NOTES AND CORRESPONDENCE

**A Supplemental Note to the Combined Role of Kinematics,
Thermodynamics and Cloud Physics Associated with Heavy Snowfall Episodes**

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1. Introduction

Auer and White (1982), in a detailed study of a heavy snowfall episode, concluded that regions of maximum rate of condensate that occur near the level of nondivergence (600 mb) at temperature regimes near -15°C must be suspect for producing heavy snowfall (>6 in/12 hr). They collaborated their claim with a climatological study of 75 heavy snowfall episodes which depicted saturated ascent through the level of nondivergence at $\theta_e = 304\text{--}309\text{K}$ (i.e., 600 mb temperature of $-13\text{--}-15^{\circ}\text{C}$). Now, four years later, the climatological sample has swelled to 213 samples of major snowfall events. Representative upper air soundings in the ascending air of the left-front quadrant of these 213 storms, producing 6 in (15 cm) or more snowfall in 12 hr, were polled for their 500 mb and 700 mb temperatures; from these two levels, a 600 mb temperature was determined, assumed to be at the level of non-divergence. Of these 213 cases, 118 were falls between 15–23 cm (6–9 in), 59 for depths between 23–30 cm (9–12 in), and 36 for accumulations greater than 30 cm (12–24 in); the synoptic classification showed 97 episodes of closed circulation at 500 mb, 84 cases associated with migrating short waves at 500 mb, and 32 events where the synoptic type was not determined.

2. Results

The results of the total data set analysis are shown in the top lines of Tables 1–3 (which can

be compared with Figure 6 of Auer and White (1982)). Approximately 77% of the cases occurred with 500 mb temperatures between -22 to -25°C (Table 1), 700 mb temperatures between -5 to -8°C (Table 2) and 600 mb temperatures of -14 to -16°C (Table 3). It should be noted from Table 1 that no heavy snowfall events occurred with a 500 mb temperature colder than -27°C , and the number is strongly curtailed for temperatures colder than -25°C . While the lack of heavy snowfall may be related to microphysical processes, a more likely explanation resides in the fact that the upper air dynamics supporting ascending vertical motion are usually displaced downstream from the coldest temperatures of the trough. At 500 mb, the mean, median, and mode temperatures for the distribution are -23.3°C , -23°C , and -25°C , respectively. From Table 2 it is seen that at 700 mb no major snowfall events occurred with temperatures colder than -11°C , while 30% of the episodes occurred with a temperature of -7°C . At 700 mb, the mean, median, and mode temperatures for the distribution are -7.3°C , -7°C , and -7°C , respectively. The temperature distribution shown in Table 3 at the assumed level of non-divergence, 600 mb, substantiates the premise that dendritic ice crystal growth at this level consumes the maximum rate of condensate for heavy snowfall events. With nearly 80% of the events characterized by temperatures between -14°C and -16°C it appears that climatologically heavy snowfall episodes are described by the occurrence of a level of non-divergence (maximum vertical velocity) at the

Table 1. Frequency of 500 mb temperatures associated with upward vertical velocity patterns of closed circulations and short waves aloft producing heavy snowfall.

Snow Depth (in)	500 mb Temperatures, C								Total cases
	-20	-21	-22	-23	-24	-25	-26	-27	
$6 \leq D \leq 24$	16	19	37	41	42	44	8	6	213
$6 \leq D \leq 9$	9	10	23	23	20	27	3	3	118
$9 < D \leq 12$	5	8	9	13	13	7	3	1	59
$D > 12$	2	1	5	5	9	10	2	2	36

Table 2. Frequency of 700 mb temperatures associated with upward vertical velocity patterns of closed circulations and short waves aloft producing heavy snowfall.

Snow Depth (in)	700 mb Temperatures, C								Total cases
	-4	-5	-6	-7	-8	-9	-10	-11	
$6 \leq D \leq 24$	6	25	32	64	45	19	17	5	213
$6 \leq D \leq 9$	3	12	23	31	26	10	10	5	118
$9 < D \leq 12$	1	12	6	24	7	4	4	1	59
$D > 12$	2	1	3	9	12	5	3	1	36

Table 3. Frequency of 600 mb temperatures associated with upward vertical velocity patterns of close circulations and short waves aloft producing heavy snowfall.

Snow Depth (in)	600 mb Temperatures, C							Total cases
	-12	-13	-14	-15	-16	-17	-18	
$6 \leq D \leq 24$	5	30	56	60	45	13	4	213
$6 \leq D \leq 9$	4	19	33	31	21	7	3	118
$9 < D \leq 12$	1	9	17	20	9	3	0	59
$D > 12$	0	2	6	8	15	3	1	36

habitat of dendritic crystals ($-13^{\circ}\text{C} - -17^{\circ}\text{C}$) which allows for the maximum delivery of condensate to be consumed by maximum crystal growth rates. Note that 95% of the events occurred within the envelope for dendritic growth ($-13^{\circ}\text{C} - -17^{\circ}\text{C}$); the small minority of events at -12°C and -18°C are probably a reflection of the variability of the level of non-divergence from its assumed height of 600 mb. The mean, median, and mode temperatures for the distribution are -14.8°C , -15°C , and -15°C , respectively . . . right in the middle of the dendritic crystal habitat.

The temperature envelopes at 500 mb, 700 mb, and 600 mb that most frequently occur during heavy snowfall episodes (77%, or 164 of the 213 cases) are conveniently confined between $\theta_e = 304\text{--}309\text{K}$ for saturated ascent. Ascent characterized by higher or lower values of θ_e (*i.e.*, warmer than -13°C or colder than -17°C at 600 mb) does not appear to be associated with

heavy snowfall production. This finding was put forth by Auer and White (1982).

Tables 1–3 show the temperatures distributions for twelve hours accumulations of 6–9 in, 9–12 in, and greater than 12 in, respectively. There is great similarity between the corresponding distributions of each Table. The heaviest snowfall events depict a slight cooling (0.5 to 1.0°C) at all levels for the mean, median, and mode values; however, this probably is not significant. The Tables still emphasize the critical envelope of temperatures necessary for heavy snowfall production.

Finally, Figure 1 shows the frequency histogram for snowfall amounts partitioned by synoptic classification. It can be noted that 82% of the events were confined to snowfalls of 30 cm or less (12 in or less). For migrating tropospheric short waves with the appropriate thermal patterns, the snow depths typically ranged between 15–20 cm (6–8 in) for a 12-hr interval. Closed

Fig. 1. Frequency histogram of the 12-hr snowfall amounts associated with migratory short waves (stippled) and closed circulations (solid).

circulations, more apt to be quasi-stationary, were found to be more conducive to produce amounts in the 25–30 cm (10–12 in) range with the proper thermal fields.

3. Summary

A mini-climatological study of upper air thermal conditions occurring in the ascending air of

synoptic circulations which yielded heavy snowfall amounts strongly supports the premise of Auer and White (1982). These investigators claimed that regions of maximum rate of condensate that occur near the level of nondivergence at temperature regimes near -15°C must be suspect for producing heavy snowfall episodes. That is, heavy snowfalls are expected to occur in regions where the level of nondivergence, *i.e.*, maximum vertical velocities for saturated ascent is coincident in elevation with the maximum growth rate of dendritic ice crystals. This study collaborates that for heavy snowfall saturated ascent through the level of nondivergence must be confined to the envelope of $\theta_e = 304\text{--}309\text{K}$ (*i.e.*, a 600 mb temperature between -13° and -17°C).

References

- Auer, Jr., A.H. and J.M. White, 1982: The role of kinematics, thermodynamics and cloud physics associated with heavy snowfall episodes. *J. Meteorol. Soc. Japan*, **60**(1), pp. 500–507.

力学・熱力学・雲物理学的に見た大雪現象に対しての補遺

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