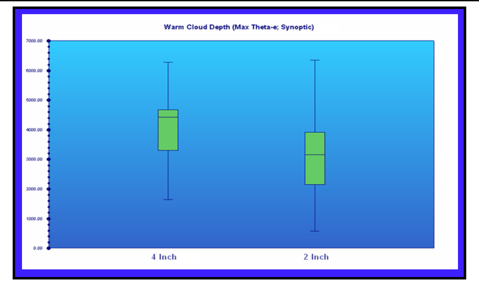


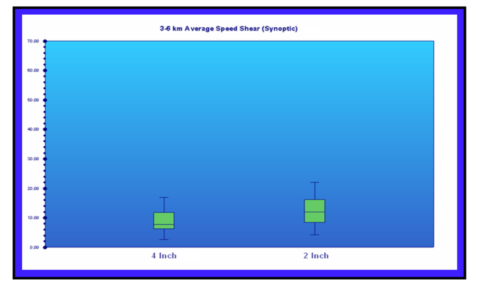
The 700-500 hPa lapse rates (not shown), 850-500 convective instability (shown above), and lid strength values decrease from the 2-inch to 4-inch rainfall categories. Coinciding with this decrease in stability, most unstable parcel convective available potential energy (MUCAPE; shown above right) increases across the rainfall categories. It is evident that the atmosphere is less stable for the 4-inch rainfall days when compared to the 2-inch days.



Nearly all instability parameters illustrated a less than one percent chance of the two rainfall categories being from the same distribution, when using the Mann-Whitney test statistic. Two parameters (most unstable parcel convective inhibition and convective temperature) demonstrated higher percentages, 2.385% and 20.327% respectively.



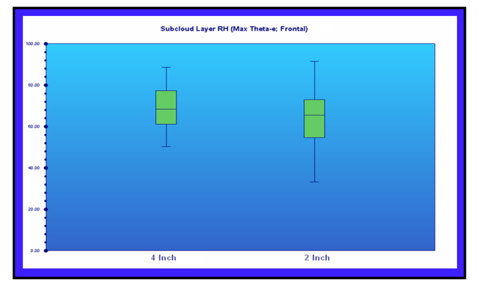


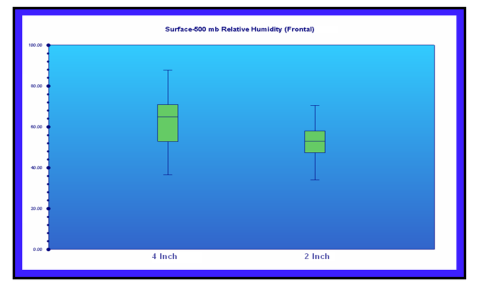


The distance between the LFC and EL (above left) increases from the 2-inch to 4-inch category. The warm cloud depth (above) values also increased, indicating higher freezing levels in the atmosphere. The Mann-Whitney statistics depicted the warm cloud depth and the distance between the LFC and EL to have percentages of less than one percent.

0-2, 0-3, 0-6, and 3-6 km speed and directional bulk shear were compared. Only two parameters depicted a difference. 0-3 km (not shown) and 3-6 km (shown above bottom) speed shear illustrate a decrease (i.e., a decrease in wind speed) from the 2-inch to 4-inch category. However, using the Mann-Whitney statistic for these two parameters, only the 3-6 km speed shear demonstrated a less than one percent chance of the two categories being from the same distribution. The 0-3 km speed shear showed a greater than 20% chance the two rainfall categories are related.

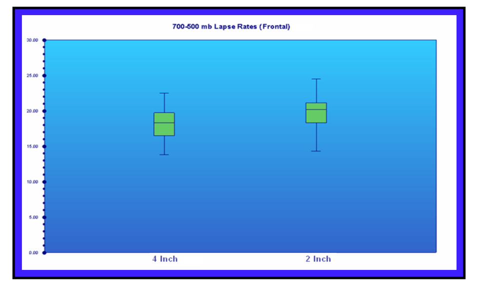
Four Inch vs Two Inch Frontal-Type Events

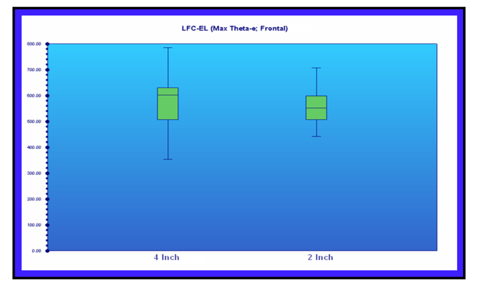




Only three parameters showed an increase in moisture from the 2-inch category to the 4-inch category. These key parameters are precipitable water (not shown), subcloud layer relative humidity (above left), and surface-500 hPa relative humidity (above right). Just as with the synoptic-type heavy rainfall events, an increase in these values was anticipated since there is an increase in rainfall amount, but for only three parameters to show a difference between rainfall categories was surprising.

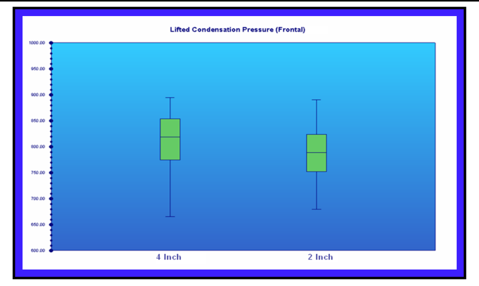
Of the three moisture parameters, only one demonstrated a less than one percent chance that the two rainfall distributions are related, or could have come from the same population, when utilizing the Mann-Whitney test statistic. This parameter was the surface-500 hPa relative humidity with a percentage of 0.038. The other two, PW and subcloud layer relative humidity, have percentages of 12.714 and 3.438, respectively.

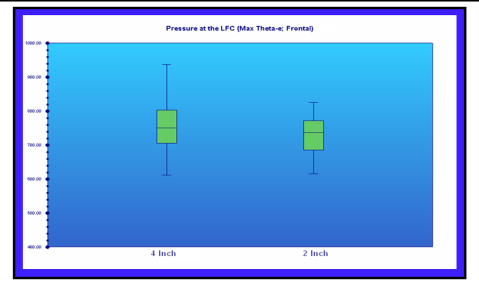




The 700-500 hPa lapse rates (above left), 850-500 hPa convective instability (not shown), and convective temperature (not shown) illustrate differences from the 2-inch to 4-inch rainfall categories. These are the only instability parameters that depict a difference between rainfall categories, which was another surprise.

The Mann-Whitney test was utilized once more. Of the three instability parameters that showed a difference, utilizing boxplots, only one illustrated a less than one percent chance of the two rainfall categories being from the same distribution. Surface-500 lapse rates have a percentage of 0.199. The other two parameters (850-500 hPa convective instability and convective temperature) have demonstrated higher percentages, which happen to be identical (10.383%).





Other parameters investigated also show little change between rainfall categories. The distance between the LFC and EL (directly left), LCP (above left), and the pressure level of the LFC (above right) were the only three additional parameters to depict an increase in values from the 2-inch to 4-inch categories. Therefore, there are lower LFC and LCL heights in the 4-inch rainfall category than the 2-inch, which allows for a greater distance between the LFC and EL.

The Mann-Whitney statistics identified the top three parameters in this category to be the distance between the LFC and EL, LCP, and the pressure level of the LFC with percentages of 4.363, 4.846, and 7.353, respectively. Thus, only two parameters illustrate a 95% confidence interval that the two rainfall categories are not related.

Wind shear (speed and directional) parameters were investigated. Only one parameter depicted a difference, 3-6 km directional shear (not shown), illustrates a decrease (i.e., a change in wind from a northerly to a northwesterly direction) from the 2-inch to 4-inch category. Otherwise, the atmospheres associated with the two rainfall categories are very similar with typically northerly low-level winds at roughly 18-20 ms^{-1}.

Summary and Conclusions

The results for the synoptic-type heavy rainfall setting demonstrate the typical results the researchers anticipated.

1) As the rainfall accumulation increases, the moisture parameters indicate an increase in moisture and the stability of the atmosphere decreases.

2) There are steeper lapse rates, lower LCL heights, colder equilibrium temperatures, a greater distance between the LFC and EL, and an increase in MUCAPE values, which indicates a longer (taller), more moist, and less stable profile than the two-inch rainfall events.

3) The increase in warm cloud depth values illustrates that heavier rainfall events rely on warm cloud precipitation processes to produce greater rainfall accumulations.

4) While the majority of the wind shear parameters did not depict noticeable differences between the rainfall categories, the 3-6 km speed shear parameter was the only outlier. This potentially indicates that the wind, in this layer, is not as strong in the four-inch cases, and therefore, the heavy rainfall producing cells are not advected as quickly as they are in the two-inch cases.

On the other hand, the comparison between four-inch and two-inch rainfall days associated with a frontal-type heavy rainfall setting illustrated some surprising results. Numerous parameters that showed significant variations in the synoptic-type setting did not show the same results here.

1) Overall, the moisture, instability, wind shear, and additional parameters illustrate that there are minor differences between the four-inch sounding profile and the two-inch profile.

2) Only two parameters (700-500 hPa lapse rates and surface-500 hPa relative humidity) illustrating a less than one percent chance of the two rainfall categories being from the same distribution.

3) Only another four parameters illustrated a less than five percent chance that the two rainfall categories are related.

It becomes evident that a forecaster will have a more difficult time discerning whether a frontal-type heavy rainfall event will produce rainfall accumulations of two inches or if the accumulations will be greater than four inches just by utilizing proximity soundings.

Future Research

1) Devise normalized heavy precipitation parameter formulas to help guide forecasters in identifying a potentially dangerous heavy rainfall event for the community.

2) Develop composite soundings for each precipitation category given the atmospheric setting.

3) Determine if the strength of the atmospheric setting is a major factor in determining the difference between the rainfall settings, as well.

On the Web

http://www.eas.slu.edu/CIPS/Presentations.html