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UPPER AIR CONSTANT PRESSURE COMPOSITES OF MIDWESTERN THUNDERSNOW EVENTS

Patrick S. Market*[,1], Angela M. Oravetz[1], David Gaede[2], Evan Bookbinder[2], Rebecca Ebert[1], and Christopher Melick[1]

[1]*Department of Atmospheric Science*
University of Missouri-Columbia
Columbia, MO

[2]National Weather Service Forecast Office
Springfield, MO

1. INTRODUCTION

Thundersnow events from 1961 through 1990 were examined. Events chosen for further scrutiny occurred in the Midwest on synoptic hours and featured thunder and snow only, a process that led to 97 cases of thundersnow. The thundersnow events were classified into categories based upon the setting in which each event occurred; examples include: with a cyclone, with a front, in a lake effect situation, *etc.* Events that occurred with a cyclone (N=80) were the focus of this study, and further classified based upon where the thundersnow occurred in relation to the cyclone (northwest of it, northeast, *etc.*) in keeping with previous work (Market et al. 2002). These event classes were then subject to a composite process, which is described below.

2. METHOD

Mean fields of standard atmospheric variables at several levels (900 mb, 850 mb, 700 mb, 500 mb, and 300 mb) were generated with the compositing software of Moore et al. (2003) for the time of initiation as well as 12, 24, 36, and 48 hour prior to thundersnow initiation, hereafter referred to as T-00, T-12, T-24, T-36 and T-48, respectively. This was done in hopes of determining which dynamic and thermodynamic features are present, not only when the thundersnow is occurring, but also before the event; the intention was to produce more accurate forecasts of thundersnow in the future.

All composites were centered on the location of thundersnow initiation. Given the relatively small sample size, the maximum number of events was sought; thundersnow reports from hours 0800 Universal Time Coordinated (UTC) to 1900 UTC were evaluated with 1200 UTC rawinsonde data while thundersnow reports for the 2000 UTC to 0700 UTC period were represented by 0000 UTC balloon data.

Corresponding author: Patrick S. Market, University of Missouri-Columbia, 387 McReynolds Hall, Columbia, MO 65211. E-mail: market@bergeron.snr.missouri.edu

3. COMPOSITE RESULTS

Such convective snow events associated with cyclones occur in a dynamic environment, with ample moisture and lift. The composite thundersnow event occurring northwest of a cyclone center (N=33) tends to occur with deeper, better-developed, negatively-tilted cyclones as a result of upright convection. Conversely, the composite thundersnow event occurring to the northeast of a cyclone (N=19) tends to be associated with weaker, less-developed, neutrally-tilted systems and more likely the result of slantwise motions.

A majority of the thundersnow events occurred to the northwest of the cyclone in question. The composites depicted distinct differences between events northwest of the cyclone center (NWC) and those northeast of the cyclone center (NEC). The rationale for this approach is based on the work of Market et al. (2002), and their scatter diagram suggesting that these two areas are preferred for thundersnow development in a given cyclone (see their Fig. 6). Although thundersnow to the north of a cyclone was composited, further investigation into this group was not pursued for this project.

Finally, we note that these composites are intended as much for pattern recognition as they are for dynamic understanding. Obtained from averaged grids, the fields shown herein lack many of the important features present in each individual case. However, those regions where thundersnow exists are, on average, ones of copious moisture and robust forcing for ascent.

3.1 T-00 - Northwest of cyclone

With these cases, thundersnow is in progress to the northwest of a surface cyclone, and we begin our examination close to the surface. We note, too, that discussions of parameter values are valid at the thundersnow initiation site unless otherwise noted.

At 900 mb, heights over the thundersnow initiation site are at their lowest (Fig. 1a), at 910 gpm. The mean heights fall at 850 mb (not shown) to their lowest levels over the course of the previous 48 hours as well, to 1368 gpm. This is a 45 gpm fall from T-12. The mean relative humidity is at its peak value, at 86 percent, while the divergence at 850 mb is -1.9 x 10^{-5} s^{-1} and the absolute vorticity advection at 850 mb is -3.2 x 10^{-9} s^{-2}.

At 700 mb (Fig. 1b) , the θ_e pattern reveals a distinct ridge that originates southeast of the event sites and east of the 700 mb low and arches northwestward and over the thundersnow location. The θ_e advection (not shown) and temperature advection at 700 mb have both hit their peak and are already decreasing. That these values are decreasing farther suggests that NWC cases occur with cyclones beginning the decay process.

The mean 500-mb (Fig. 1c) heights are at 5485 gpm, a 60 gpm drop over 12 hours and the relative humidity at this level is still near 60 percent, which indicates that the atmosphere is moistening throughout the profile. The absolute vorticity advection at 500 mb is a positive vorticity advection (PVA) maximum at 12.0 x 10^{-9} s^{-2}, representing an increase of 8.5 x 10^{-9} s^{-2} from T-12.

At 300 mb, (Fig. 1d) the mean heights fall 70 gpm to 9060 gpm and the divergence at 300 mb is 2.2 x 10^{-5} s^{-1}, which is nearly double the value at T-12. Moreover, the height pattern reveals a negatively tilted trough upstream from the event site.

Again, the difference in the divergence values between 850 mb and 300 mb is greatest of all the five times composited. Upward motion is likely, given the divergence profiles between 850 mb and 300 mb. In addition, the absolute vorticity advections from 850 mb to 500 mb suggest forcing for ascent, with the magnitude of the difference between the values at 850 mb and 500 mb being 15.2 x 10^{-9} s^{-2}. However, the temperature advection at 700 mb has hit its peak and is now decreasing. Coupled with the broad trowal (trough of warm air aloft) signature at 700 mb this change in temperature advection further evinces NWC cases as ones that are beginning the decay and weakening stages.

3.2 *T00 - Northeast of cyclone*

The mean heights at 900 mb (Fig. 2a) make their greatest fall in NEC cases as the thundersnow begins. They fall by 40 gpm over 12 hours to 945 gpm. The mean heights at 850 mb (not shown) fall to 1395 gpm, also a 40 gpm drop. The mean relative humidity increases to 77 percent, while the mean divergence value at 850 mb is -2.2 10^{-5} s^{-1}, a decrease similar to T-12. The absolute vorticity advection at 850 mb rises to +1.0 x 10^{-9} s^{-2}, an increase of 2.9 x 10^{-9} s^{-2}.

The θ_e field at 700 mb (Fig. 2b) is quite different from that of the NWC cases (Fig. 1b). Here, the bulk of the analysis reveals a θ_e pattern that is still zonal, with only a suggestion of a θ_e ridge southeast of the event with its axis over the 700 mb cyclone center. The θ_e advection (not shown) and temperature advection at 700 mb (Fig. 2b) continue to rise as well to their peak values of 8.0 x 10^{-4} K s^{-1} and 4.5 x 10^{-4} K s^{-1}, respectively.

The mean 500-mb (Fig. 2c) heights fall to 5490 gpm, while the mean relative humidity there increases to 62 percent. The absolute vorticity advection at 500 mb increases to 14.0 x 10^{-9} s^{-2}. This is a 12.5 x 10^{-9} s^{-2} rise from T-12. The mean heights also fall at 300 mb by 20 gpm (Fig. 2d), while the divergence at 300 mb is 1.5 x 10^{-5} s^{-1}, which is an increase of 1.3 x 10^{-5} s^{-1}. Also, the event site resides just upstream of the 300 mb ridge axis at this time. This configuration is similar to that at 500 mb (Fig. 2c), placing the thundersnow event in a region of anticyclonically curved flow aloft. Unlike NWC cases, the NEC cases are much more likely to be the result of symmetric instability release, culminating in elevated convection ahead of a surface warm front. This point is further supported in our companion paper (this volume).

4. SUMMARY

The composites suggest that thundersnow occurring to the northeast of a cyclone does so in a system that is still developing and has not yet reached maturity. The divergence from 850 mb to 300 mb indicates that upward motions are likely.

From a quasi-geostrophic perspective, the absolute vorticity advection from 850 mb to 500 mb indicates forcing for ascent, while the temperature advection at 700 mb is at its peak value. The unremarkable θ_e pattern at 700 mb and the location of the event near the 300 mb ridge axis further indicates that the NEC cyclone is still increasing in intensity. Additionally, all of these values do not possess the magnitude of those in NWC cases, thus advancing the case that NEC cyclones are less mature.

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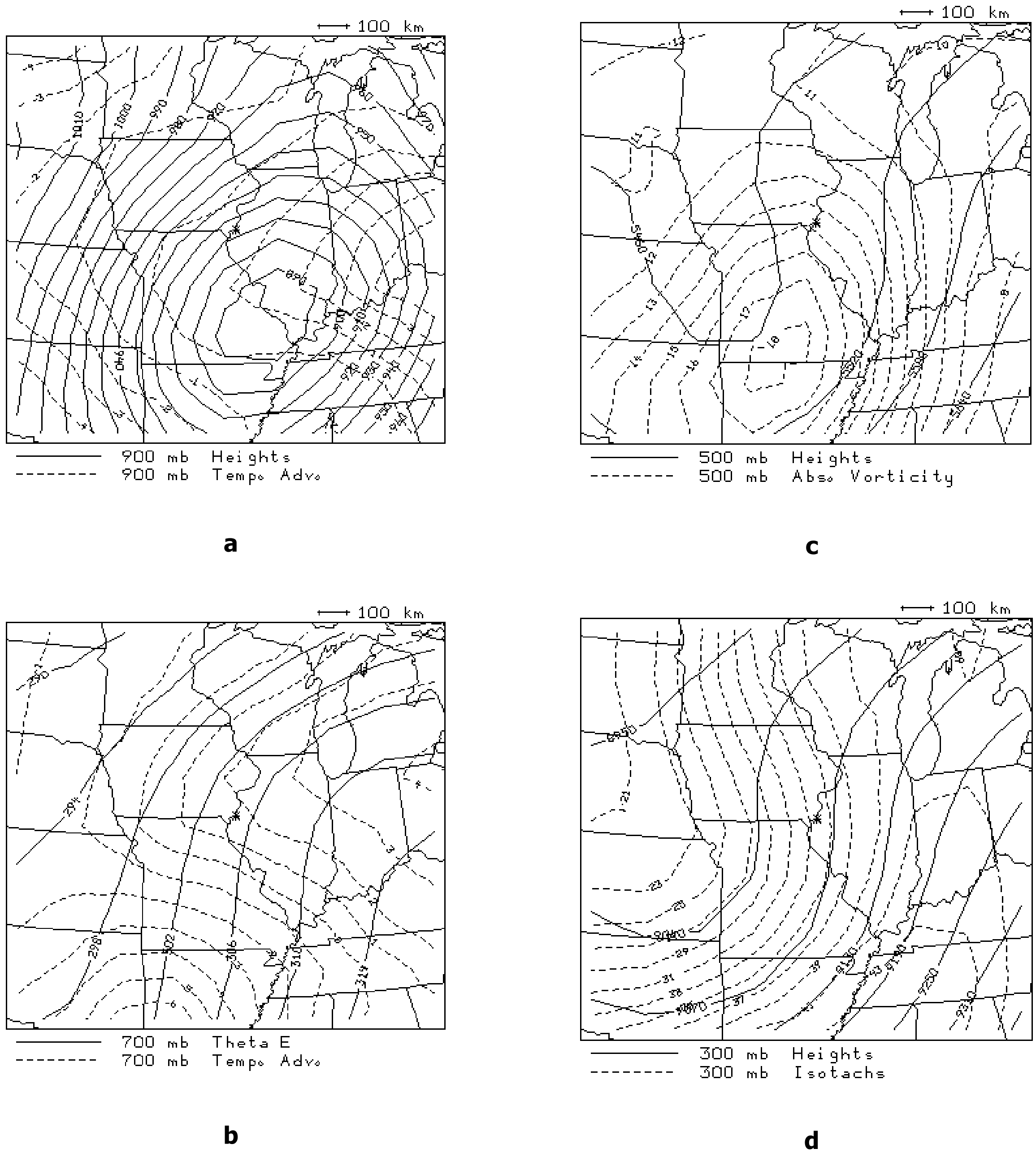

Figure 1. Mean fields of **a**) 900 mb geopotential height (gpm) and temp. advection (10^{-4} K s^{-1}), **b**) 700 mb θ_e (K) and temp. advection (10^{-4} K s^{-1}), **c**) 500 mb geopotential height (gpm) and absolute vorticity (10^{-5} s^{-1}), and **d**) 300 mb geopotential height (gpm) and isotachs (m s^{-1}) for thundersnow events northwest of a surface cyclone. Composites are centered on the thundersnow initiation site (∗); the map background is supplied for scale reference ***only***.

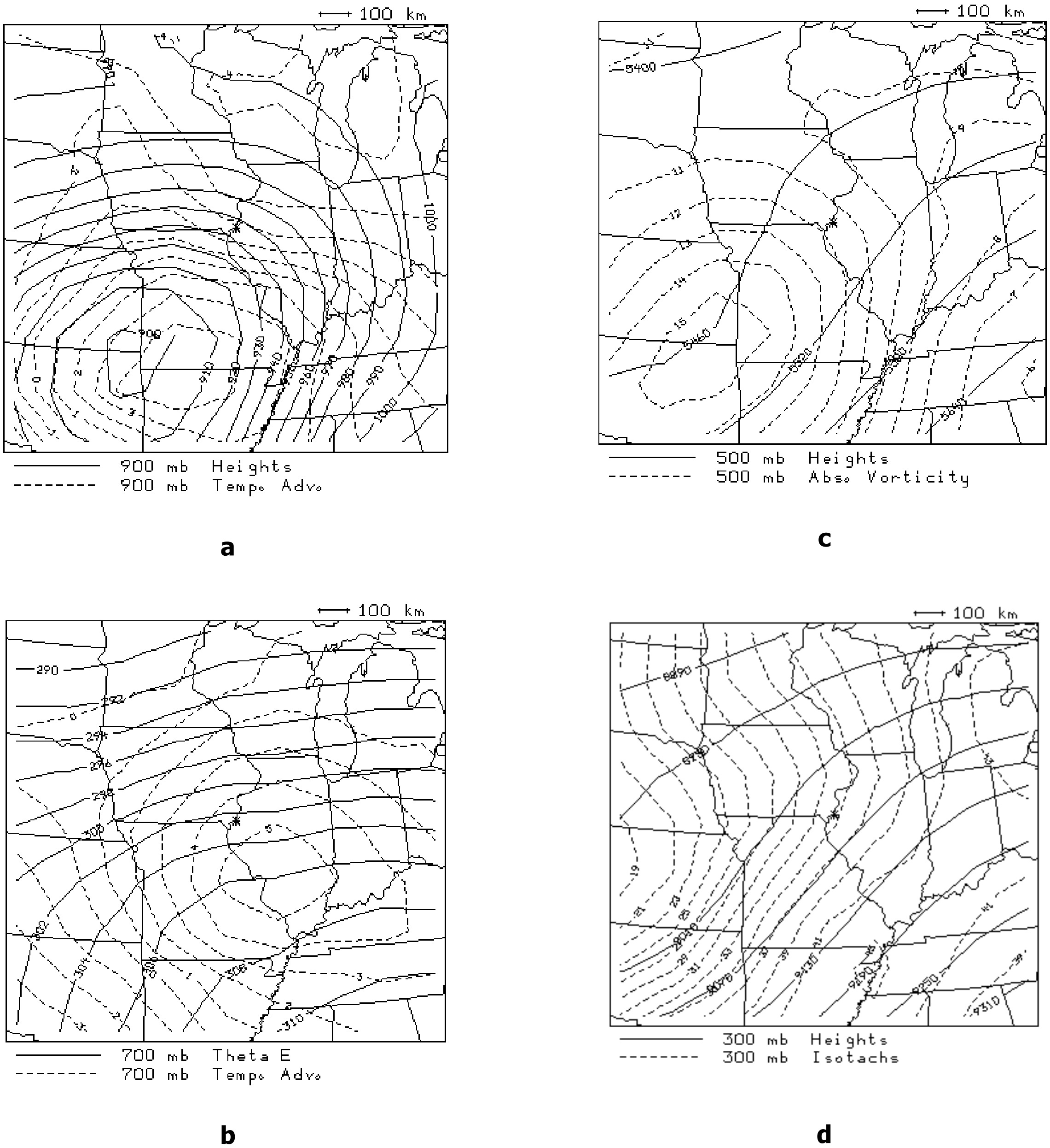

Figure 2. As in Figure 1, but for events occurring northeast of the surface cyclone center.