P4.2

# PROXIMITY SOUNDING COMPOSITES OF MIDWESTERN THUNDERSNOW EVENTS

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## 1. INTRODUCTION

Sounding profiles of the atmosphere during thundersnow are examined. Horizontal composite fields (Market et al. 2004, this volume) paint a vivid portrait of an active snowstorm, but fail to distinguish clearly a typical cyclone from one that harbors an electrified cloud and thundersnow. Proximity soundings were found in 12 thundersnow events and are defined and discussed presently.

These profiles add value to the horizontal composites produced previously, which revealed thundersnow events to be occurring in otherwise unremarkable, snow bearing extratropical cyclones. Working on the assumption that some feature (instability) makes these events unique, and that convection resulting from instability is the source of charge separation for lightning production, these profiles were constructed. What appears most clearly is the presence of an elevated layer of potential instability in events northwest of a cyclone center (N=8). While not deep, it generally exists in a region of deep moisture and forcing for ascent. Cases of thundersnow northeast of a cyclone center (N=4) are potentially neutral, but again with profiles rich in moisture and forcing for ascent. Although not statistically significant, these profiles would seem to support the hypothesis of potential instability related convection dominating in thundersnow cases northwest of a cyclone (hereafter abbreviated NWC) and potential symmetric instability related convection dominating in cases occurring northeast of the cyclone center (NEC).

## 2. PROXIMITY SOUNDINGS

The thundersnow events included in this study were used to generate proximity soundings as well as derived and typical profiles. The proximity soundings employed *actual* data, whereas the derived and typical profiles were created from gridded files created through the objective analysis of rawinsonde data.

This work is patterned after Curran and Pearson (1971); a reanalysis of their sounding profile is reproduced in Figure 1. Proximity soundings were found in 12 thundersnow events and are discussed and defined presently. Four of the events occurred at the exact time and location of a sounding. Four of the events occurred at the exact time of a sounding but were not at the exact location the sounding occurred; the location of thundersnow was within 90 nautical miles (nmi; 166.68 km) of the sounding station. The remaining four cases occurred within 90 nmi of the sounding station and the thundersnow report occurred in a window of zero to three hours after the rawinsonde was released.

### 2.1 *Mean Profiles*

The mean profiles used raw data from 12 balloon flights; these were not fitted to a grid first. The proximity soundings show mean temperature, mean dew point, mean wind speeds, and *median* wind direction throughout the atmosphere.

The northwest proximity sounding (Fig. 2a) was created from eight cases. Unlike earlier work (Fig. 1), no CAPE was present in this sounding nor was potential instability (PI) present. However, the lapse rate was moist-neutral from 700 mb to 550 mb. Winds veer from the surface up to 600 mb, indicating warm air advection. From 600 mb to 400 mb the winds back with height, indicative of cold air advection. From 400 mb to 200 mb the winds veer with height again, indicating another warm air advection layer.

The proximity sounding for northeast cases (Fig. 2b) was created from a relatively small data set: only four cases. However, it does provide insight into the atmosphere present in the scenario. No CAPE was present in this sounding, and no PI was present either. However, a moist-neutral lapse rate is present from 500 mb to 400 mb. This layer is shallower, and found higher than in the soundings northwest of the cyclone center (Fig. 2a).

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Another difference from the NWC profile is the consistent veering in the wind profile throughout the troposphere. No backing of the winds with height is found in this NEC profile, suggesting a more homogeneous, less complex atmospheric structure for these cases as opposed to the NWC cases.

### 2.2 *Derived Profiles*

Mean derived profiles were generated from upper air data objectively analyzed to a grid with a horizontal grid spacing of 150 km and a 50 mb vertical spacing. Simple averages were used to create these profiles. Events were chosen if the thundersnow occurred at 0000 UTC, 0300 UTC, 1200 UTC, or 1500 UTC. This was to ensure that the 0000 UTC and 1200 UTC soundings that were used had sampled the atmosphere during or before the time when thundersnow began. The location of the thundersnow with respect to the location of the sounding was not a limiting factor, as these profiles were derived from a grid. These cases were further stratified into NEC and NWC. The NEC cases had a data set of nine soundings while the NWC data set contained 13 events.

The $\theta_e$ values in NEC cases (Fig. 3a) increase with height throughout the atmosphere. The values increase rapidly from 950 mb to 750 mb, and beyond 750 mb, increase less rapidly. Yet, this profile suggests a potentially *stable* environment throughout the lower and mid-troposphere. The $\theta_e$ values in NWC cases (Fig. 3b) also increase with height throughout the atmosphere. However, above 750 mb, $\theta_e$ increases more in NWC cases, suggesting a more stable atmosphere throughout the deep troposphere. We note that in both of these profiles, a potentially stable atmosphere is depicted everywhere. However, inspection of individual cases clearly shows that a number of them harbor layers of potential *instability*. The difficulty is that those layers do not always recur in the same region of the atmosphere. They are transient, and may be higher or lower, depending on the system.

McCann's (1995) form of equivalent potential vorticity (EPV) was used in developing the profile. This version of EPV is useful because it simplifies the method of determining if an atmosphere is symmetrically unstable or stable, for it does not require a cross section. McCann (1995) also used a three dimensional EPV which can be plotted on horizontal levels and over which $\theta_e$ and relative humidity can be laid to assess the potential instability of the atmosphere. The EPV profile for NEC (Fig. 4a) depicts a maximum EPV relatively low in the atmosphere, near 850 mb. The EPV decreases to its minimum value at 700 mb but then increases slightly up to 600 mb. From 500 mb up throughout the atmosphere the EPV values increase. The EPV profile in NWC (Fig. 4b) is much different than in NEC. There is still a maximum in the lower atmosphere, near 850 mb, and this maximum is greater than the one in NEC. However, the change from 900 mb to 850 mb is less than in NEC. The values of EPV decrease throughout the atmosphere to 600 mb and then increase again. This increase is more dramatic than in NEC.

Recall that in order for the atmosphere to be declared potentially unstable, the three dimensional EPV must be negative at some point in the sounding. The mean profiles do not depict this because they are averages. Of the 22 cases examined to create the two EPV profiles, the three dimensional EPV did reach negative values, but as with $\theta_e$ they were at different levels in each sounding. Thus, when combined into mean profiles, details are lost and none of the values are negative.

### 2.3 *Typical Profiles*

The typical profiles were developed also based upon objectively analyzed data fitted to a grid. Blind averages were *not* used here, as in Section 2.2. Instead, each case was examined individually in order to assess the existence of potential instability, and if present, where. While not a quantitative assessment of the profiles, these typical profiles reflect the patterns seen most often.

The $\theta_e$ profiles of the 13 NWC cases were examined individually to assess the potential instability in a typical sounding. The soundings were examined in 50 mb layers. Ten of the 13 depicted a potentially unstable layer somewhere within the sounding. The two most common locations for a potentially unstable layer were near the surface, usually 950 mb to 900 mb, and aloft in the range of 700 mb to 600 mb. A typical $\theta_e$ profile (Fig. 5a) was created for NWC, depicting the two common locations for potentially unstable layers. While the near surface PI layer is usually a late-fall or early spring occurrence, the mid-tropospheric layer occurs throughout the year, and speaks of a source of heat and moisture aloft. In a well-developed cyclone, warm moist air northwest of the surface low is most likely the result of the warm conveyer belt, especially the trowal.

Similarly, the $\theta_e$ profiles were examined in the nine NEC cases. Five of the nine soundings exhibited at least one potentially unstable layer. However, the most common location for PI was near the surface, from 1000 mb to 950 mb. A secondary location of nearly neutral $\theta_e$ change was also found higher in the atmosphere, around 650 mb to 600 mb. A typical $\theta_e$ profile (Fig. 5b) was created for the NEC cases. This arrangement in the mid-troposphere is one of moist neutrality which in itself is conducive to moist vertical displacement.

The three dimensional EPV was determined for the same cases to help assess the instability of the atmosphere. Looking at northwest cyclone cases, the three cases that did not show any potentially unstable layers also exhibited positive EPV. The remaining cases all depicted negative EPV, or possessed a value of zero or very close to zero.

The northeast cyclone cases did not depict the same pattern the northwest cyclone cases did. Most of the layers that were not potentially unstable had a positive EPV. However, about 40 percent of the layers that did have a potentially unstable layer also had a positive EPV value. Overall though, all of the values of EPV were very close to zero.

## 3. SUMMARY

These profiles add value to the composites produced previously. The horizontal composite charts revealed that thundersnow events occur in otherwise unremarkable, snow-bearing extratropical cyclones. Working on the assumption that some feature (instability) makes these events unique, and that convection resulting from instability is the source of charge separation for lightning production, these profiles were constructed.

What appears most clearly is the presence of an elevated layer of potential instability in NWC cases. While not deep, it generally exists in a region of deep moisture and forcing for ascent. Moreover, the veering wind profile in NWC cases (Fig. 2b) exists up through the potentially unstable layer depicted in the typical $\theta_e$ profile (Fig. 4a), providing evidence that such instability is fashioned in part by the trowel airstream. NEC cases are often potentially neutral, but with profiles rich in moisture and again forcing for ascent. While not *statistically* significant, these profiles would seem to support the hypothesis of potential instability generated convection dominating in NWC cases and potential symmetric instability generated convection dominating in NEC cases.

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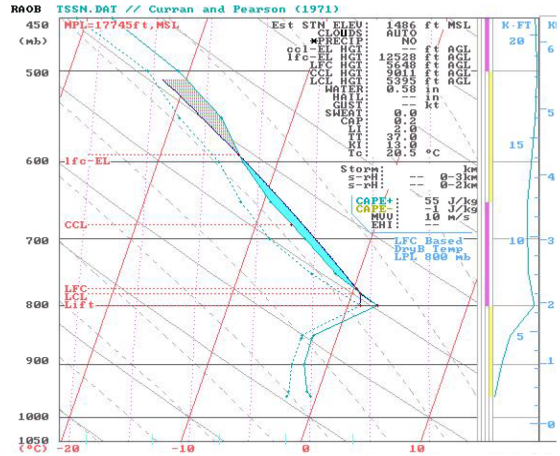



Figure 1. Reanalyzed skew-*T* log *p* diagram of sounding data taken from Curran and Pearson (1971). CAPE is based upon a parcel lifted from 800 mb. A crude potential stability diagram is presented on the extreme right.

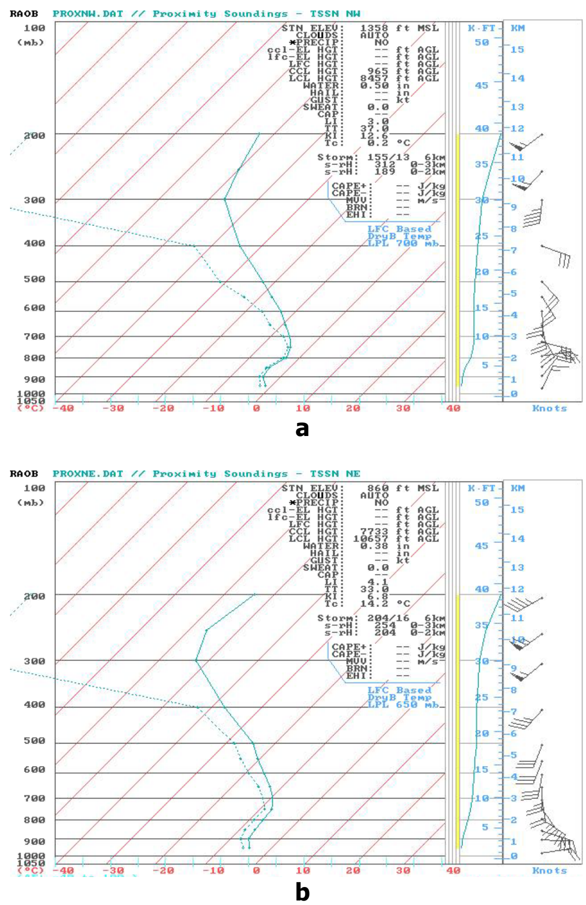
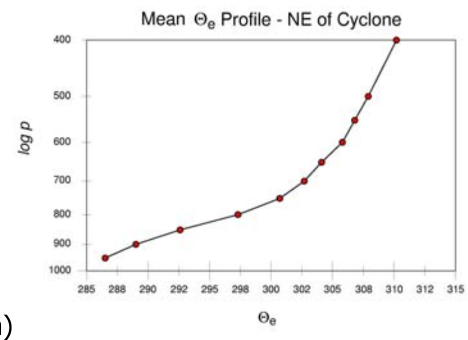
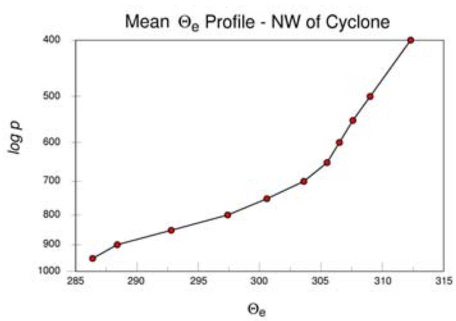



Figure 2. Skew-*T* log *p* depiction of the mean proximity sounding profiles of temperature and dew point **a**) northwest, and **b**) northeast of a cyclone center. Winds at right are plotted in knots; mean speed is plotted on the median wind direction shaft.

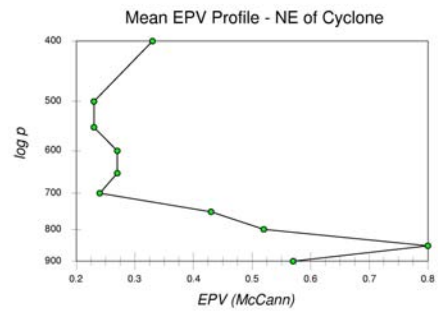



a)

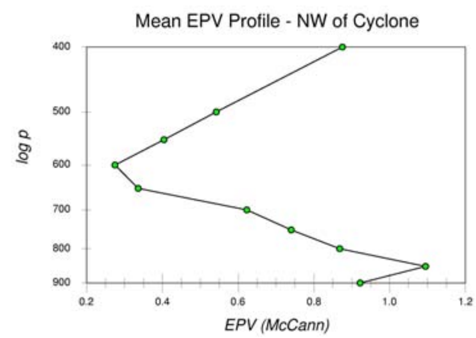



b)

Figure 3. Mean profiles of the equivalent potential temperature (K) for events occurring a) northeast of a surface cyclone, and b) northwest of a surface cyclone.

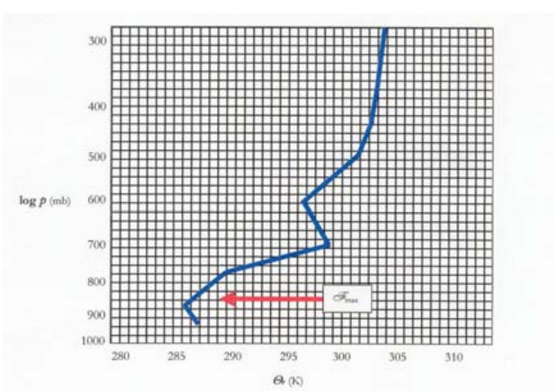



a)

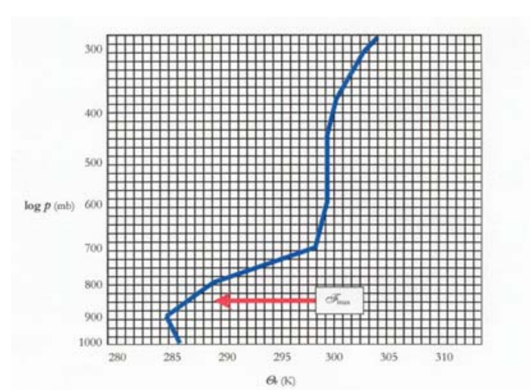



b)

Figure 4. Mean profiles of the equivalent potential vorticity ($10^{-6}$ K $m^2$ $kg^{-2}$ $s^{-1}$) for events occurring a) northeast of a surface cyclone, and b) northwest of a surface cyclone.




a)




b)

Figure 5. The typical $\theta_e$ profile (K) for **a)** NWC cases and **b)** NEC cases. These plots are qualitative renderings of typical cases based upon visual inspection of all available soundings.