JP3.8 A SYNOPTIC CLIMATOLOGY OF WINTER STORMS IN THE TWIN CITIES AREA

Lisa Schmit *, Tom Hultquist
NOAA / National Weather Service
Chanhassen, Minnesota

1. INTRODUCTION

Although modern observing and modeling systems have resulted in improved forecasts of winter storms (Olson et al. 1995), there remains room for improvement. One factor which can have a significant influence on forecast accuracy is forecaster experience, particularly when that experience is acquired in the same area over many years. One benefit of such experience is increased skill in *pattern recognition* (Root et al. 2007), which although intangible, can be of great importance when identifying potentially significant winter storms. Since it is desirable to maximize forecast skill in all situations, there is a need to provide forecasters with a means by which to increase their familiarity with atmospheric signals which are typically associated with significant winter storms in their forecast area. In an effort to achieve this, a climatology of significant winter storms in the Twin Cities area from 1950 through 2007 was constructed.

Events which produced six or more inches of snow were identified, resulting in a total of 109 events from 1950 through 2007. Snowfall in St. Cloud, Minnesota (approximately 65 miles from the Twin Cities) during these same events was briefly analyzed for comparison purposes to provide a quick glimpse of the spatial variability associated with these events. Basic meteorological charts from each event were reviewed, and events were categorized into six separate synoptic archetypes. Compositing (Moore et al. 2003) was then performed for each archetype, and mean synoptic charts detailing conditions over the course of each type of event were produced. Compositing was performed utilizing the National Centers for Environmental Prediction (NCEP) / National Center for Atmospheric Research (NCAR) global reanalysis dataset (NNRP) (Kalnay et al. 1996).

Basic climatological information for each archetype is presented, providing general information on the snowfall which occurred, along with the seasonality of each type of event. Composite synoptic charts for each archetype are also presented, highlighting the surface and upper air patterns which are associated with the different event types. It is hoped that having a comprehensive yet concise summary of such events will provide forecasters with basic *pattern recognition* information, and help them anticipate the potential for significant Winter Storms in the Twin Cities area.

2. METHODOLOGY

In order to generate statistical information and perform compositing analysis, it was necessary to first develop a dataset of events which produced six inches or more of snow in the Twin Cities in a 24-hour period. The six inch threshold was chosen arbitrarily, but it is consistent with events which would require the issuance of winter weather advisory or warning products by the National Weather Service (NWS). Although mixed precipitation and ice events have a significant impact on the public, they were not included explicitly in this study due to the difficulty in acquiring detailed climatological data of their occurrence. Once the events were determined, they were partitioned into specific archetypes based upon their synoptic-scale patterns. The methodology was based upon a similar climatology developed for Grand Rapids, Michigan (Graham and Ostuno 2002).

2.1 Data Collection & Analysis

Snowfall information from the Minneapolis-St. Paul International Airport (KMSP) was the sole source of data for this study, although it must be mentioned that these measurements were taken at the NWS in Chanhassen, MN from 2001-2004. The site was chosen for a number of reasons, most notably its long period of record, completeness of data, and high temporal resolution. Since the study sought to determine 24-hour periods when six inches or greater of snow occurred, it was desirable to evaluate data with a temporal resolution of greater than 24 hours. As a result, events were not constrained by calendar day, and spanned multiple days in many instances. Information from the National Climatological Data Center (NCDC) and the

* Corresponding author address: Lisa Schmit, NOAA/National Weather Service, 1733 Lake Drive W, Chanhassen, MN 55317.

Midwest Climate Center (MCC) were used in the analysis.

In order to isolate events which produced six inches or more of snowfall, a threshold search was performed utilizing the MCC database. These results were refined using the Local Climatological Data (LCD) information from NCDC. Figure 1 illustrates an example of an event which would not satisfy the six inch criteria on a calendar day basis, but does so over a 24 hour period over two days. When events spanned multiple days, the LCDs were evaluated to determine if there were any gaps in snowfall of 6 hours or greater. If such gaps existed, then an event was considered to be multiple events and each was re-evaluated to determine if it met the 6 inch criteria. The data analysis resulted in a total of 109 events during the period from 1950-2007.

In addition to identifying the events themselves, an attempt was also made to determine when the snowfall was at its most intense during each event. Although this information was not necessary for determining the archetypes, it would be needed when constructing composites for the various archetypes. In order to identify *prime time* for each event, an analysis of the hourly surface observations was performed. The Minnesota State Climatologist's office provided a decoded form of the hourly observations which helped simplify this process given the overwhelming amount of data. From this decoded set of data, snowfall intensity from the hourly observations was evaluated, and a *prime time* for each event was identified by choosing the nearest 6-hourly synoptic time to the time of maximum snowfall intensity. In most instances, this time corresponded fairly well with when the 6 inch snowfall threshold was reached. How this event *prime time* was utilized within the archetype compositing will be discussed in greater detail within Sec. 4.1.

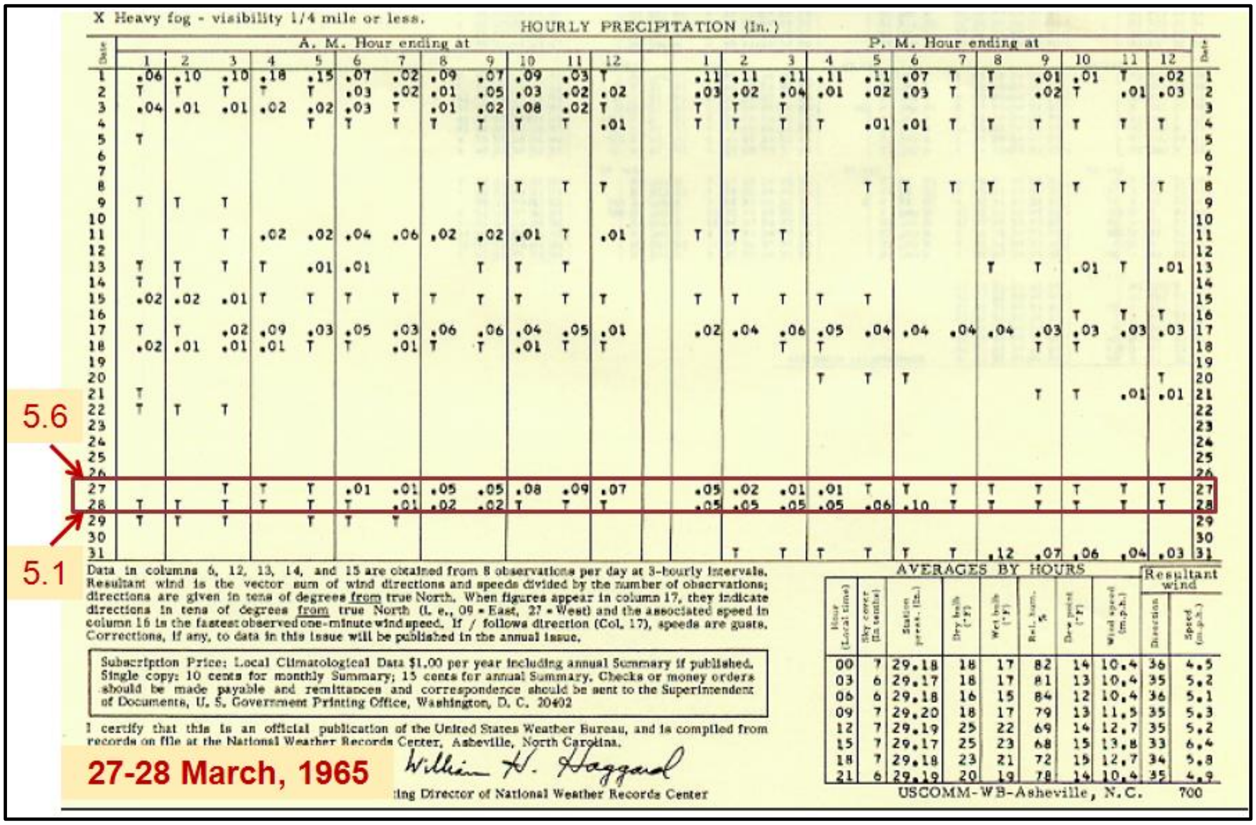

Figure 1. Local climatological data (LCD) illustrating two calendar days (27-28 March 1965) which do not meet the six inch snowfall criteria, yet do when considered as a multi-day event.

2.2 Pattern Typing

Since the Twin Cities area can experience significant snowfall from a variety of weather systems, an effort was made to categorize the events into archetypes demonstrating similar synoptic-scale characteristics. This categorization was done subjectively since a simple objective method to do so could not be found. Archetypes were not chosen ahead of time, but rather the events themselves were evaluated individually and the descriptions of each were then analyzed in order to group them into similar types. Information from the NNRP was evaluated at 6-hourly time steps for each event to help formulate a synoptic-scale pattern description. The Daily Weather Map archive was also used to assist in this process given its greater focus on surface weather maps. Once qualitative descriptions of each event were completed, these descriptions were re-evaluated and the events were separated into common archetypes which exhibited similar characteristics. Although the evolution of the mean sea level pressure field had the greatest correlation with the archetype chosen, upper air fields were heavily utilized as well. When possible, commonly used terminology was chosen for the archetypes in order to aid in comprehension of the results. The pattern typing process resulted in the identification of six archetypes: Alberta Clipper (AC), Colorado Low (CL), Gulf Inverted Trough (GIT), Gulf Coast Low (GCL), Panhandle Hooker (PH), and Plains Low (PL). Given the subjective nature of the pattern typing, there are similarities in several archetypes, particularly the CL, PL, and PH. The most notable characteristics for each archetype, along with their specific snowfall climatology within the dataset, is discussed in Sec. 3.

3. ARCHETYPE CLIMATOLOGY

3.1 Plains Low

The PL archetype was the most prevalent type within the dataset, accounting for 34 of the 109 events. This type was also the least well defined in terms of synoptic pattern, and could possibly be sub-divided into additional sub-types. The CL archetype could be considered a special case of the PL, and is described in Sec. 3.2. The PL was characterized by lee side surface low formation along the eastern slopes of the Rockies from Montana to northern Colorado. The subsequent track of the surface low was in an east-northeast direction through the Great Plains and into the lower Great Lakes. An overview of the PL surface low track (resulting from the composite analysis discussed in Sec. 4) is shown in Fig. 2a.

3.2 Colorado Low

The CL (Clark 1990) archetype accounted for 27 of the 109 events. As mentioned in Sec. 3.1, this archetype could be considered a special case of the PL type, whereby lee side surface low formation was focused over east-central or southeast Colorado. The subsequent surface low track was northeast through the Great Plains and Mississippi Valley and into southeast Wisconsin and northern lower Michigan. An overview of the CL surface low track is shown in Fig. 2b.

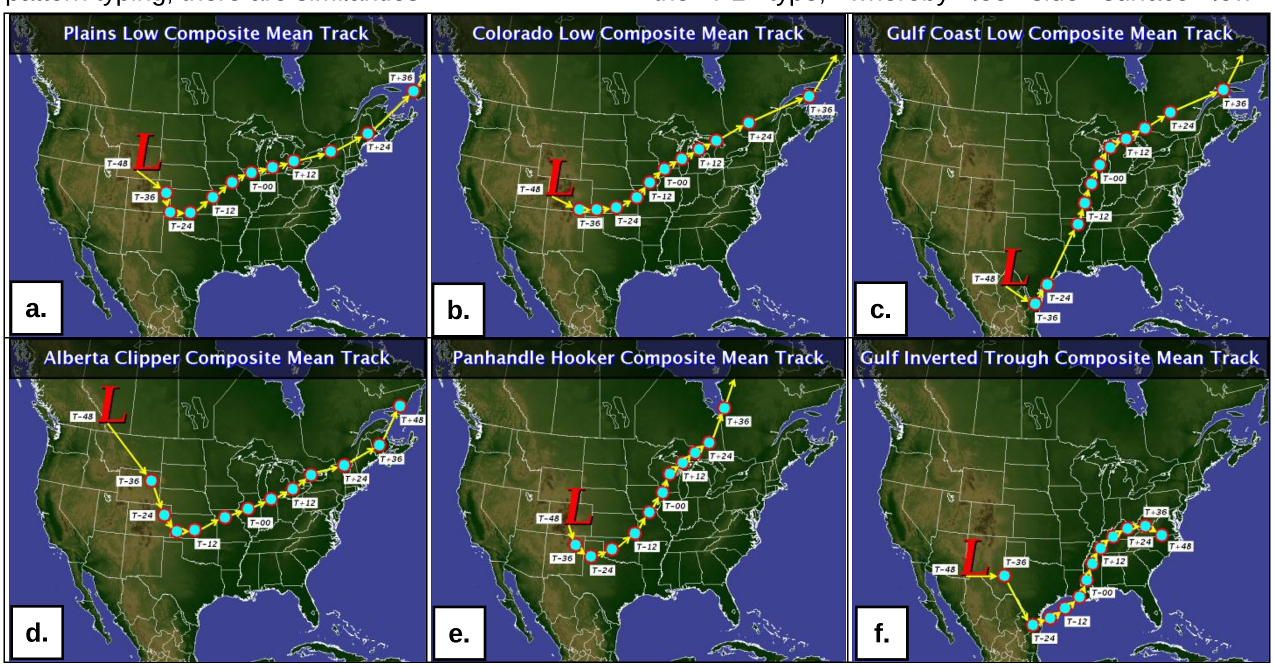

Figure 2. Composite mean surface low track for (a) Plains Low, (b) Colorado Low, (c) Gulf Coast Low, (d) Alberta Clipper, (e) Panhandle Hooker, (f) Gulf Inverted Trough

3.3 Gulf Coast Low

The GCL archetype was seen in 16 of the 109 events. This was a well-defined archetype with a consistent pattern of development and evolution. It was characterized by surface low development from south Texas to the Gulf of Mexico coast, then a nearly due north surface low track up the Mississippi Valley. This archetype exhibited highly variable snowfall amounts in the Twin Cities area. An overview of the GCL surface low track is shown in Fig. 2c.

3.4 Alberta Clipper

ACs (Whittaker and Horn 1981) are a well-known winter weather feature in the northern portion of the continental United States. These systems are typically associated with minor snowfall accumulations, and are most notable for their continental origin and the associated arctic air they bring. Since this climatology focuses on snowfall events of six inches or more, it is not surprising that the AC archetype comprised only 13 of the 109 events. Since the AC events in this study were those which produced six inches or more of snowfall, they did not fit the typical pattern associated with ACs in the upper Midwest. The ACs in this study exhibited greater southward digging/development east of the Rockies than the more common *non-significant* ACs. A cursory examination of this archetype may suggest it is consistent with the PL archetype, but a more detailed analysis yields important differences in their dynamic evolution. While the PL was associated with upper-level short waves of Pacific origin, the AC was associated with upper-level short waves of Arctic origin. Notable differences are apparent in many of the upper atmospheric features detailed in the composite analysis shown in Sec. 4. This archetype was characterized by surface low formation in the lee of the Canadian Rockies, followed by a southeast track east of the Rockies to the central High Plains, then an east-northeast track toward the lower Great Lakes. An overview of the AC surface low track is shown in Fig. 2d.

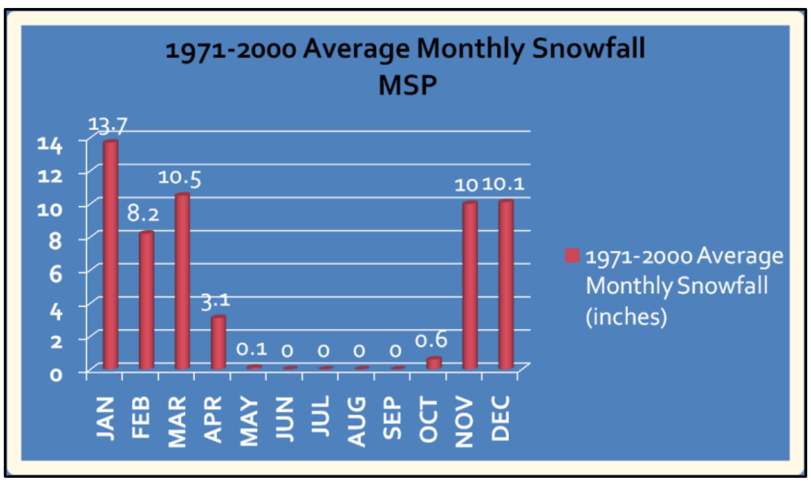

Figure 3. Average monthly snowfall for Minneapolis-St. Paul International Airport (in.)

3.5 Panhandle Hooker

The PH archetype comprised 11 of the 109 events. Although similar in many respects to the CL archetype, it exhibited consistent well-defined behavior which sufficiently differentiated it from the CL to be considered its own archetype. This archetype was characterized by surface low formation near the New Mexico/Texas border, and a subsequent eastward track through the Texas panhandle and Oklahoma, then a sharp northeast track through Missouri, eastern Iowa, and Wisconsin. An overview of the PH surface low track is shown in Fig. 2e.

3.6 Gulf Inverted Trough

The GIT archetype exhibited a fairly consistent pattern of development and evolution, and comprised 8 of the 109 events. The surface low associated with the GIT remained a significant distance from the Twin Cities, although an inverted trough extended from the surface low into the upper Mississippi valley. This archetype saw weak surface low formation in Texas, followed by a meandering track along the Gulf of Mexico coast northeastward toward the eastern Ohio Valley. An overview of the PH surface low track is shown in Fig. 2f.

3.7 Archetype Snowfall Climatology

To get an appreciation for how the various archetypes fit into the overall snowfall climatology for the Twin Cities, basic statistical analysis was performed on the archetypes to gain a clearer picture of their variability, magnitude, and seasonality. On average, the Twin Cities receives 56.3 inches of snow annually. The average monthly distribution of snowfall is shown in Fig. 3.

Of note is the peak in snowfall seen in January, with the majority of snowfall occurring from November through March.

If only significant events are considered, as described by this study, a different monthly distribution is evident as shown in Fig. 4. Although the November through March time frame still stands out, a significant portion of the events are seen to occur during the month of March. In addition, significant events are also a somewhat routine occurrence during April, which only accounts for 3.1 inches of the annual average snowfall. Although January accounts for the greatest portion of annual average snowfall, it is third with respect to the number of significant snowfall events.

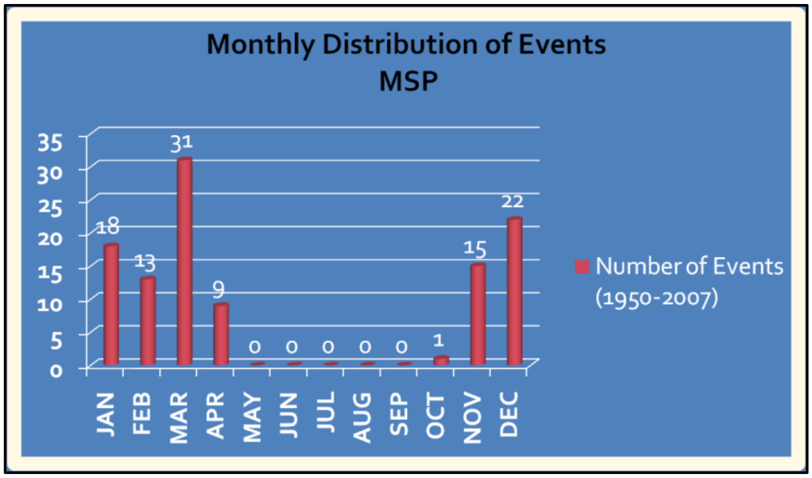

Figure 4. Monthly distribution of signifcant snowfall events at Minneapolis-St. Paul International Airport.

Additional details are apparent when the monthly distribution of significant event archetypes is considered (Fig. 5). PLs and CLs dominate the archetypes which occur during the peak month of March, although both are common during the November through March time frame. ACs are most prevalent during December and January, which is not surprising given the propensity for arctic airmasses to impact the upper Midwest during that time.

Figure 6 provides a quick means through which to view the snowfall variability associated with each archetype within the database. This box and whiskers diagram provides information on the event total snowfall maxima, maxima, and median, along with the 25th and 75th percentile. The minimum for each archetype is artificially bounded by the 6 inch value since that was the 24-hour snowfall threshold used for the study. A significant amount of variability in the maximum snowfall can be seen for PL, GCL, CL, and PH events. This is not surprising since these events tended to be associated with significant surface and upper-level features, as will be shown in Sec. 4.2. The AC archetype had very little variability in snowfall amount, and most of these events only marginally exceeded the 6 inch threshold. This is not a surprising result since ACs are of continental origin, and have a much lower moisture content as a result. The GIT archetype was also confined to the low end of the snowfall scale, likely due to its lack of a strong surface low and its significant distance from the area of interest.

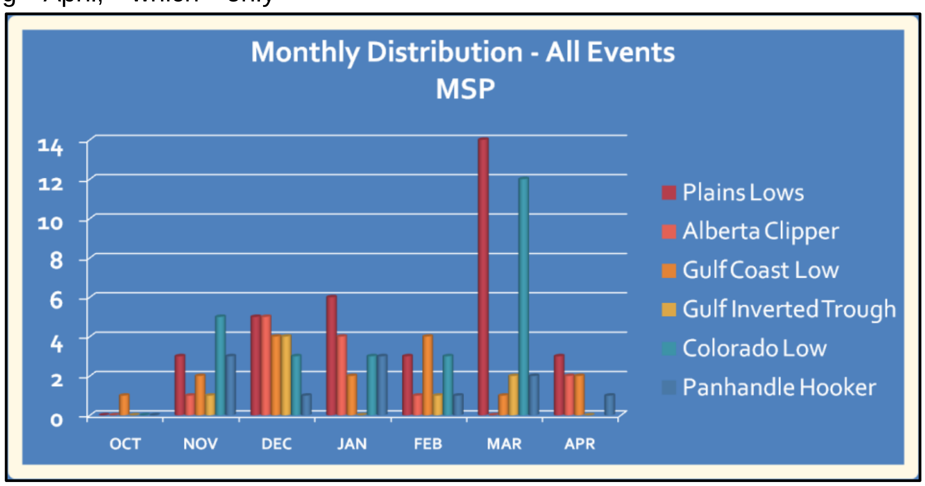

Figure 5. Montly distribution of significant events at Minneapolis-St. Paul International Airport, by archetype.

4. COMPOSITE ANALYSIS

Once the significant snowfall events were identified and categorized, compositing was performed to generate charts depicting mean

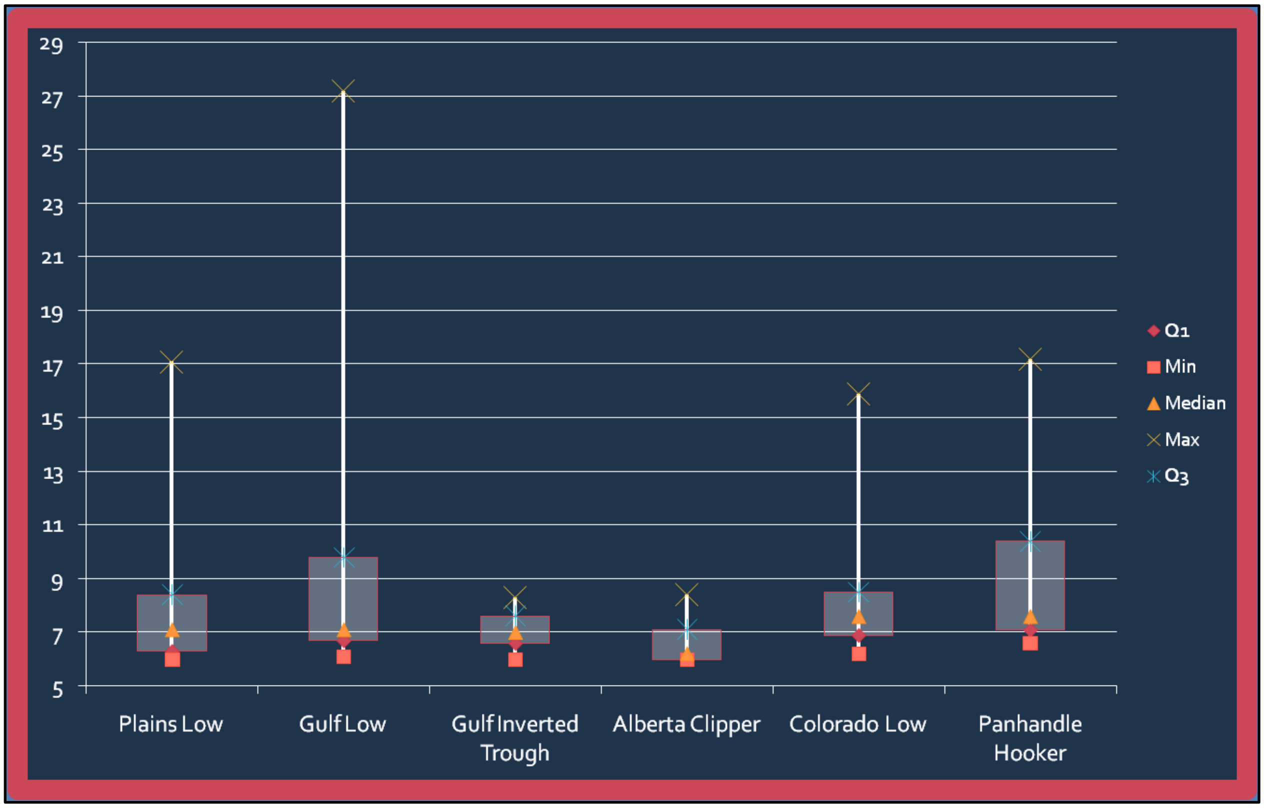

Figure 6. Snowfall (in.) statistics for each archetype. Minimum, 25th percentile, media, 75th percentile, and maximum are shown.

values of various synoptic-scale fields. Such charts may allow forecasters to more easily identify forecast patterns which could be conducive to significant snowfall events in the Twin Cities area since they would be able to associate them with past significant events. Although compositing will provide a significantly smoothed depiction of features in comparison to viewing the same features for one specific event, stronger large scale signals can remain. Such large scale signals can be important in identifying the potential for a significant event, and can help forecasters to more quickly acquire *pattern recognition* skills.

4.1 Compositing Process

The composite analyses for each archetype were constructed using data from the NNRP. The valid times for the composites were based on the *prime time* which was identified for each event as described in Sec. 2.1. Centering each event at the most intense portion of the event allowed for composites to be produced from 48 hours prior to *prime time* to 48 hours after *prime time*. In the subsequent discussion, prime time is denoted by T, times preceding prime time are denoted by T-hr, and times following prime time are denoted by T+hr (hr represents the number of hours). Compositing was performed at a time interval of 12 hours from T-48 through T-24 and T+24 through T+48, with a 6 hour time interval from T-24 through T+24. No effort was made to re-center the grid during the compositing process, since all events were based on snowfall observations at a single point. Compositing was done using online tools available from the National Oceanic and Atmospheric Administration's Earth Systems Research Laboratory. Composite means were produced for the following fields: Sea-level Pressure, 850 hPa Height, 850 hPa Temperature, 850 hPa Wind, 850 hPa Specific Humidity, 700 hPa Height, 700 hPa Specific Humidity, 500 hPa Height, and 300 hPa Wind.

4.2 Archetype Composite Details

Given the substantial number of composites performed, 6 archetypes X 13 times X 9 fields (702 composites), only a very small subset is included here to illustrate some of the more interesting features of each archetype and how they compare to one another. The composite

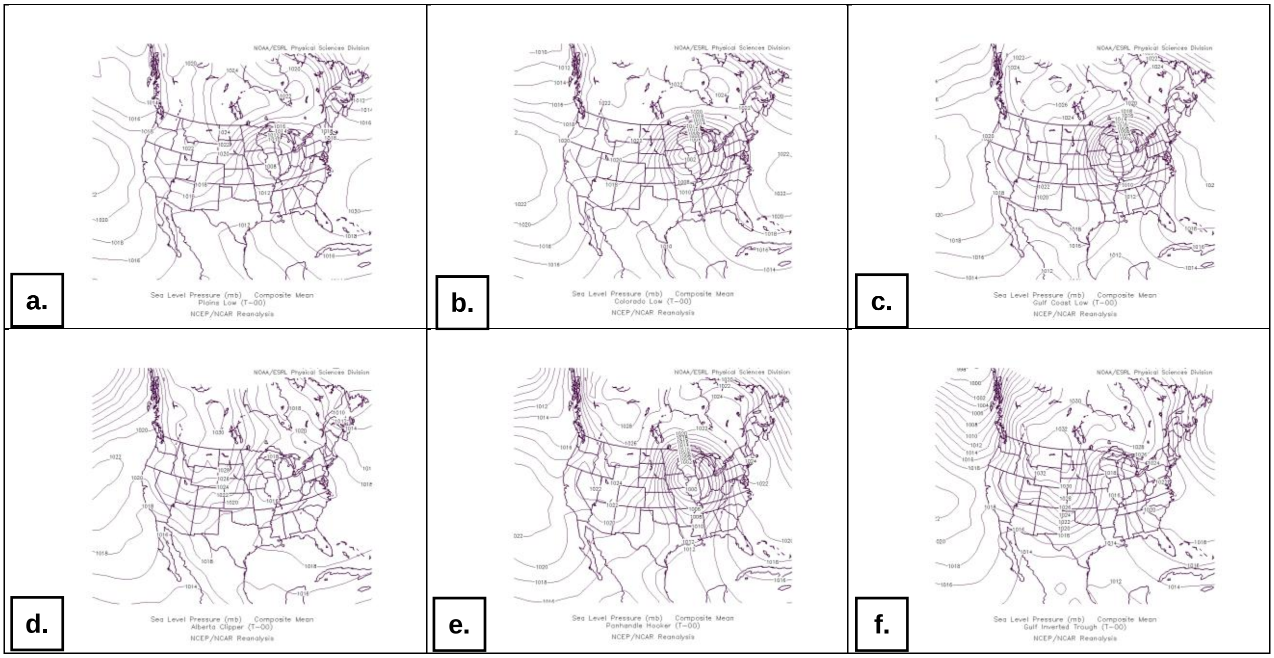

Figure 7. Composite mean-sea level pressure (mb) at T-00 for (a) Plains Low, (b) Colorado Low, (c) Gulf Coast Low, (d) Alberta Clipper, (e) Panhandle Hooker, (f) Gulf Inverted Trough

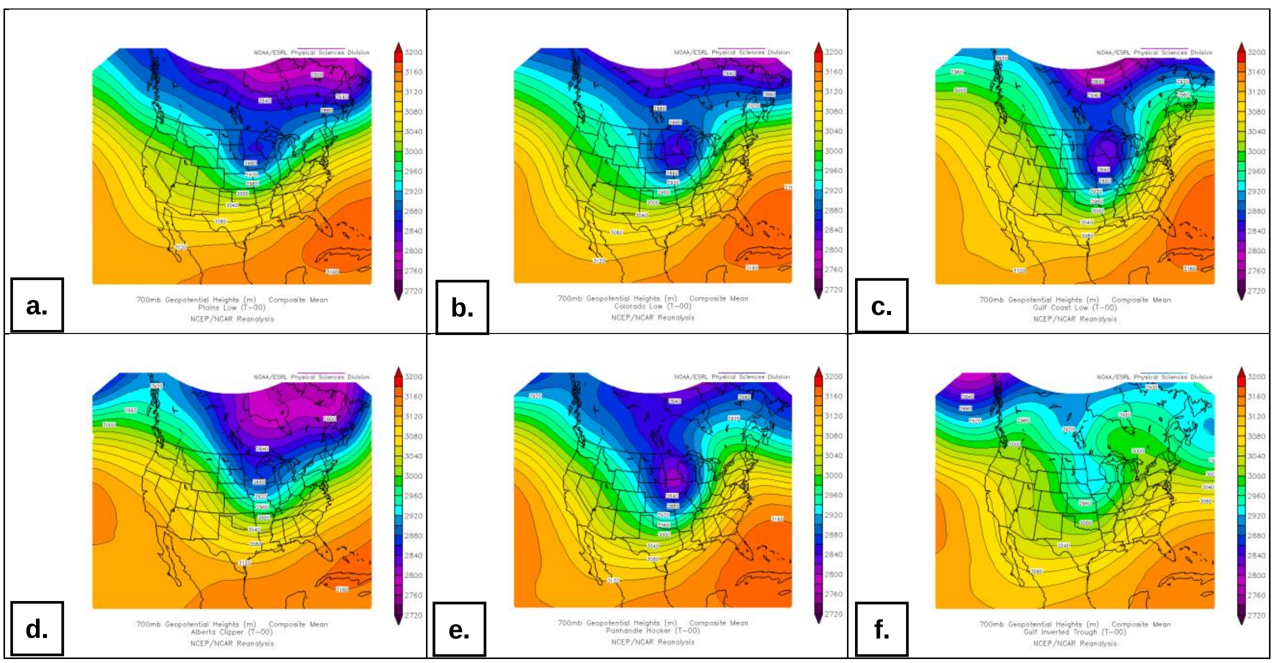

Figure 8. Composite 700 hPa height (m) at T-00 for (a) Plains Low, (b) Colorado Low, (c) Gulf Coast Low, (d) Alberta Clipper, (e) Panhandle Hooker, (f) Gulf Inverted Trough

surface low tracks for each archetype are shown in Fig. 2.

Figure 7 depicts the sea-level pressure field at T-00 for each archetype. Of note is the very consistent position of the surface low between all of the archetypes, generally centered from eastern Iowa to southeast Wisconsin. The exception to this is the GIT archetype, which does not have a closed surface low at T-00, but does indicate an inverted trough axis extending from the western Gulf of Mexico into the upper Mississippi Valley. The most intense surface lows are present in the

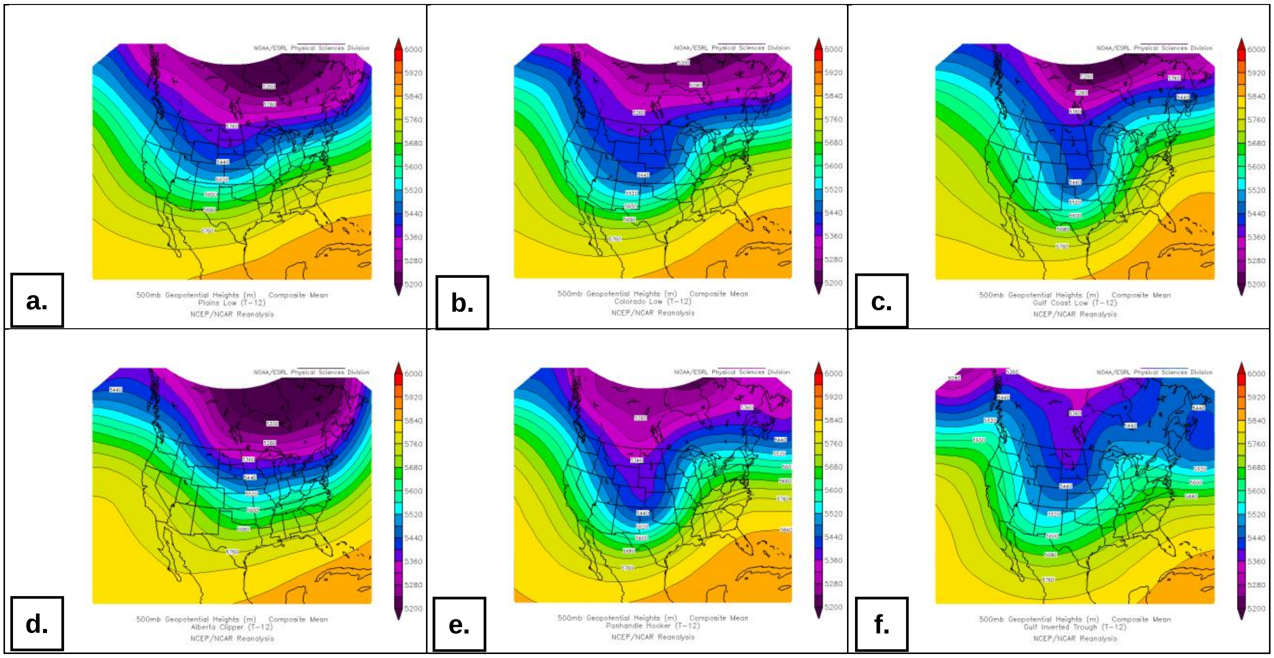

Figure 9. Composite 500 hPa height (m) at T-12 for (a) Plains Low, (b) Colorado Low, (c) Gulf Coast Low, (d) Alberta Clipper, (e) Panhandle Hooker, (f) Gulf Inverted Trough

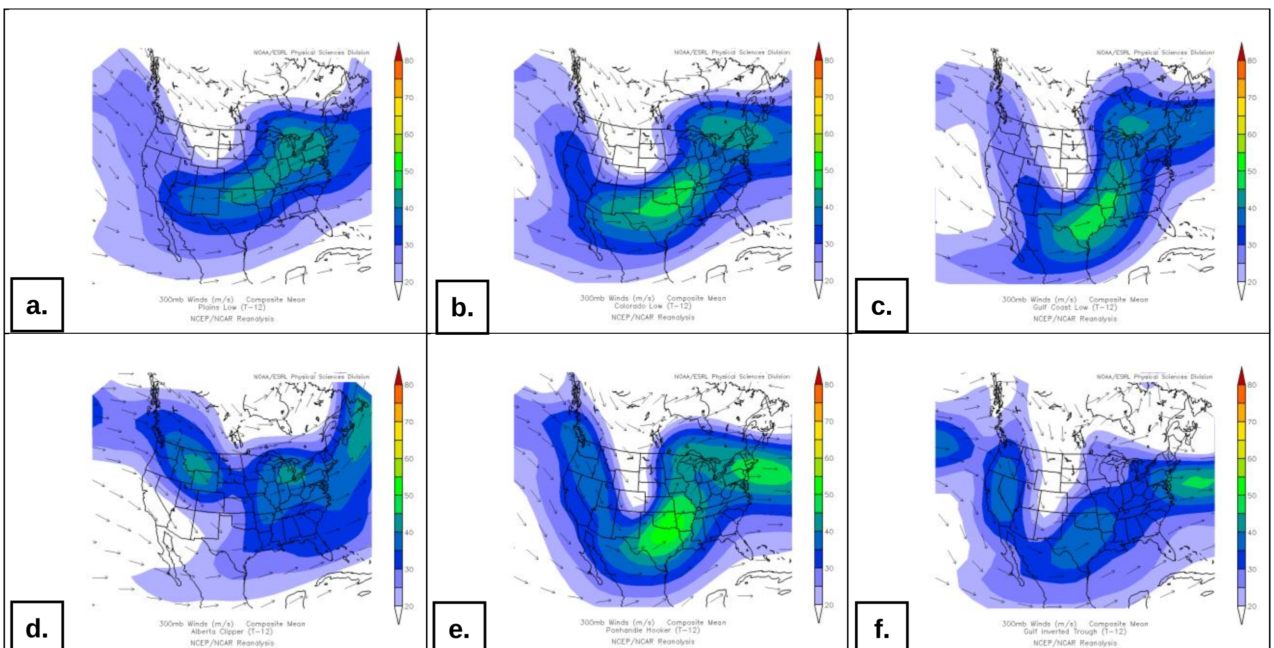

Figure 10. Composite 300 hPa wind (ms^{-1}) at T-12 for (a) Plains Low, (b) Colorado Low, (c) Gulf Coast Low, (d) Alberta Clipper, (e) Panhandle Hooker, (f) Gulf Inverted Trough

GCL, PH, and CL composites, which is consistent with the high snowfall totals which were seen with those events (Fig. 6). The strong agreement in surface low placement among the archetypes suggests a strong correlation between surface low position and significant snowfall events in the Twin Cities. However, it must be noted that additional statistics such as standard deviation, were not computed in the composites, so the mean fields can be potentially misleading.

A field commonly used by forecasters for many years in assessing the potential for significant winter storms has been the track of the 700 hPa

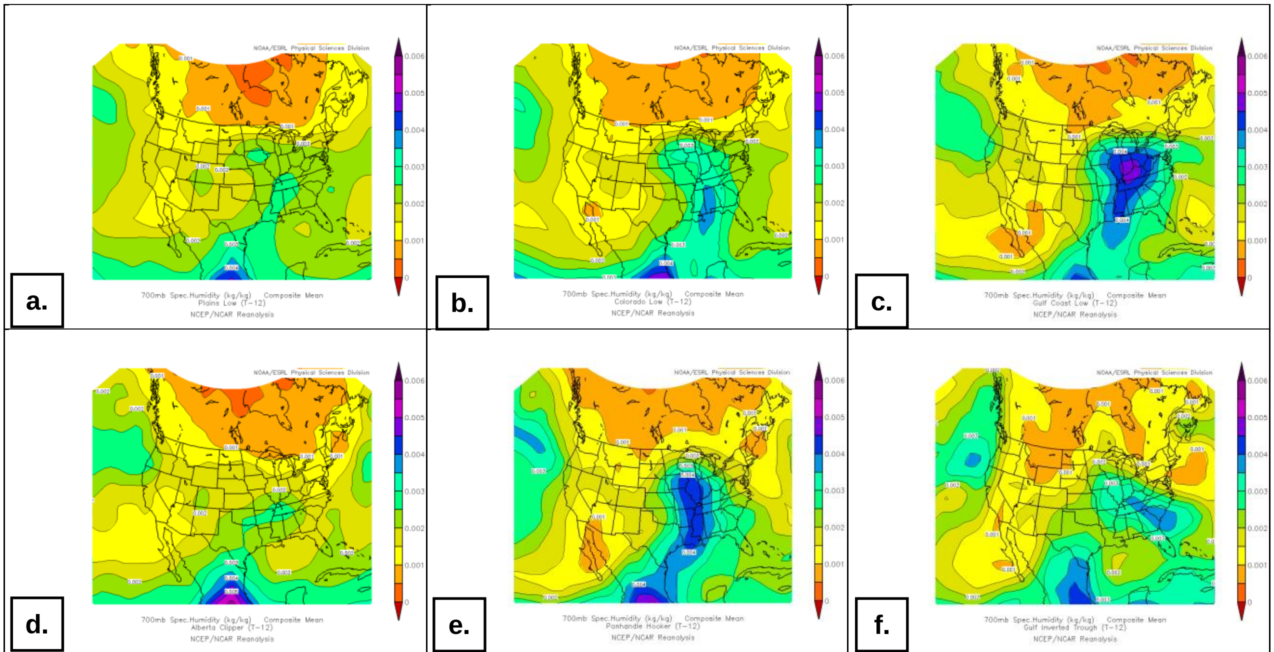

Figure 11. Composite 700 hPa specific humidity (gKg^{-1}) at T-12 for (a) Plains Low, (b) Colorado Low, (c) Gulf Coast Low, (d) Alberta Clipper, (e) Panhandle Hooker, (f) Gulf Inverted Trough

low (Nicosia and Grumm 1999). The composites of the 700 hPa height field at T-00 for each of the archetypes shown in Fig. 8 suggests that this approach may be useful for events in the Twin Cities area. A closed 700 hPa low is apparent in 4 of the 6 archetypes, with the GIT possibly closed if a finer contour interval were used. It should also be noted that although the GIT does not produce a surface low in the upper Midwest, it does have a significant 700 hPa feature. The AC does not exhibit a closed 700 hPa low, but does show a prominent 700 hPa trough centered over the area of interest. The position of the closed 700 hPa is very similar for the archetypes which exhibit that feature, and is located very close to the Twin Cities area. This may suggest that the often used method of using the forecast track of the 700 hPa low to anticipate the location of heaviest snowfall may be useful in providing a reasonable first guess.

Figure 9 shows the 500 hPa composites for each archetype at T-12. This time would typically be during the deepening phase of storms impacting the area, and may provide some indication as to intensity. The PH, GCL, and CL exhibit the most prominent 500 hPa trough features, with a slight negative tilt (Gaza and Bozart 1990) noted with the PH and GCL. The presence of these features, and the apparently stronger nature noted with the PH and GCL is consistent with the greater snowfall production observed with these events (Fig. 6).

Another synoptic-scale feature often utilized in assessing the potential for significant winter storms is the position and character of the upper-level jet. In particular, coupled jet structures (Uccellini and Kocin 1987) are often associated with the most intense systems, and can be a harbinger of the most intense winter storms. The 300 hPa wind at T-12 for each archetype is shown in Fig. 10. On can infer the presence of a coupled jet structure in the area of interest in the composites for the CL, GCL, and PH, which is once again consistent with the more significant snowfall which occurred during those events. In addition, a split jet, and perhaps a coupled structure, is apparent in the composite for the AC. Since ACs which produce snowfall of six inches or more in the Twin Cities are rare, this feature could be useful in identifying those ACs which are more significant in nature.

Mid-level moisture is an important ingredient in the development of significant snowfall in winter storms. The 700 hPa specific humidity, shown in Fig. 11, can be used assess the presence and magnitude of mid-level moisture. Once again, the CO, GCL, and PH archetypes stand out, exhibiting the greatest amount of moisture nosing into the area of interest, with values of 3-4 gKg^{-1} present. The AC archetype clearly has the driest mid-level

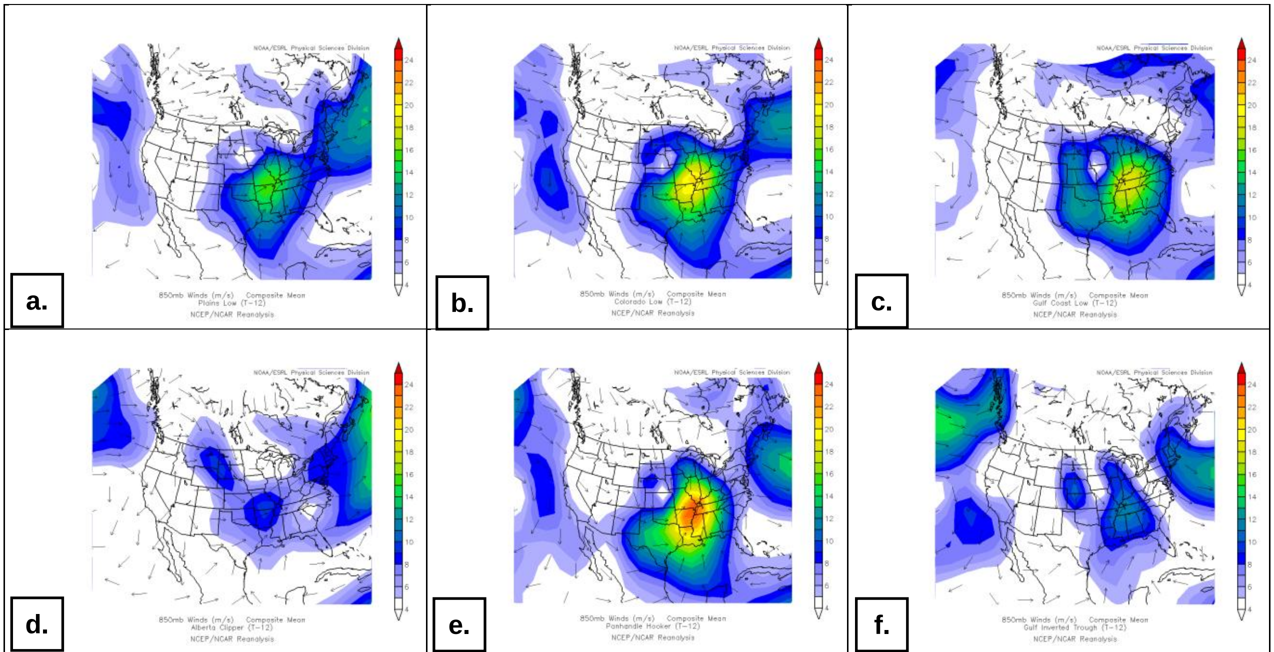

Figure 12. Composite 850 hPa wind (ms^{-1}) at T-12 for (a) Plains Low, (b) Colorado Low, (c) Gulf Coast Low, (d) Alberta Clipper, (e) Panhandle Hooker, (f) Gulf Inverted Trough

conditions, which is not surprising given the Arctic origin of these systems.

Advection of moisture north from the Gulf of Mexico can be instrumental in generating higher snowfall totals in the upper Midwest (Roebber and Bosart 1998). Such advection can be tied to the strength of the low-level jet (Djuric and Ladwig 1983) ahead of systems moving into the Mississippi Valley. Figure 12 depicts the 850 hPa wind field at T-12 for each of the archetypes. The PC has the most intense low-level jet feature, with values approaching 25 ms^{-1}. The CL and GCL archetypes are slightly weaker, but still have significant low-level jet features of around 20 ms^{-1} apparent in the composites. In all of the archetypes with exception of the AC, the low-level jet extends north into the area of interest, with the nose of the jet extending toward the upper Mississippi Valley. This suggests that the advection of moisture north from the Gulf of Mexico may be a key ingredient in generating significant snowfall in the Twin Cities area in all but the AC archetype. This is not a surprising finding, but is encouraging since it helps quantify a feature which forecasters have long identified qualitatively.

5. CONCLUSION

On average from 1950-2007, the Twin Cities experienced snowfall events of six inches or greater nearly two times per year (109 events in 58 years). An analysis of the synoptic-scale conditions for each of these events indicated that there were six basic pattern types responsible for significant snowfall in the Twin Cities area. Although there were similarities in several of these archetypes, a composite analysis of common meteorological parameters revealed important differences. The position of the surface low during the height of the events exhibited a striking similarity among the archetypes, with only the GIT archetype showing a marked difference. Other features which were common in several archetypes, and varied primarily in magnitude, were: (1) the presence of a low-level jet extending from the western Gulf of Mexico into the upper Mississippi Valley, (2) a coupled upper-jet structure with an inferred area of enhanced upper-level divergence over the upper Mississippi Valley, (3) the presence of a 700 hPa low in the vicinity of the Twin Cities at the height of the events. The archetypes most likely to produce greater snowfall amounts, the CL, GCL, and PH, exhibited markedly stronger synoptic-scale features than the other archetypes.

This study helped quantify and validate many common *rules of thumb* which forecasters have used when forecasting winter storms in the Twin Cities area. The composite analyses should help forecasters to better anticipate the potential for significant snowfall events in the area, particularly those who lack experience in the local area. Although certain archetypes are traditionally associated with the potential for heavy snow in the Twin Cities area, such as the CL and PH, the identification of additional archetypes such as the AC and GIT may help to dispel misconceptions and biases that more experienced forecasters may have.

6. REFERENCES

Clark, J. H. E., 1990: An observational and theoretical study of Colorado lee cyclogenesis. *J. Atmos. Sci.*, **47**, 1541-1562.

Djuric, D. and D. S. Ladwig, 1983: Southerly low-level jet in the winter cyclones of the southwestern Great Plains. *Mon. Wea. Rev.*, **111**, 2275-2281.

Gaza, R. S. and L. F. Bozart, 1990: Trough-merger characteristics over North America. *Wea. Forecasting*, **5**, 314-331.

Graham, R. A. and E. Ostuno, 2002: Grand Rapids significant winter storm climatology. *Great Lakes Operational Meteorology Workshop*, 10 October 2002.

Kalnay, E., M. Kanamitsu, R. Kistler, W. Collins, D. Deaven, L. Gandin, M. Iredell, S. Saha, G. White, J. Woolen, Y. Zhu, A. Leetmaa, R. Reynolds, M. Chelliah, W. Ebisuzaki, W. Higgins, J. Janowiak, K. C. Mo, C. Ropelewski, J. Wang, R. Jenne, and D. Joseph, 1996: The NCEP/NCAR 40-year reanalysis project. *Bul. Amer. Meteor. Soc.*, **77**, 437-471.

Moore, J. T., F. H. Glass, C. E. Graves, S. M. Rochette, and M. J. Singer, 2003: The environment of warm-season elevated thunderstorms associated with heavy rainfall over the central United States. *Wea. Forecasting*, **18**, 861-878.

Nicosia, D. J. and R. H. Grumm, 1999: Mesoscale band formation in three major northeastern United States snowstorms. *Wea. Forecasting*, **14**, 346-368.

Olson, D. A., N. W. Junker, and B. Korty, 1995: Evaluation of 33 years of quantitative precipitation forecasting at NMC. *Wea. Forecasting*, **10**, 498-511.

Roebber, P. J. and L. F. Bosart, 1998: The sensitivity of precipitation to circulation details: Part I: an analysis of regional analogs. *Mon. Wea. Rev.*, **126**, 437-455.

Root, B., P. Knight, G. Young, S. Greybush, R. Grumm, R. Holmes, and J. Ross, 2007: A fingerprinting technique for major weather events. *J. App. Meteor. and Clim*, **46**, 1053-1066.

Uccellini, L. W. and P. J. Kocin, 1987: The interaction of jet streak circulations during heavy snow events along the east coast of the United States. *Wea. Forecasting*, **2**, 289-308.

Whittaker, L. M. and L. H. Horn, 1981: Geographical and seasonal distribution of North American cyclogenesis. *Mon. Wea. Rev.*, **109**, 2312-2322.