9.1 INVESTIGATING STABILITY EVOLUTION OF TWO WINTER STORMS USING MOBILE GAUS DATA

Larry L. Smith*, B. P. Pettegrew, C. J. Melick, and P. S. Market

Department of Soil, Environmental and Atmospheric Sciences
University of Missouri-Columbia
Columbia, Missouri

1. INTRODUCTION

During the winter of 2004/2005 a field investigation of thundersnow (TSSN) began. On 07 February 2005 the intensive investigation period began, which continued through 20 March 2005. Based on climatological studies by Market et al. (2002) this period encompasses the two peak months of thundersnow occurrences nation wide. Unfortunately only 26 TSSN events were recorded in the central United States for the year of which only four events occurred during the IOP. Two of these events produced substantial snowfall in a 24-hour period, one of which also exhibited electrical activity accompanying this heavy snow; these two events will be the focus of this paper. The NCAR GAUS mobile sounding system was used to collect upper air data on these events.

Much is known about the environment supportive of banded snow events, which share similar synoptic profiles to thundersnow events. Market et al. (2004) provided a set of guidelines (composite maps) that define the synoptic profile of thundersnow. Several authors (e.g., Jurewicz and Evans 2004) have also investigated banded snowstorms as well as snow events with which lightning occurred. To compliment the plan view composites of Market et al (2004) this study seeks to examine the stability profile of lightning producing snow events. With this in mind the field data gathered from two snow events during the winter of 2004/2005 will be examined with special attention to stability and the thermodynamic profile found in these two events. The methodology developed by this study will then by applied to a larger data set for a future study.

2. METHODOLOGY

This study addresses the evolution of stability in two similar environments in which significant snowfall was occurring. One environment produced both heavy snow and lightning was occurring in the vicinity. Vaisala RS92-SGP radiosondes were launched on site during both events beginning at least three hours prior to the forecasted peak of each event. Launches were carried out at the top of every synoptic hour continuing until at least three hours after the forecasted peak event. Data collected from these two events are analyzed with particular attention given to traditional stability indices. These indices include Total Totals (TT), most unstable lifted index (MULI), most unstable CAPE (MUCAPE) and TQ (Henry 2000). Mid-tropospheric lapse rates are also addressed to aid in deducing instability in each profile.

Furthermore, cross sectional analysis is carried out for each event. These cross sections will address mesoscale phenomena such as frontogenesis and conditional symmetric instability (CSI). This study will follow procedures for assessing CSI set by Moore and Lambert (1993) in which CSI is diagnosed objectively through analysis of absolute geostrophic momentum (M_g) and equivalent potential temperature (θ_e). An additional criterion for assessing CSI is that the observed layer should be sufficiently saturated, therefore for CSI to be diagnosed the layer must be of at least 80% relative humidity (e.g., Moore and Lambert 1993). As per Moore and Lambert (1993) these cross sections are taken normal to the thermal wind as represented by the 850 to 300mb thickness.

Synoptic scale analysis will be carried out in fashion developed by Market et al. (2004) using RUC 20 initial model data. This analysis is dependent on a composite approach of four common levels of the atmosphere, specifically 300, 500, 700, and 900 mb.

3. ANALYSIS

3.1 *Dumas, Texas, 15 March 2005*

On 15 March 2005, the Texas panhandle experienced heavy snow over much of the region. Areas to the south such as Amarillo received as much as thirteen inches of snow, while areas to the north near Dumas, TX, received up to seven inches. Although abundant snow fell during this event no lightning was reported in conjunction with this snow. Yet, the Dumas, TX, event will set the stage for this study as a non-lightning snow event. Twelve soundings were collected beginning at 0600 UTC 15 March 2005 through 1700 UTC 15 March 2005 capturing a majority of the event.

---

* **Corresponding author**: Larry L. Smith, University of Missouri-Columbia, 302 Anheuser-Busch Natural Resources Building, Columbia, MO 65211.
E-mail: llsbm4@mizzou.edu

Synoptically a large positively tilted 300-mb trough axis is located from northeast Wyoming through southwest Arizona (Fig. 1a). Thus, upper level flow is southwesterly over Dumas, similar to the composite of Market et al. (2004). Within this jet streak, winds of 40ms^{-1} pass over the panhandle region. At this time Dumas, TX, is located under the right entrance region of this jet streak, which is the favorable location for upper level divergence. A secondary 30ms^{-1} jet streak is also evident with Dumas under the left exit region of the jet streak, which is also a favorable area of upper level divergence.

A trough is also evident at 500 mb (Fig. 1b) with southwest flow over the Texas panhandle. This trough eventually became a closed low and slowly moved east across New Mexico into Texas. A large area of cyclonic vorticity advection is located over western New Mexico and some portions did move across the Texas panhandle toward the end of the observation period.

A trowal (trough of warm air aloft) was not evident over the Texas Panhandle at 700 mb for this event. However, a warm front was apparent as a tight horizontal gradient of θ_e stretched across the panhandle (Fig. 1c). Abundant WAA at the beginning of the period was also apparent across the panhandle reaching a peak at 1200 UTC. This boundary gradually dissipated as the surface system moved off to the southeast.

Spatially, the surface setting approached the outer bounds of the range suggested by Market et al. (2002). This is primarily due to the fact that the 900-mb low was centered some 500 km away from Dumas, near El Paso TX. The position of the low in reference to the Texas panhandle also allowed for a slightly warmer easterly flow to push into the region. This warm moist boundary layer flow approached 25 kts and produced substantial orographic lift enhancing snowfall over the region. These effects continued as the 900mb low moved to the south-southeast into Mexico.

The vertical profile over Dumas during the investigation was very stable with near saturated conditions through 500mb (Fig. 2). Stability in the boundary layer was marked by lifted index values of 10.5. This value varied only slightly through the duration of this event. Only a small area of the sounding could be described as conditionally unstable. This thin layer of conditional instability was found between 600 and 500mb at the beginning of the observation period. Soon after, a subsidence inversion set in above the 500-mb level, which effectively increased stability over the area.

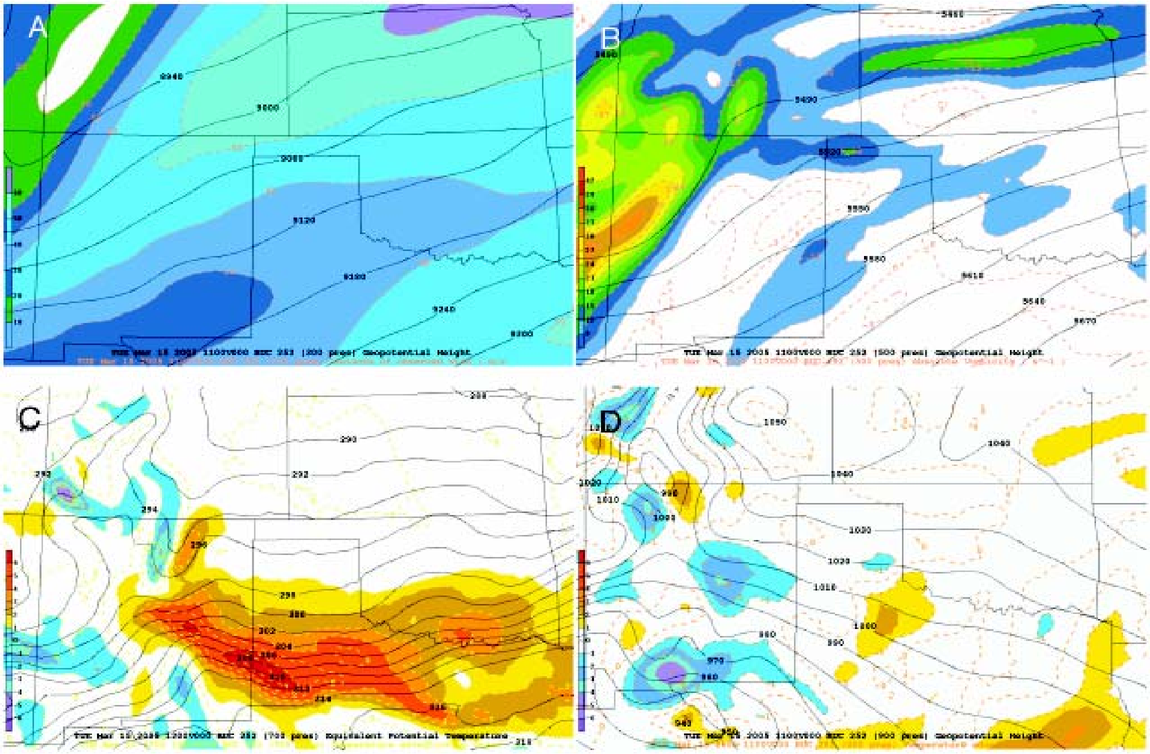

Figure 1. RUC-20 initialization valid 1100 UTC 15 March 2005. **A.** 300-mb heights (every 60 gpm; black) and isotachs (every 10 m s^{-1}; dashed and shaded). **B.** 500-mb heights (every 60 gpm; black) and absolute vorticity (every 3 x 10^{-5} s^{-1}; dashed and shaded). **C.** 700-mb θ_e (every 2 K; black) and temperature advection (every 2 x 10^{-4} K s^{-1}; dashed and shaded). **D.** 900-mb heights (every 10 gpm; black) and temperature advection (every 2 x 10^{-4} K s^{-1}; dashed and shaded).

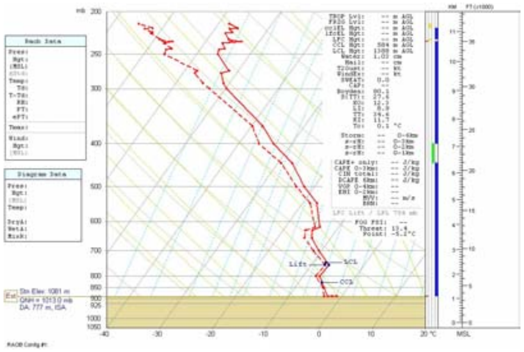

Figure 2. Dumas, Texas, sounding valid 1033 UTC 15 March 2005.

Further evidence of a stable atmosphere can be seen in the 700 to 500-mb lapse rates, which only approached 4.5°C km^{-1} indicating a stable atmosphere. Likewise, lapse rates from 850 to 500 mb were also near 4.5°C km $^{-1}$ throughout the duration of the event. Due to the temperature dependence of traditional stability indices such as K-index and Total Totals, these meager lapse rates are also reflected during analysis of the above-mentioned parameters. In fact values for the K-index averaged only 12.8, where an environment suitable for thunderstorms is characterized by K-index values 24 plus. Again less than desirable values of Total Totals also occur during this event. These values averaged 36 and only reached a maximum of 38.

Alternative stability indices, in particular the Showalter index and TQ, offered similar solutions to the traditional indices. It was hoped that these indices would offer a clearer sense as to the instability of the environment since some of the stability found in boundary layer would be ignored (i.e. Showalter index is based on a parcel lifted from 850 mb only, rather than the various layers or levels found in the lifted index).

Values of the Showalter index depicted a stable environment with an average value of 13. Similar values were found for the MULI. Henry (2000) found through empirical investigation of TQ that in order for low-topped thunderstorms to occur a threshold value of 12 was required. Although, values of TQ fell short of Henry's TQ 12 they seemed to represent the atmosphere well when considering that we are not working with a deeply unstable warm season convective environment. TQ values ranged from 8 to 12 averaging 9.8 varying only slightly through time. During the first nine hours of this event no CAPE was present as the environment was absolutely stable during most of the period. What CAPE did exist was based on parcels lifted from above 500 mb, and not of operational significance.

Cross sectional analysis (Fig. 3) performed normal to the thermal wind from Akron, CO (AKO) to San Angelo, TX (SJT), revealed several things. CSI was present from 0600 UTC through 1200 UTC over the Dumas area (Fig. 3). A large area of frontogenesis was apparent between 700 and 400mb during this time. Negative values of omega over the warm sector along with positive values of omega in the cold sector suggest that a thermally direct circulation may have released the previously mentioned CSI between the 0600 UTC and 1200 UTC. Areas of saturation in the vicinity of frontogenesis are favorable locations for the release of CSI, because slantwise ascent, directed up a sloping frontal zone, typically occurs within the upward branch of a thermally direct circulation (Jurewicz and Evans 2004). After this period CI began to dominate and the frontogenesis axis shifted south and east.

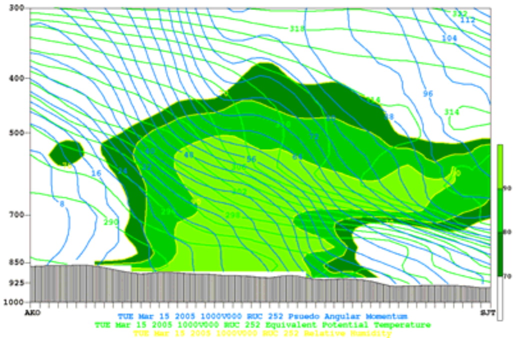

Figure 3. RUC-20 cross section from AKO to SJT valid at 1000 UTC 15 March 2005, with analysis of absolute geostrophic pseudo-angular momentum (every 4 kg m s^{-1}; blue), θ_e (every 2 K; green), and relative humidity (shaded every 10%).

3.2 *St. James, Minnesota, 18 March 2005*

A winter storm occurring on 18 March 2005 left 25 to 50 cm (10 to 20 inches) of snow along the border of Iowa and Minnesota. The snow was deep enough for officials to shut down Interstate 90 between Worthington and Albert Lea, Minnesota. Along with this heavy snow the NLDN recorded several lightning strikes between the hours of 1100 UTC and 1300 UTC over Albert Lea (Fig. 4). It is likely that lightning may have been occurring for a longer period over a larger aerial extent, unfortunately NLDN data were missing during various parts of our observation period.

While this event was transpiring data were being collected on location at St. James, Minnesota. Fifteen balloons were launched in St. James beginning at 0600 UTC 18 March 2005. The storm system sampled in this case was more representative of a true convective snow event, since the NLDN documented cloud-to-ground lightning strikes over the Albert Lea area during our intensive observation period. Albert Lea is located ~75 km southeast of St. James. Therefore the synoptic conditions where similar in St. James and Albert Lea on 18 March 2005.

Figure 4. NLDN data valid for 1330UTC 18 March 2005.

Unlike the Dumas, Texas, event this system featured a small amplitude trough located over South Dakota and Nebraska (Fig. 5a). This trough weakened and the 300-mb flow took on a zonal pattern, with a small 40 m s^{-1} jet streak embedded in the flow. Although marginal, the 300-mb pattern was diffluent over southern Minnesota and Iowa providing some support for this event. Similarly, the 500-mb flow was southwesterly and strongly diffluent (Fig. 5b). The 500-mb trough was more robust than that found at the 300-mb level and amplified over the period. downstream of the central Minnesota/Iowa border cyclonic vorticity advection was located and was more impressive than that found in Dumas.

Warm air advection apparent at the 700-mb level helped to destabilize the environment. The WAA continued to intensify throughout the period. Additionally a trowal-like feature was evident with a pronounced gradient of equivalent potential temperature located over the Minnesota, Iowa boarder (Fig. 5c). Mechanical forcing was present and was due to a well-developed 900-mb low (Fig. 5d), which slowly tracked east across Iowa. Again at 900 mb, a large area of WAA was present located along the warm frontal boundary just south of the Minnesota/owa boarder. The St. James area was much closer to the center of the surface low (roughly 250 km north) than the Dumas event was.

The boundary layer observed at St. James was very stable. This was partially due to a frontal inversion, which was entrenched at 900 mb for the entire observation period (Fig. 6). Below this inversion the environment was stable and nearly saturated. Above 900 mb the atmosphere gradually dried out, unlike the profile found in Dumas, which remained nearly saturated through 500 mb. Also an isothermal layer was present usually between the 900 and 700mb layer.

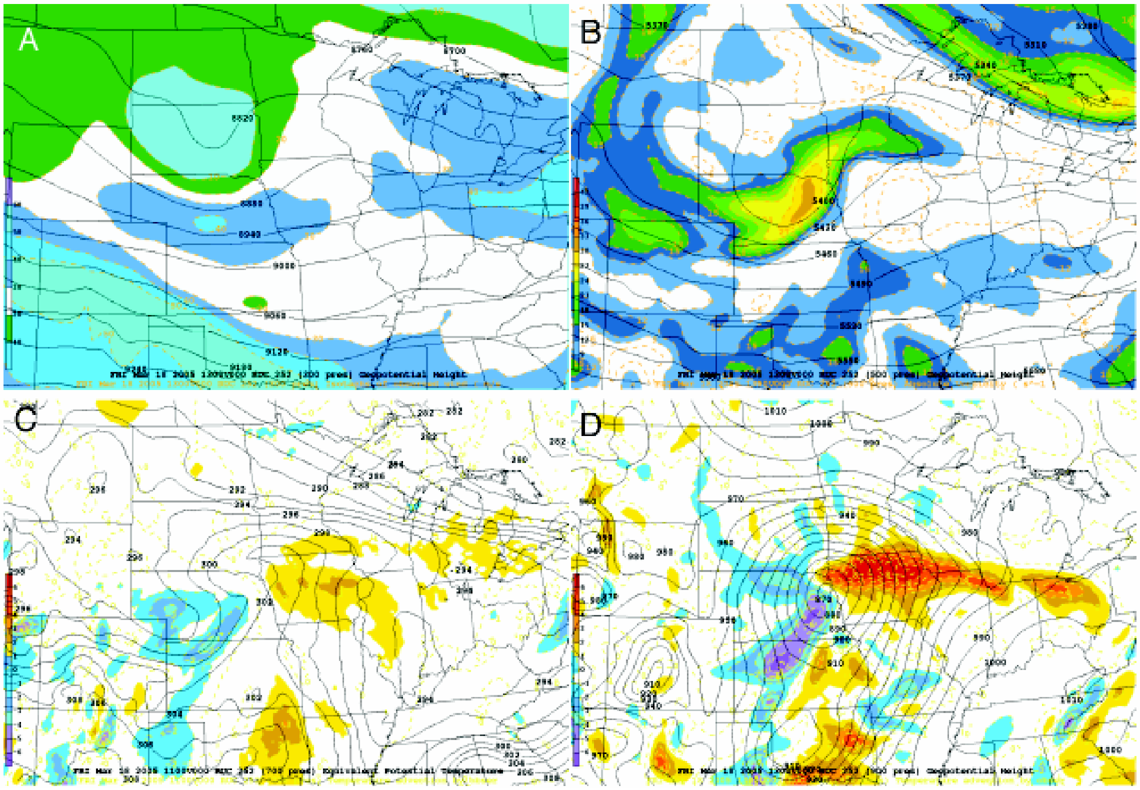

Figure 5. As in Figure 1, but valid at 1200 UTC 18 March 2005.

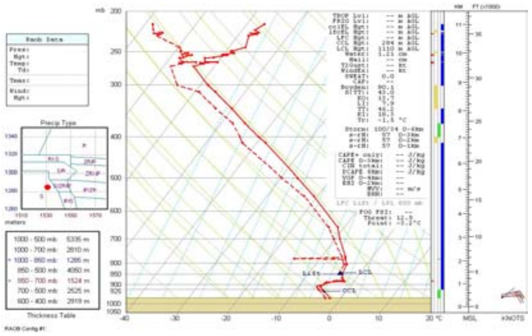

Figure 6. St. James, Minnesota, sounding valid 1059 UTC 18 March 2005.

Above the isothermal layer the sounding appeared to be stable, at the beginning of the observation period, with only a shallow layer of conditionally unstable air above 540 mb. However, at 1210 UTC this layer of conditional instability deepened with a base of 680 mb, remaining adiabatic to the tropopause. Again it should be noted that lightning was observed over Albert Lea between 1100 UTC and 1300 UTC. The environment remained conditionally unstable between 500 mb and 300 mb from 1317 UTC to 1432 UTC at which point at the environment gradually became more stable.

Lapse rates from 700 to 500 mb observed during this event were substantially greater than those observed in Dumas. Average lapse rates observed during this event were 7.0°C km^{-1}, with a lapse rate of 7.3°C km^{-1} occurring between 1200 UTC and 1500 UTC. After this period, the lapse rate fell to 5.9°C km^{-1} and then began to rebound back to 7.0°C km^{-1} over the remainder of the observation period. A positive impact from these lapse rates was seen in both the K-index and Total Totals. The average value for K-index was 16 with values ranging from 20 to 22 at the beginning of the event. Values for Total Totals were also more impressive than those found in Dumas. Average TT for this event was 46, with values observed as high as 49.

Although the average value of TQ was less than average values observed in Dumas, TQ resolved the stability observed over St James well. Values of 14 looked reasonable at the beginning of the period and gradually the atmosphere became more stable, yielding TQ values of 10 by 1000 UTC. A spike in TQ was present between the hours of 1200 UTC and 1400 UTC after which TQ values stabilized. Initially a stable atmosphere was depicted by the Showalter index but it trended toward increasing instability with a sharp dip in values near 1200 UTC then stabilizing before becoming increasingly unstable. Average values of the Showalter index were once again less than average values found in Dumas. The peak value for Showalter was found to be only 13.5 compared to average values in Dumas of 14. As with the Dumas, TX, event, little CAPE was found with this event.

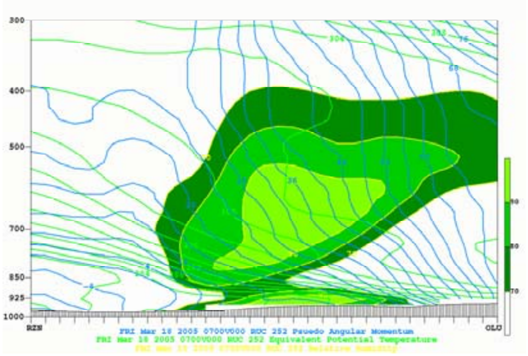

Figure 7. As in Figure 3, but from Siren, Wisconsin (RZN), to Columbus, Nebraska (OLU), valid at 0700 UTC 18 March 2005.

Conditional symmetric instability was observed over St. James between 0600 UTC to 0700 UTC in an elevated area between 600 mb and 500 mb (Fig. 7). Also evident is the presence of a surface frontal boundary shown by the upward slope of the isentropes toward the cooler air mass. Frontogenesis (not shown) on the order of 2 to 4 K 100 km^{-1} 3 hr^{-1} existed nearby in a layer from 925 mb to 650 mb; more intense values were seen to the south towards Columbus, Nebraska.

The layer of CSI quickly diminished by 1100 UTC (not shown). Surprisingly a deep layer of frontogenesis was present from 850mb tilting north to 450mb between the hours of 1100 and 1400 UTC, again corresponding to the time period in which lightning was observed over Albert Lea. The atmosphere remained neutral to symmetric instability for the remainder of the observation period. The deep layer of frontogenesis remained over St James until 1900UTC when frontolysis finally began to set in.

4. DISCUSSION

It has been established that synoptically the snow events that occurred in Dumas, Texas, and St James, Minnesota, were similar. However, some aspects such as the proximity to the center of the low and the amplitude of the 300-mb trough may have been substantially different. These differences may have had profound impacts on the synoptic scale forcing of each event.

Thermodynamically, the St. James event appeared much more unstable than that of Dumas with more impressive lapse rates and greater values of both Total Totals and the K-index. Another intriguing aspect of these events is that noticeable trends in the stability profile are evident throughout the duration of each event. This discussion will now focus on the evolution of these trends in effort to establish new ground for future research in the evolution of stability in convective snow events.

First, the evolution of instability can be depicted using the K-index (Fig. 8). More intriguing than the actual values observed were the variations of the values over time. When looking at the Dumas case the values for K-index were low, averaging 12 with very little variation through the event. However, not only were the K-index values found at St. James more impressive, average being 16 and peaking at 23, but a noticeable trend can be seen. The K-index value fell slowly from 23 to 15 during the first seven hours of the event followed by a noticeable increase. This increase in the K-index corresponds temporally with the recorded NLDN CG lightning activity over Albert Lea, Minnesota, between 1100 UTC and 1300 UTC. After that period, K-index values fall to below that level found in Dumas, then rise slightly to around thirteen for the remainder of the event.

Results from analysis of the Total Totals index were similar to that found in the K-index analysis. Values of TT observed in St James were greater than those found in Dumas. Also a similar trend can be seen in TT as can be seen in the K-index, Dumas remaining steady throughout the period with a noticeable spike in instability occurring over St. James in periods seven through ten (Fig. 9). Once again this spike in TT corresponds temporally with observed CG lighting over Albert Lea, Minnesota.

Further evidence of the instability spike is seen when plotting values of the most unstable lifted index. A jump in instability is noted in the values of MULI over Dumas at time steps five through seven, after which then the MULI trends toward more stable values (Fig. 10). Once again observed values at St. James show a general stabilizing trend from the initial period through period seven with a spike of instability corresponding with the observed CG lightning over Albert Lea.

Comparison of alternative stability indices particularly the Showalter index and TQ revealed similar trends. Showalter index values observed at Dumas were more stable than those observed at St. James. These values averaged 13 over Dumas and little variation was seen through the duration of the event. Meanwhile, the Showalter values for St. James appeared greater, with a value of 4 at the beginning of the event gradually stabilizing to 10. A noticeable spike of instability is noted between time steps seven and nine followed by a stabilizing trend (refer to Fig. 11).

As previously mentioned, TQ values initially observed at St. James were more impressive than observed values from Dumas. The TQ values observed at Dumas illustrated a trend of increasing instability over the period of

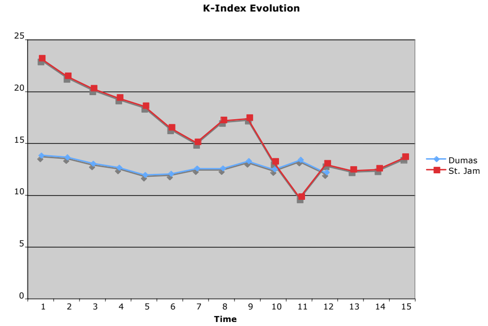

Figure 8. Hourly evolution of the K-index for both cases. The x-axis number represents each successive hourly flight, corresponding to a sounding's place in the sequence of flights, and ***not*** a particular time.

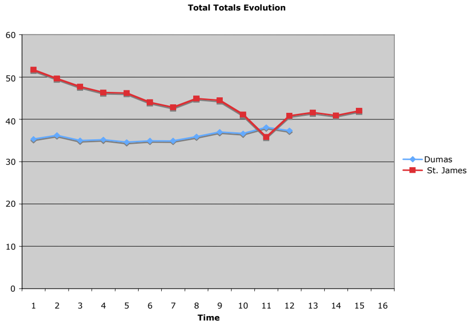

Figure 9. As in Figure 8, but for the Total Totals Evolution.

Figure 10. As in Figure 8, but for MULI Evolution.

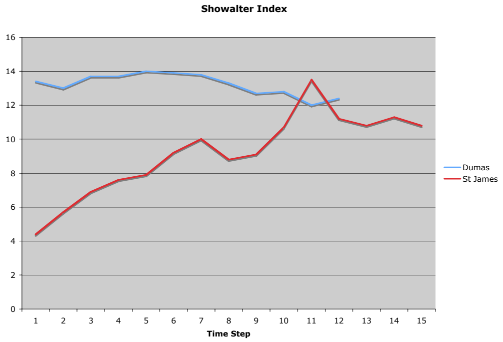

Figure 11. As in Figure 8, but for Showalter Index evolution.

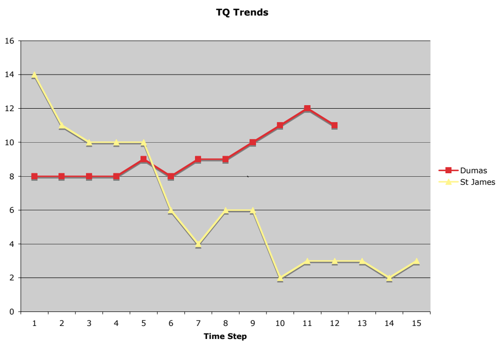

Figure 12. As in Figure 8, but for TQ Index evolution.

observation (Fig. 12). While TQ depicted a stabilizing environment over St. James with the now characteristic spike of instability between time steps seven and ten.

5. SUMMARY

This study examined data gathered in the field during two separate winter storms, which produced heavy snowfall. One of these two events also exhibited electrical activity along with heavy snow. Through analysis it was established that the two events shared similar synoptic environments. Further analysis showed that the mesoscale environments differed between the two events especially in terms of stability.

Not only were the magnitudes of instability found to be greater in association with the snowstorm over St. James in which lightning was observed, but a notable trend was also discovered in the evolution of stability in this area. A spike in instability was observed to occur during the hours that lightning was observed in the area near St. James. However, this spike in instability was not noted in association with the heavy snow event over Dumas, Texas, which did not display evidence of electrical activity. Furthermore all of the stability indices analyzed in this study reflected the spike over the St. James area during the same time period. None of the indices revealed the instability spike over Dumas with the exception to the TQ index, which displayed a brief spike in instability for one time step.

Conditional symmetric instability and frontogenesis were also examined in this study. A series of cross sectional analyses were generated in order to reveal any trends or relations to the release of CSI during both events. CSI was present over the Dumas area for the first six hours of observation at which time the environment took a subtle transition to a conditionally stable environment. Frontogenesis was present for the Dumas event and may have been responsible for the release of the CSI over the area. Similarly CSI was present during the first four hours of the St. James event after which a rapid change to neutral symmetric instability occurred. At the time of this change in instability, frontogenesis was occurring with a magnitude between 1.5 and 2.5 K 100 km^{-1} 3 hr^{-1}. Later, a deep frontogenesis maximum was observed over the area and tilting to the north.

6. CONCLUSION

A trend in the evolution of stability during a convective snow event was documented. An instability anomaly was noted in all stability indices, which occurred during a period in which both snow and lighting were recorded. This instability spike was not observed during a similar heavy snow event in which lightning was not observed. No broad conclusions can be made at this point as to whether this instability spike is a recurring feature in thundersnow events, but we plan to expand this study to a larger data set. Methodology developed in this study will be incorporated into a larger examination of this phenomena in regards to both heavy snow events which both exhibited and do not exhibit electrical activity.

Acknowledgements This work is supported in part by the National Science Foundation (NSF), Award No. ATM-0239010. Any opinions, findings, conclusions or recommendations expressed herein are those of the author(s) and do not necessarily reflect the views of NSF.

REFERENCES

Henry, N. L., 2000: A static stability index for low-topped convection. *Wea. Forecasting*, **15**, 246-254.

Jurewicz M. L., and M.S. Evans, 2004: A comparison of two banded, heavy snowstorms with very different synoptic settings. *Wea. Forecasting*, **19**, 1011-1027.

Market, P. S., A. M. Oravetz, D. Gaede, E. Bookbinder, R. Ebert, and C. Melick, 2004: Upper air constant pressure composites of Midwestern thundersnow events. *Preprints, 20th Conference on Weather Analysis and Forecasting*, Amer. Meteor. Soc., Seattle, WA, CD-ROM, P4.6.

Market, P. S., A. M. Oravetz, D. Gaede, E. Bookbinder, B. Pettegrew, and R. Thomas, 2004: Proximity sounding composites of Midwestern thundersnow events. *Preprints, 20th Conference on Weather Analysis and Forecasting*, Amer. Meteor. Soc., Seattle, WA, CD-ROM, P4.2.

Moore, J.T., Lambert, T.E., 1993: The use of equivalent potential vorticity to diagnose regions of conditional symmetric instability. *Wea. Forecasting*, **8**, 301-308.