A Climatology and Statistical Classification of Midwestern Snow Bands: A Process-Oriented Approach

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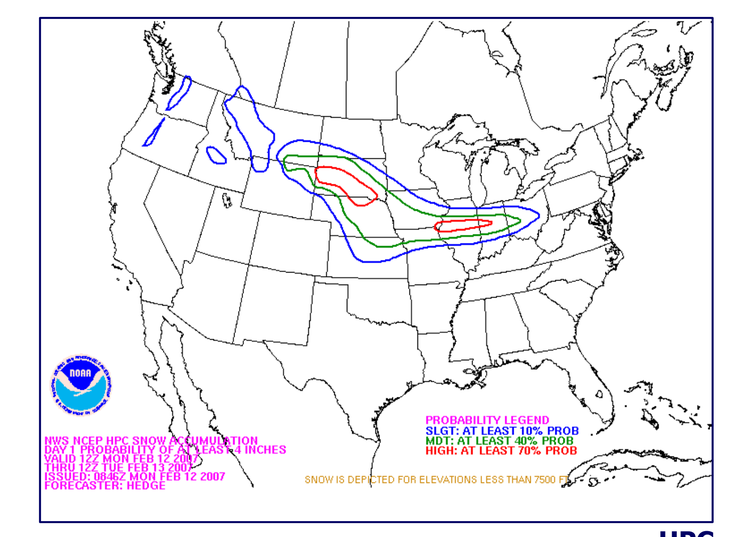
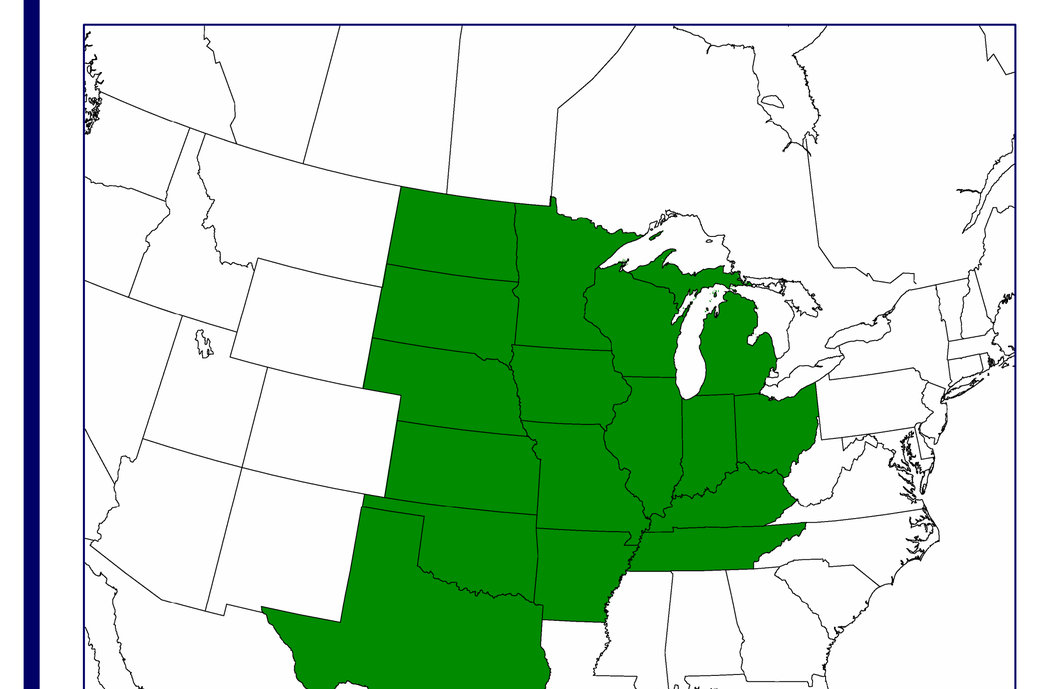
Introduction

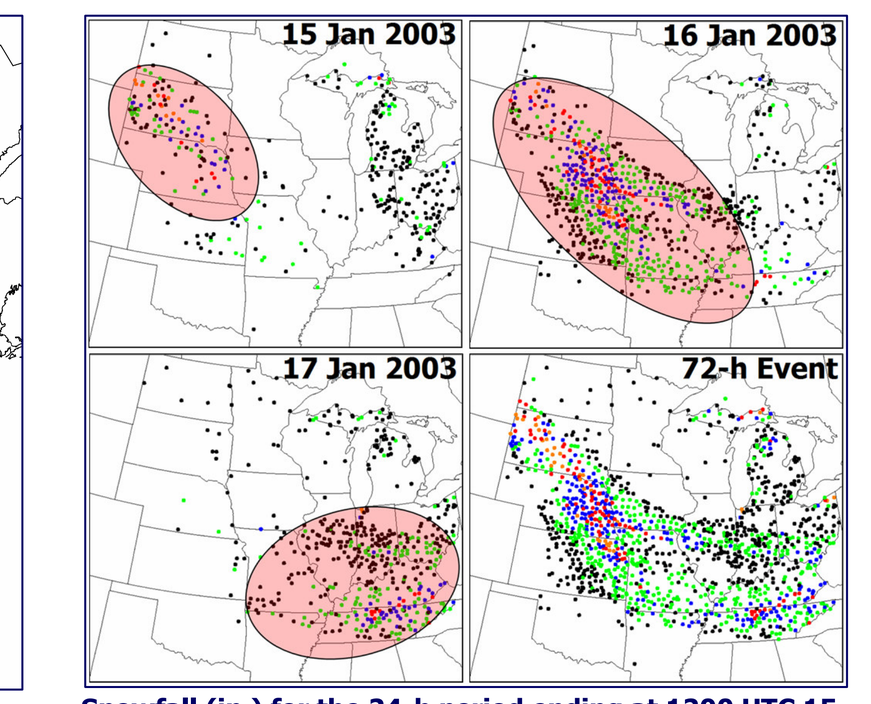
- By 2010, one of NOAA's performance objectives is to increase the lead time on winter storm warnings by 21% (from 14 to 17 hours). However, NOAA states that winter storm formation, tracking, and precipitation amounts and types need to be better understood and quantified to provide more effective forecasts and warnings.
- In this presentation, a 5-yr climatology of organized synoptic-scale snow events (banded) in the Midwest is presented in an effort to develop guidance that will support operations at the Hydrometeorological Predictions Center's Winter Weather Desk.
- Using the National Climate Data Center (NCDC) Cooperative Summary of the Day (COOP) data, a 5-yr database of organized snow events in the Midwest was developed and their temporal and spatial characteristics were examined. In addition, using hourly surface data from the Automated Surface Observing Systems (ASOS) and the North American Regional Reanalysis (NARR) dataset, the synoptic-climatological relationship between heavy snowfall and surface/upper-air features was revisited.



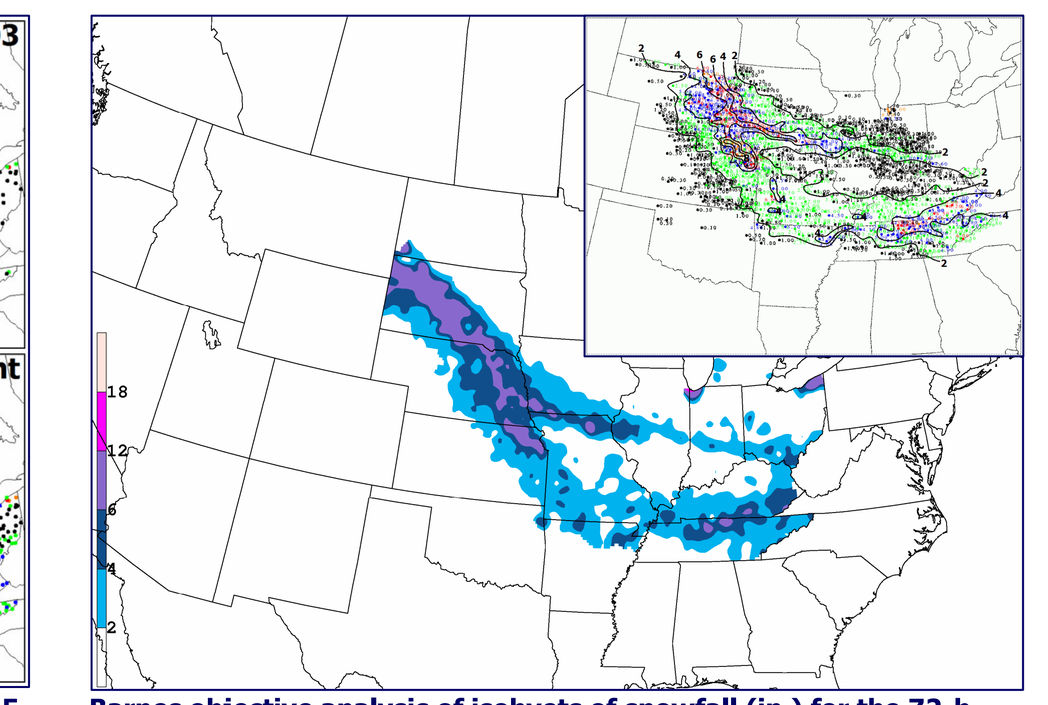
Methodology



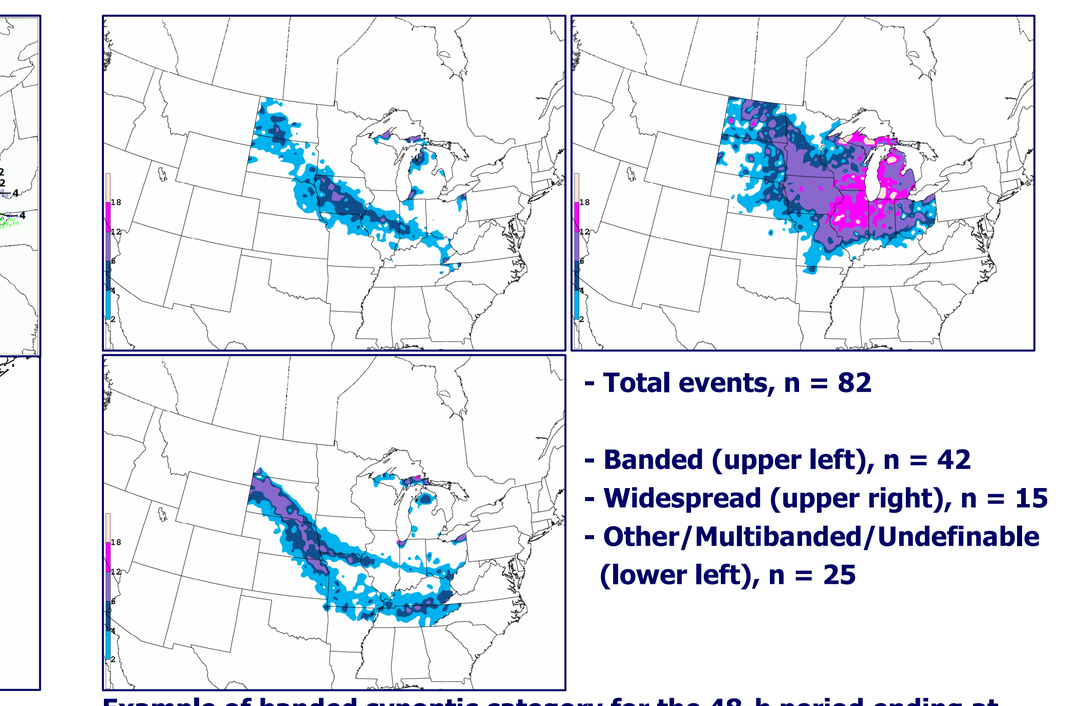
Midwest case selection domain for the present study. Shaded states are those included in the domain.



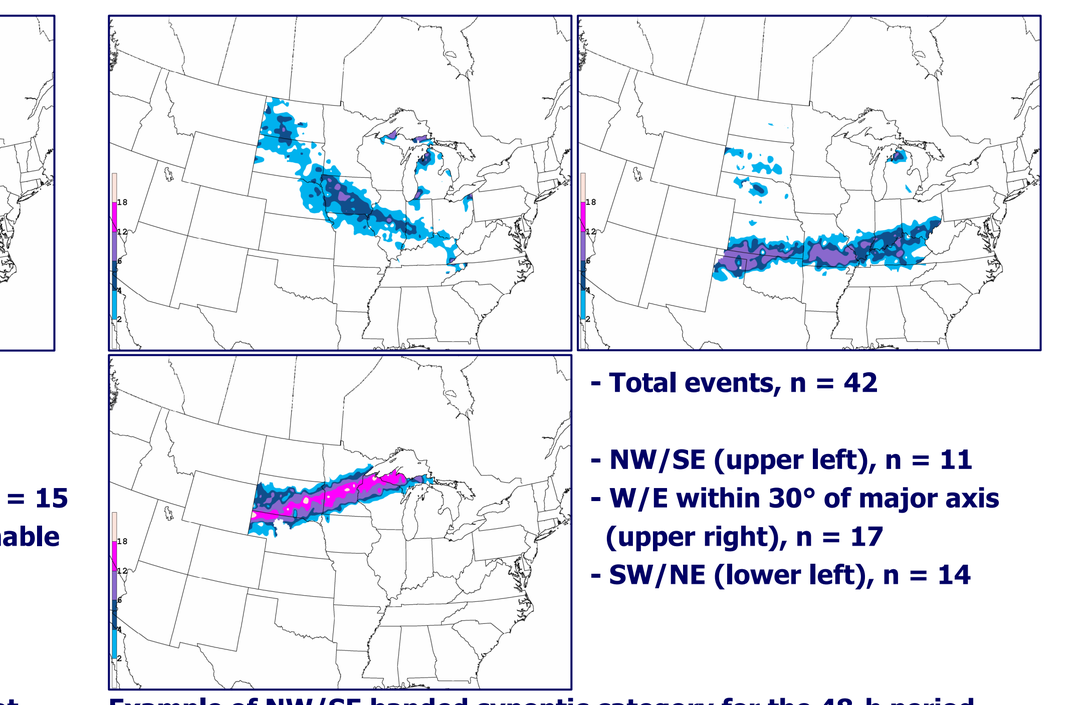
Snowfall (in.) for the 24-h period ending at 1200 UTC 15 January 2003 (top left), 16 January 2003 (top right), 17 January 2003 (bottom left), and 72-h total event snowfall ending at 1200 UTC 17 January 2003 (bottom right) based upon COOP station data from NCDC. Pink shaded areas represent studied regions of the total event snowfall.



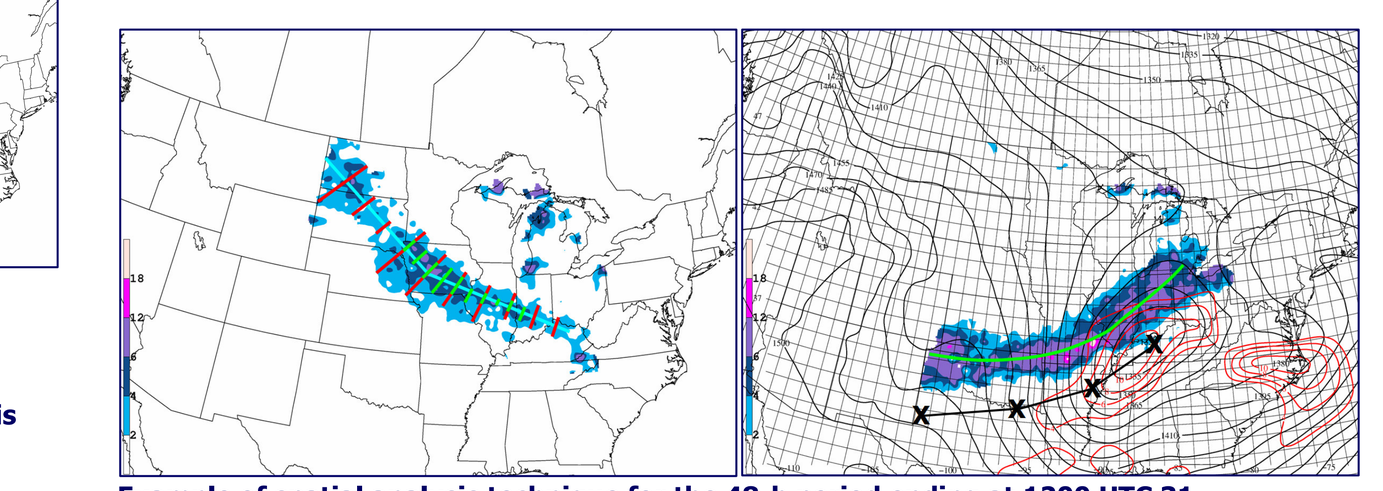
Barnes objective analysis of isohyets of snowfall (in.) for the 72-h period ending at 1200 UTC 17 January 2003 based upon COOP station data from NCDC. Inset figure is the subjective analysis of isohyets of snowfall (in.) for the 48-h period ending at 1200 UTC 17 January 2003.



Example of banded synoptic category for the 48-h period ending at 1200 UTC 31 December 1998 (top left), widespread synoptic category for the 96-h period ending at 1200 UTC 04 January 1999 (top right), and other synoptic category for the 72-h period ending at 1200 UTC 17 January 2003 (bottom left) based upon COOP station data from NCDC.

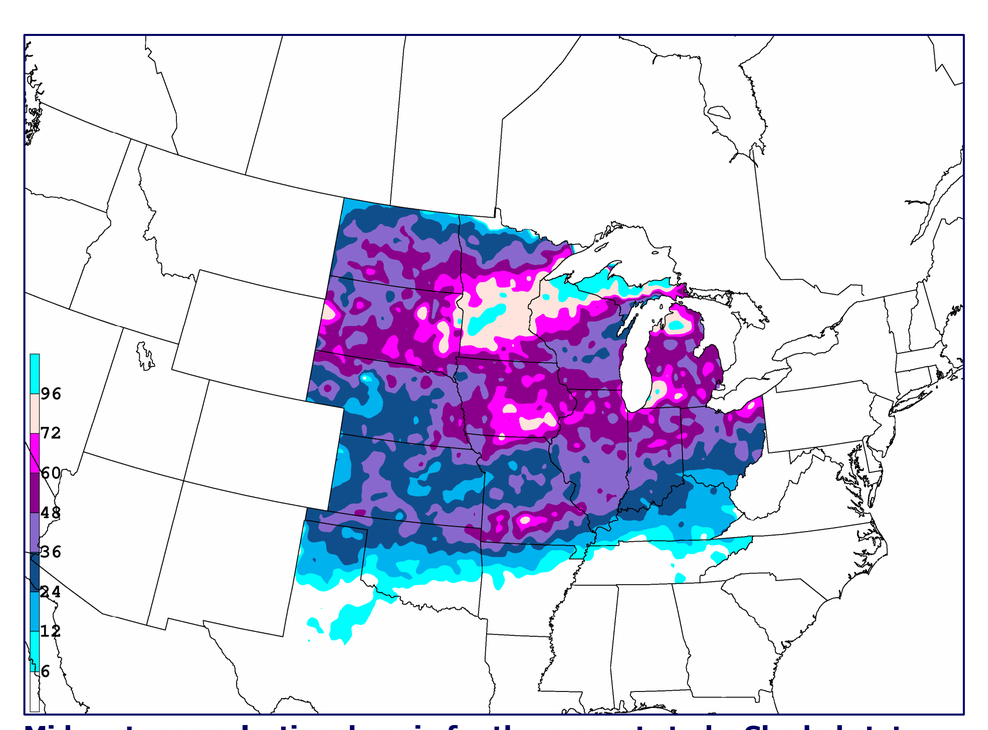


Example of NW/SE banded synoptic category for the 48-h period ending at 1200 UTC 31 December 1998 (top left), W/E banded synoptic category for the 48-h period ending at 1200 UTC 05 December 2002 (top right), SW/NE banded synoptic category for the 48-h period ending at 1200 UTC 15 March 2002 (bottom left) based upon COOP station data from NCDC.

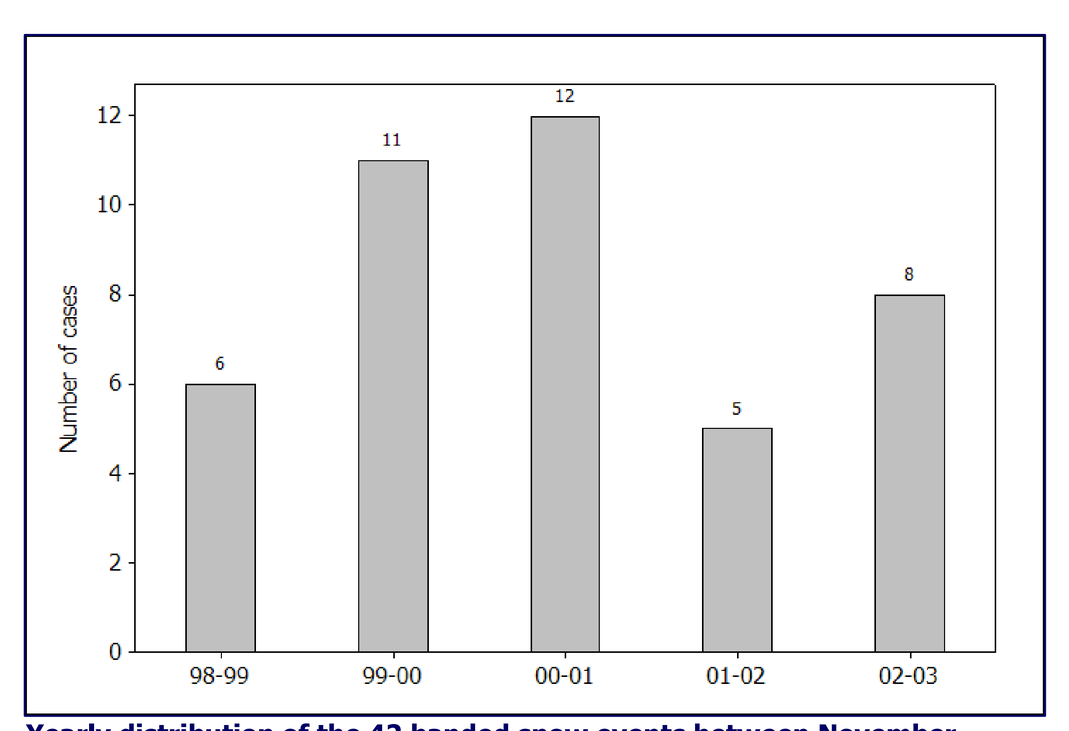


Example of spatial analysis technique for the 48-h period ending at 1200 UTC 31 December 1998 (left). Blue line is the length of the ≥ 2.0" band, red lines are locations where calculations were taken for the width of the ≥ 2.0" band, and green lines are locations where calculations were taken for the width of the ≥ 4.0" band. Example of 850 hPa height center tracking technique for the 72-h period ending at 1200 UTC 25 December 2002 (right). 850-hPa heights (m, black), 850-hPa relative vorticity (10^{-5} s^{-1}, red), band axis (green line), and 850-hPa storm track (black line) and center positions (Xs) are shown.

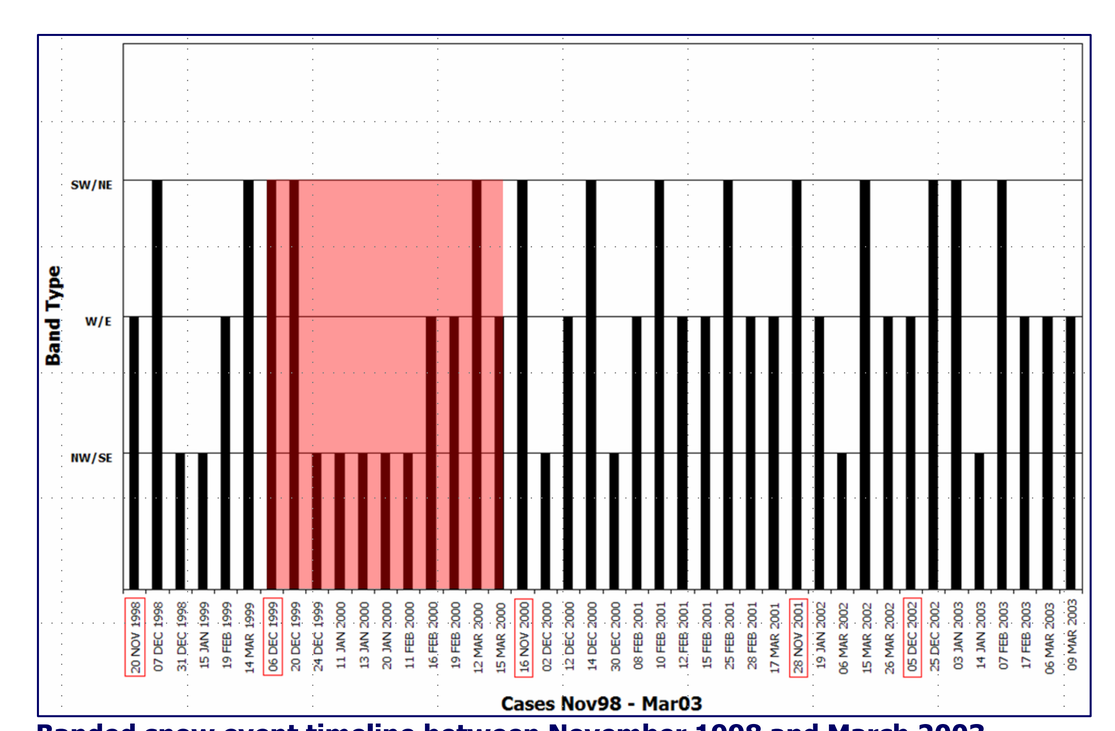
Climatology - Overview



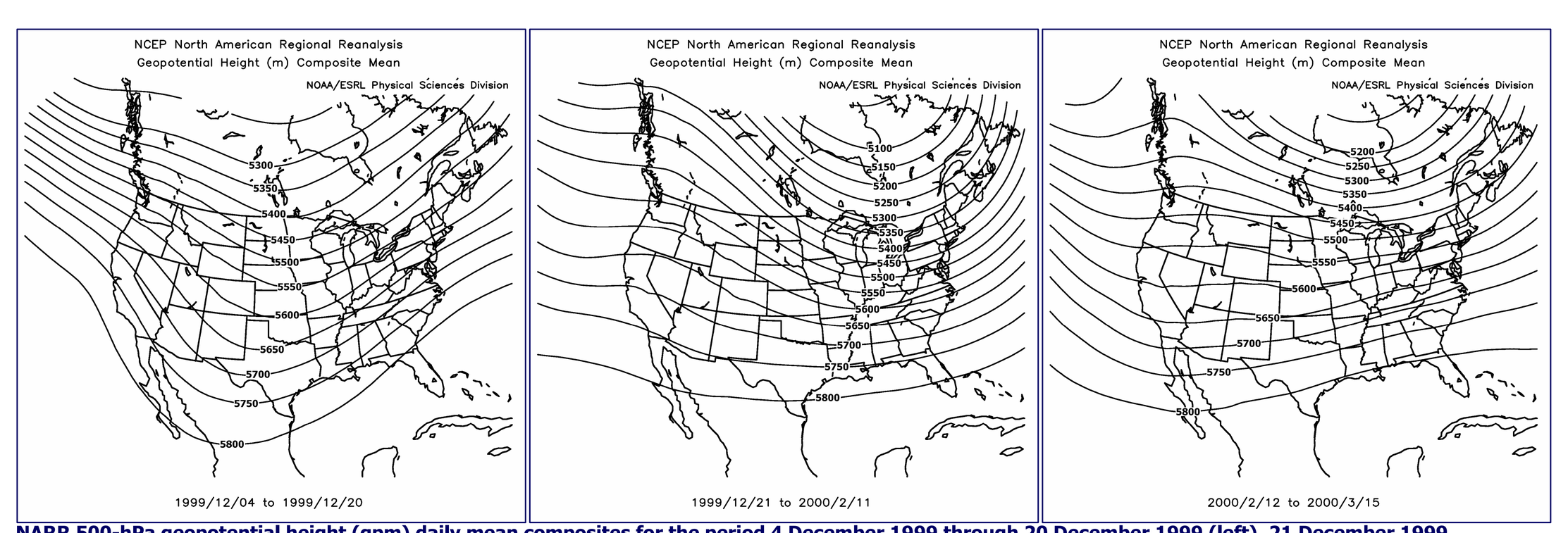
Midwest case selection domain for the present study. Shaded states are those included in the domain.



Yearly distribution of the 42 banded snow events between November 1998 and March 2003. Number of cases in each season appears at the top of each bar.



Banded snow event timeline between November 1998 and March 2003. Dates marked in red indicate first event for the corresponding winter season and red shading denotes the 1999-2000 winter season.

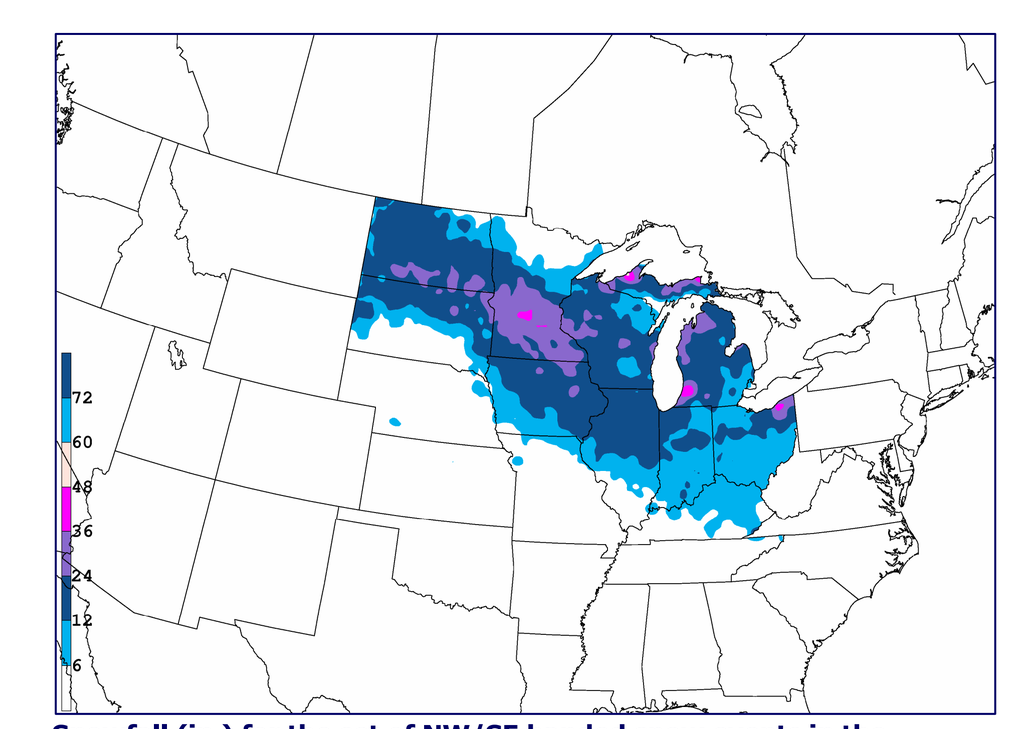


NARR 500-hPa geopotential height (gpm) daily mean composites for the period 4 December 1999 through 20 December 1999 (left), 21 December 1999 through 11 February 2000 (middle), and 12 February 2000 through 15 March 2000 (right).

- A yearly distribution of the all the organized banded snow events reveals that the 1999–2000 and 2000–2001 winter seasons had a higher frequency of snow events (11 and 12, respectively) than the other years in the database. It is hypothesized that the higher frequency of events may be in part due to a shift in the El Niño Southern Oscillation (ENSO).
- It was shown that there may be distinguishable mid- to upper-level flow patterns within the banded snow event categories. NW/SE cases are typically associated with northwest flow aloft, SW/NE cases have southwest flow at mid-levels, and W/E cases have more zonal flow across the domain.

Climatology - Northwest/Southeast Oriented Bands

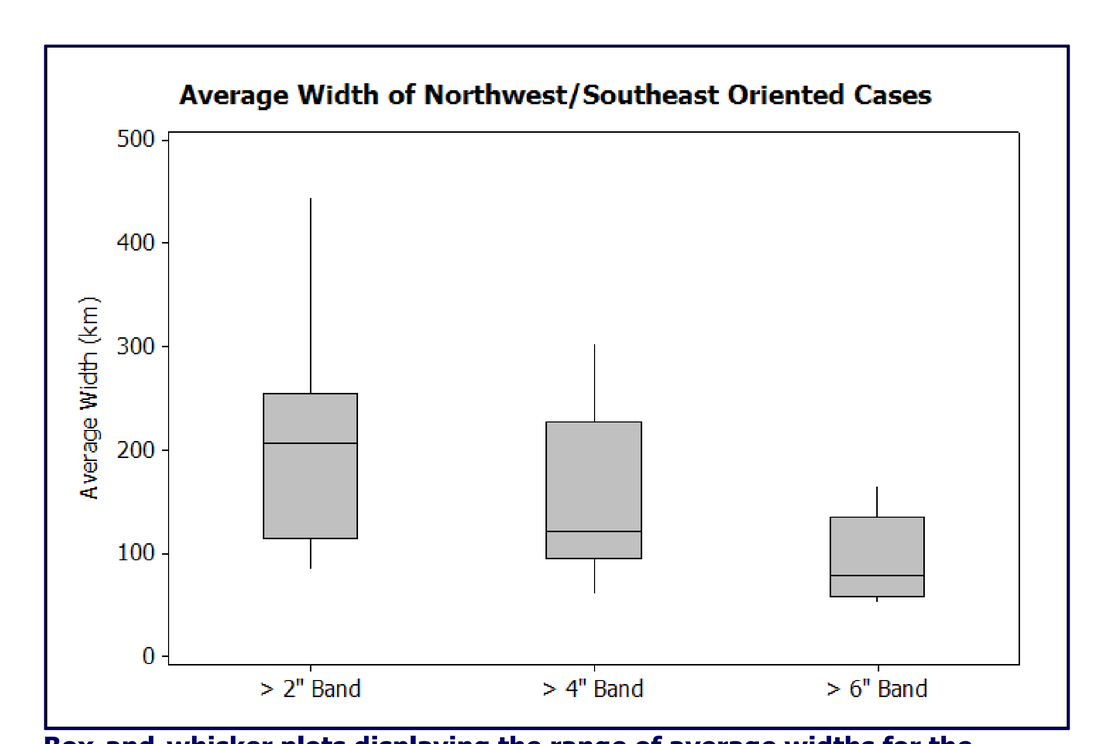
- NW/SE oriented snow bands are most commonly found with northwest flow aloft and are frequently associated with lee-side cyclogenesis in the northern Rockies, more commonly known as the Alberta clipper.
- Although they usually have a weak signature in mass and precipitation fields, Alberta clippers often are associated with dangerous winter weather (Thomas and Martin 2007).
- Upper-level pattern reveals a ridge over western North America and a lee trough east of the Rocky Mountains (found between 21 Dec 1999 and 11 Feb 2000).



Snowfall (in.) for the set of NW/SE banded snow events in the database based upon COOP station data from NCDC.

Snow Event Date	Width ≥ 2"	Width ≥ 4"	Width ≥ 6"	Width ≥ 12"
31 DEC 1998	239.3	123.2	64.5	none
15 JAN 1999	215.0	61.0	none	none
24 DEC 1999	105.4	none	none	none
11 JAN 2000	115.0	none	none	none
13 JAN 2000	183.0	89.0	52.8	none
20 JAN 2000	440.4	259.7	106.0	none
11 FEB 2000	206.3	119.6	none	none
02 DEC 2000	255.1	129.6	79.4	none
30 DEC 2000	444.6	303.0	165.0	none
06 MAR 2002	142.3	113.3	none	none
14 JAN 2003	84.2	none	none	none
$\bar{x}$	220.96	149.79	93.55	none
$q_{0.5}$	206.25	121.37	79.43	none
σ	122.82	84.94	44.61	none
$\hat{\sigma}$	37.03	30.03	19.95	none
$q_{0.3}$	142.29	113.88	67.49	none
$q_{0.7}$	239.30	129.98	100.69	none
$q_{0.9}$	440.43	272.70	141.40	none

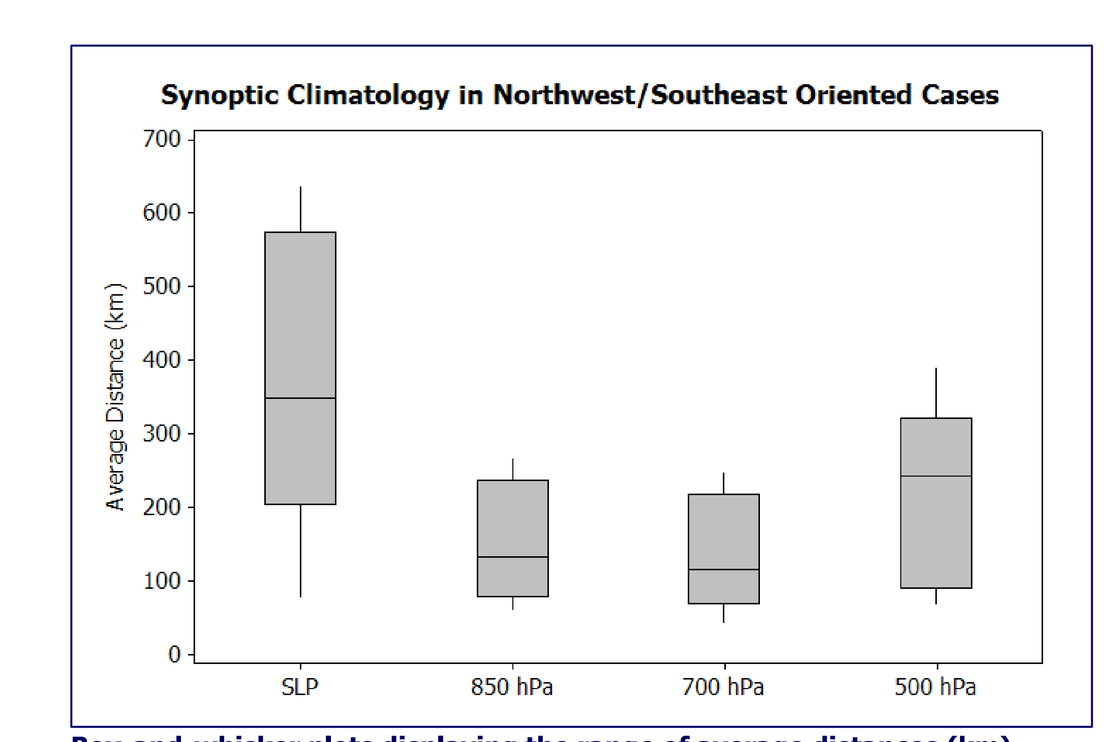
Average width (km) of NW/SE oriented snow events for the period November 1998 – March 2003, where $\bar{x}$ is the average, $q_{0.5}$ is the median, σ is the simple standard deviation (SD), $\hat{\sigma}$ is the normalized SD, $q_{0.3}$ is the 30th percentile, $q_{0.7}$ is the 70th percentile, and $q_{0.9}$ is the 90th percentile.



Box-and-whisker plots displaying the range of average widths for the ≥ 2", ≥ 4", and ≥ 6" bands in the NW/SE oriented snow events for the period November 1998 – March 2003. In each category the horizontal line within each box represents the 50th percentile, the top (bottom) line of the box is the 75th (25th) percentile, and the end of the top (bottom) line outside the box represents the upper (lower) limit.

Snow Event Date	SFC (mb)	850 hPa	700 hPa	500 hPa
31 DEC 1998	354.8	140.8	42.5	116.7
15 JAN 1999	none	83.7	64.4	303.8
24 DEC 1999	184.0	64.0	75.7	none
11 JAN 2000	76.7	59.8	214.7	327.3
13 JAN 2000	632.0	232.8	180.3	218.1
20 JAN 2000	342.3	249.8	248.7	67.5
11 FEB 2000	639.2	175.9	none	none
02 DEC 2000	402.8	267.3	220.6	390.7
30 DEC 2000	267.4	124.7	115.8	267.0
06 MAR 2002	none	none	none	none
14 JAN 2003	none	95.7	76.2	80.7
$\bar{x}$	362.39	149.44	137.66	221.47
$q_{0.5}$	348.53	132.78	115.83	242.54
σ	197.81	78.07	78.64	121.44
$\hat{\sigma}$	69.94	24.69	26.21	42.93
$q_{0.3}$	274.89	92.09	75.88	126.80
$q_{0.7}$	398.00	192.93	200.93	300.12
$q_{0.9}$	634.16	251.57	226.22	346.35

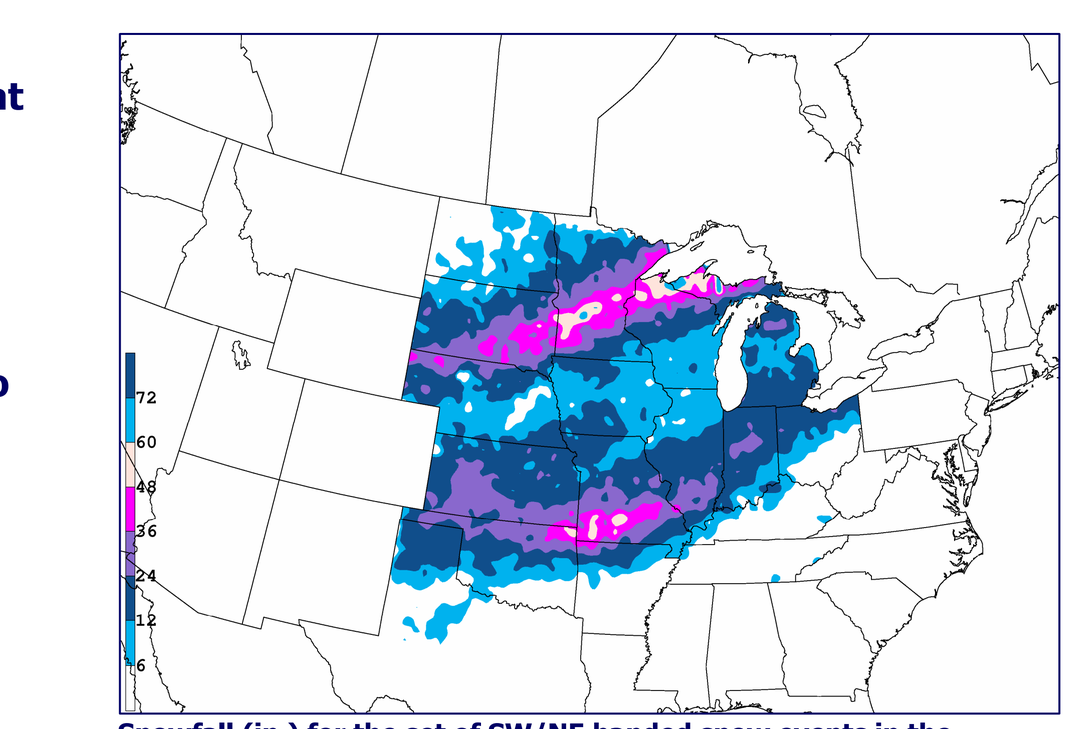
Average distance (km) between surface/upper-air features and the axis of heaviest snow in NW/SE oriented snow events for the period November 1998 – March 2003, where $\bar{x}$ is the average, $q_{0.5}$ is the median, σ is the simple standard deviation (SD), $\hat{\sigma}$ is the normalized SD, $q_{0.3}$ is the 30th percentile, $q_{0.7}$ is the 70th percentile, and $q_{0.9}$ is the 90th percentile.



Box-and-whisker plots displaying the range of average distances (km) between surface/upper-air features and the axis of heaviest snow in NW/SE oriented snow events for the period November 1998 – March 2003. Shown are distances between SLP, 850-hPa, 700-hPa, and 500-hPa features and the axis of heaviest snow. In each category the horizontal line within each box represents the 50th percentile, the top (bottom) line of the box is the 75th (25th) percentile, and the end of the top (bottom) line outside the box represents the upper (lower) limit.

Climatology - Southwest/Northeast Oriented Bands

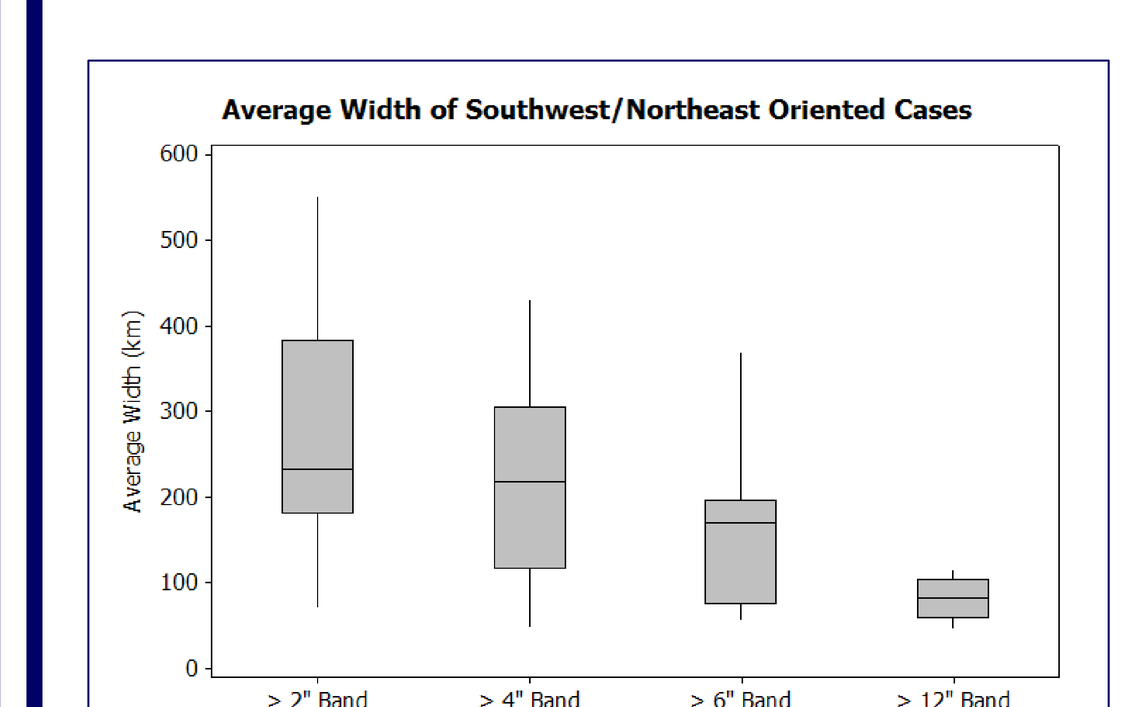
- High Snow events with SW/NE oriented snow bands are typically found with southwest flow at mid-levels (Hoskins and Hodges 2002).
- When a surface system is present, cyclogenesis takes place usually in one of two regions of origin: in the lee of the Rocky Mountains (Colorado Low) or in the western Gulf of Mexico (Whittaker and Horn 1981).
- In contrast to NW/SE oriented bands, these systems are in better proximity to the Gulf of Mexico, which may account for their higher snowfall amounts.



Snowfall (in.) for the set of SW/NE banded snow events in the database based upon COOP station data from NCDC.

Snow Event Date	Width ≥ 2"	Width ≥ 4"	Width ≥ 6"	Width ≥ 12"
07 DEC 1998	71.0	none	none	none
14 MAR 1999	247.9	217.4	191.3	74.8
06 DEC 1999	165.6	102.8	67.3	none
20 DEC 1999	218.0	47.8	none	none
12 MAR 2000	216.2	145.9	78.0	none
16 NOV 2000	118.9	52.7	none	none
14 DEC 2000	517.3	371.0	165.0	64.0
10 FEB 2001	304.8	243.8	153.6	none
25 FEB 2001	492.2	351.3	210.7	99.2
28 NOV 2001	552.7	431.5	371.0	116.3
15 MAR 2002	326.3	256.5	188.3	91.3
25 DEC 2002	346.4	260.4	176.9	46.8
03 JAN 2003	188.0	133.0	56.4	none
07 FEB 2003	208.3	200.4	none	none
$\bar{x}$	283.83	216.50	165.86	82.07
$q_{0.5}$	232.94	217.43	170.94	83.04
σ	148.83	120.06	91.24	25.19
$\hat{\sigma}$	39.78	33.30	28.85	10.29
$q_{0.3}$	206.30	140.73	130.94	69.38
$q_{0.7}$	328.34	258.05	189.23	95.25
$q_{0.9}$	509.78	367.07	226.70	107.75

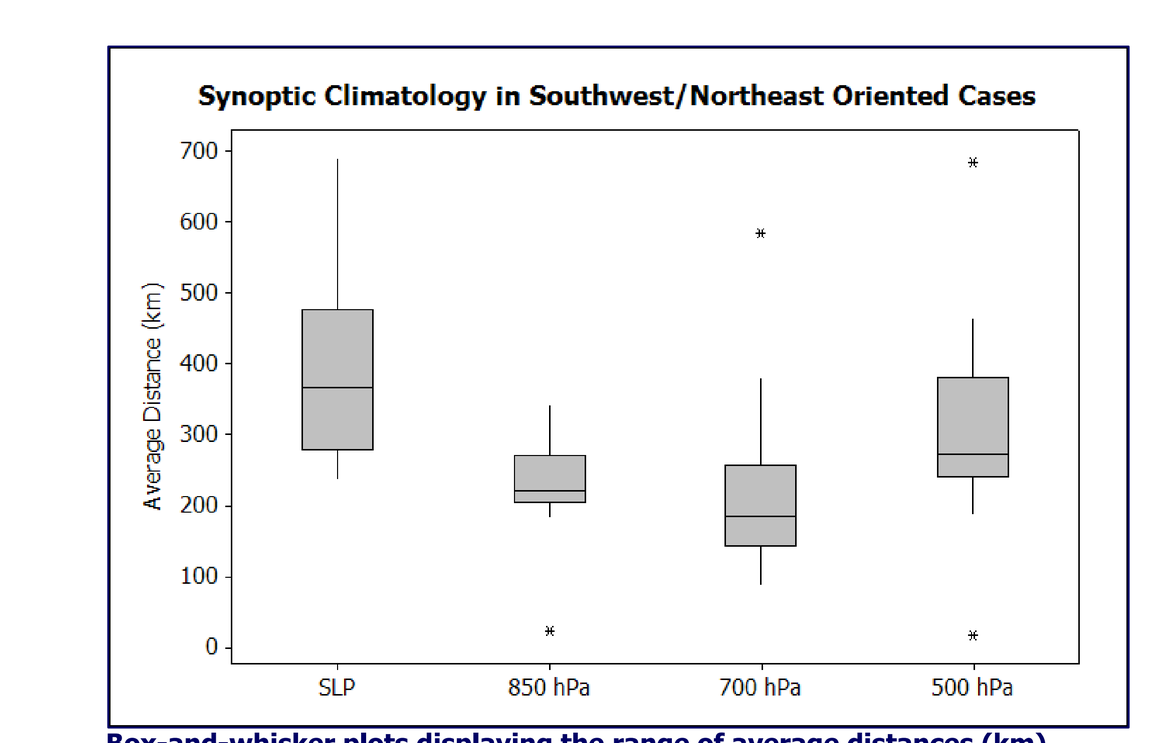
Average width (km) of SW/NE oriented snow events for the period November 1998 – March 2003, where $\bar{x}$ is the average, $q_{0.5}$ is the median, σ is the simple standard deviation (SD), $\hat{\sigma}$ is the normalized SD, $q_{0.3}$ is the 30th percentile, $q_{0.7}$ is the 70th percentile, and $q_{0.9}$ is the 90th percentile.



Box-and-whisker plots displaying the range of average widths for the ≥ 2", ≥ 4", ≥ 6", and ≥ 12" bands in the SW/NE oriented snow events for the period November 1998 – March 2003. In each category the horizontal line within each box represents the 50th percentile, the top (bottom) line of the box is the 75th (25th) percentile, and the end of the top (bottom) line outside the box represents the upper (lower) limit.

Snow Event Date	SFC (mb)	850 hPa	700 hPa	500 hPa
07 DEC 1998	263.0	221.4	131.8	17.5
14 MAR 1999	none	287.6	180.6	375.4
06 DEC 1999	354.2	213.3	152.6	251.1
20 DEC 1999	none	none	none	none
12 MAR 2000	367.7	198.3	185.5	260.9
16 NOV 2000	237.0	220.7	193.7	245.0
14 DEC 2000	none	23.3	87.2	240.7
10 FEB 2001	398.5	228.8	276.5	286.1
25 FEB 2001	303.0	234.8	238.2	685.4
28 NOV 2001	279.6	332.2	381.7	383.0
15 MAR 2002	476.6	343.0	177.6	188.1
25 DEC 2002	630.6	212.0	189.6	375.5
03 JAN 2003	470.8	183.9	585.0	465.9
07 FEB 2003	691.0	255.0	115.8	none
$\bar{x}$	406.54	227.24	222.75	314.54
$q_{0.5}$	367.67	221.35	185.53	273.51
σ	148.55	78.38	132.21	163.70
$\hat{\sigma}$	44.79	21.74	36.67	47.26
$q_{0.3}$	303.00	212.77	167.61	246.81
$q_{0.7}$	470.80	242.84	211.48	375.45
$q_{0.9}$	630.60	323.31	360.69	457.58

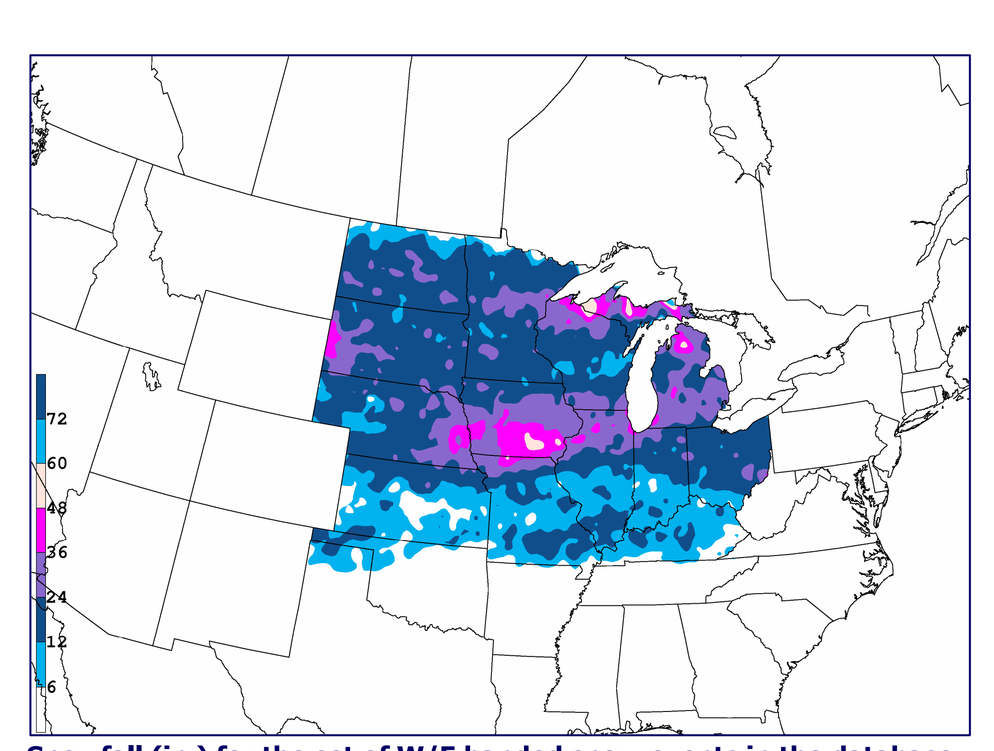
Average distance (km) between surface/upper-air features and the axis of heaviest snow in SW/NE oriented snow events for the period November 1998 – March 2003, where $\bar{x}$ is the average, $q_{0.5}$ is the median, σ is the simple standard deviation (SD), $\hat{\sigma}$ is the normalized SD, $q_{0.3}$ is the 30th percentile, $q_{0.7}$ is the 70th percentile, and $q_{0.9}$ is the 90th percentile.



Box-and-whisker plots displaying the range of average distances (km) between surface/upper-air features and the axis of heaviest snow in SW/NE oriented snow events for the period November 1998 – March 2003. Shown are distances between SLP, 850-hPa, 700-hPa, and 500-hPa features and the axis of heaviest snow. In each category the horizontal line within each box represents the 50th percentile, the top (bottom) line of the box is the 75th (25th) percentile, and the end of the top (bottom) line outside the box represents the upper (lower) limit.

Climatology - West/East Oriented Bands

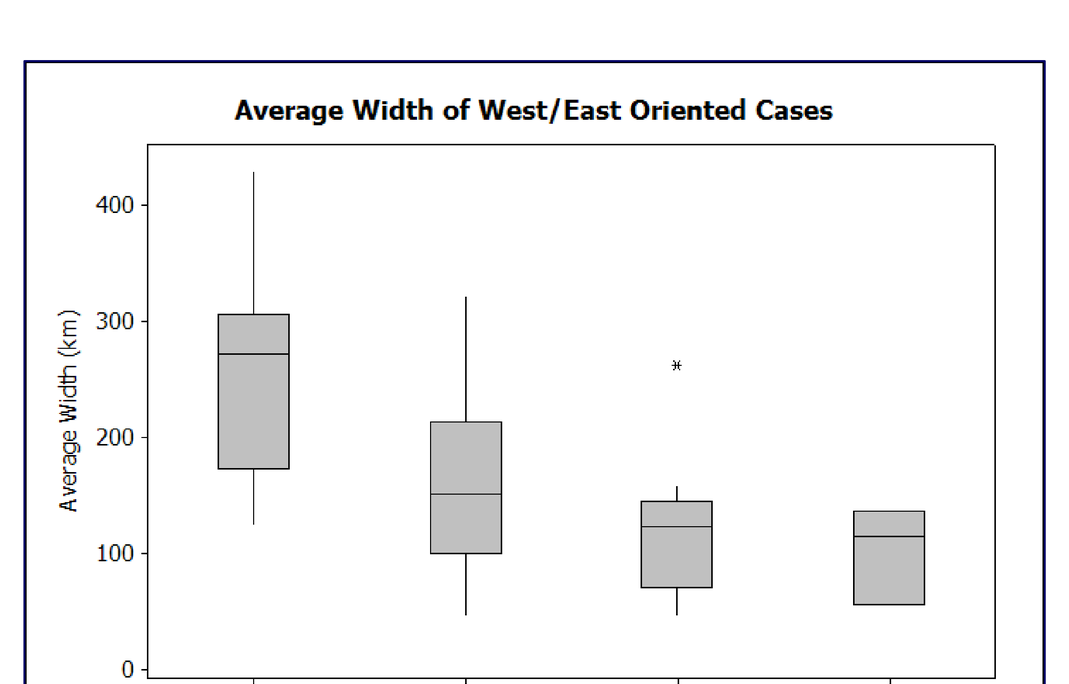
- High W/E oriented snow bands are typically associated with zonal flow at mid- upper-levels.
- Cyclogenesis occurs in the lee of the southern and central Rocky Mountains and transverses eastward towards the Appalachian Mountains and Great Lakes.
- System strength is normally weaker when compared to SW/NE cases due to zonal flow dynamics.



Snowfall (in.) for the set of W/E banded snow events in the database based upon COOP station data from NCDC.

Snow Event Date	Width ≥ 2"	Width ≥ 4"	Width ≥ 6"	Width ≥ 12"
20 NOV 1998	292.2	221.2	128.8	55.8
19 FEB 1999	171.9	95.7	46.6	none
16 FEB 2000	236.9	130.3	102.4	none
19 FEB 2000	272.9	175.8	116.6	none
15 MAR 2000	123.9	103.5	60.4	none
12 DEC 2000	429.9	321.8	262.3	136.3
08 FEB 2001	351.5	227.6	158.9	114.2
12 FEB 2001	174.4	46.4	none	none
15 FEB 2001	168.2	61.5	none	none
28 FEB 2001	281.9	144.4	94.0	none
17 MAR 2001	224.9	174.2	141.3	none
19 JAN 2002	276.2	127.4	64.1	none
26 MAR 2002	145.7	89.6	none	none
05 DEC 2002	270.8	186.8	133.0	none
17 FEB 2003	345.6	233.1	142.5	none
06 MAR 2003	271.7	205.7	154.4	none
09 MAR 2003	320.9	150.6	72.2	none
$\bar{x}$	256.43	158.56	119.82	102.09
$q_{0.5}$	271.70	150.57	122.70	114.20
σ	81.82	70.81	55.11	41.55
$\hat{\sigma}$	19.84	17.17	14.73	23.99
$q_{0.3}$	214.80	122.62	91.82	90.85
$q_{0.7}$	283.94	190.57	141.45	123.02
$q_{0.9}$	347.94	229.83	157.56	131.84

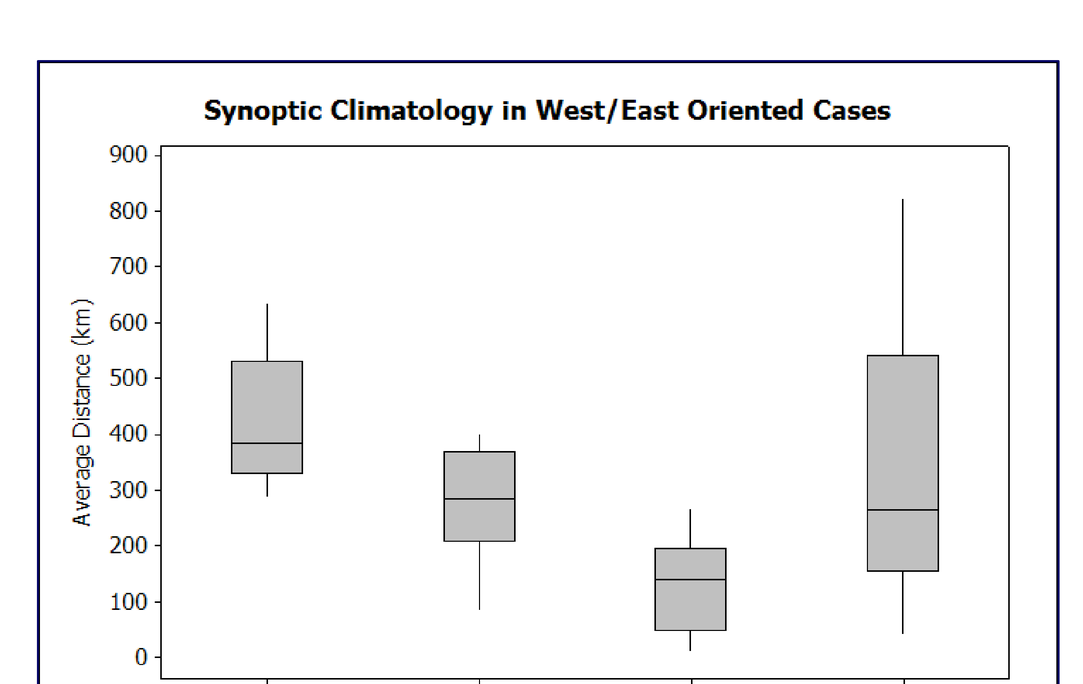
Average width (km) of W/E oriented snow events for the period November 1998 – March 2003, where $\bar{x}$ is the average, $q_{0.5}$ is the median, σ is the simple standard deviation (SD), $\hat{\sigma}$ is the normalized SD, $q_{0.3}$ is the 30th percentile, $q_{0.7}$ is the 70th percentile, and $q_{0.9}$ is the 90th percentile.



Box-and-whisker plots displaying the range of average widths for the ≥ 2", ≥ 4", ≥ 6", and ≥ 12" bands in the W/E oriented snow events for the period November 1998 – March 2003. In each category the horizontal line within each box represents the 50th percentile, the top (bottom) line of the box is the 75th (25th) percentile, and the end of the top (bottom) line outside the box represents the upper (lower) limit.

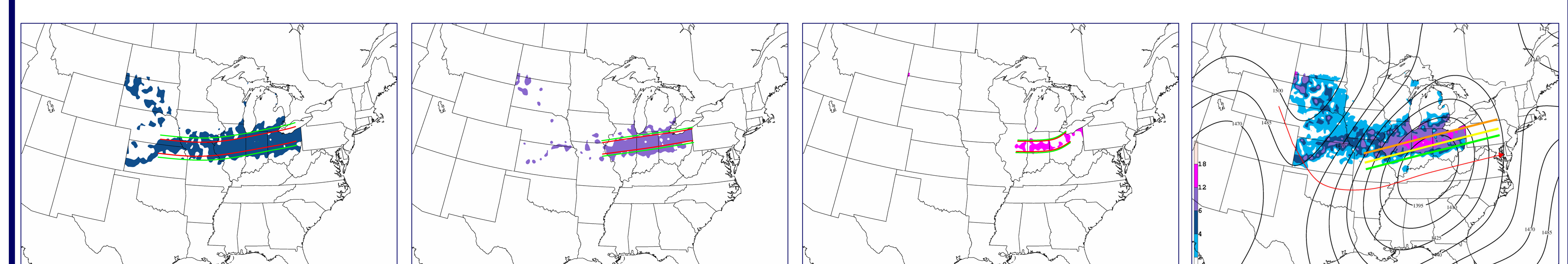
Snow Event Date	SFC (mb)	850 hPa	700 hPa	500 hPa
20 NOV 1998	461.6	222.5	125.1	660.5
19 FEB 1999	316.7	394.9	171.2	715.0
16 FEB 2000	313.5	231.8	125.1	203.9
19 FEB 2000	518.8	318.7	117.6	265.3
15 MAR 2000	384.3	146.0	none	none
12 DEC 2000	381.8	207.0	204.0	308.4
08 FEB 2001	none	378.2	none	none
12 FEB 2001	none	83.4	16.7	152.9
15 FEB 2001	570.0	355.9	11.1	139.0
28 FEB 2001	none	none	48.7	none
17 MAR 2001	287.7	261.4	267.4	423.0
19 JAN 2002	333.7	166.8	41.7	41.7
26 MAR 2002	380.7	210.6	140.1	322.6
05 DEC 2002	479.3	306.4	146.2	260.2
17 FEB 2003	563.0	400.1	202.7	823.1
06 MAR 2003	341.3	344.8	194.6	155.7
09 MAR 2003	635.3	370.8	185.4	none
$\bar{x}$	426.24	274.96	133.18	343.95
$q_{0.5}$	383.00	283.91	140.05	265.34
σ	111.35	97.58	75.78	243.84
$\hat{\sigma}$	29.76	24.39	19.57	67.63
$q_{0.3}$	340.57	216.52	119.11	184.63
$q_{0.7}$	483.20	350.37	182.53	362.75
$q_{0.9}$	567.90	386.55	203.51	704.12

Average distance (km) between surface/upper-air features and the axis of heaviest snow in W/E oriented snow events for the period November 1998 – March 2003, where $\bar{x}$ is the average, $q_{0.5}$ is the median, σ is the simple standard deviation (SD), $\hat{\sigma}$ is the normalized SD, $q_{0.3}$ is the 30th percentile, $q_{0.7}$ is the 70th percentile, and $q_{0.9}$ is the 90th percentile.



Box-and-whisker plots displaying the range of average distances (km) between surface/upper-air features and the axis of heaviest snow in W/E oriented snow events for the period November 1998 – March 2003. Shown are distances between SLP, 850-hPa, 700-hPa, and 500-hPa features and the axis of heaviest snow. In each category the horizontal line within each box represents the 50th percentile, the top (bottom) line of the box is the 75th (25th) percentile, and the end of the top (bottom) line outside the box represents the upper (lower) limit.

Case Study - 12-14 February 2007

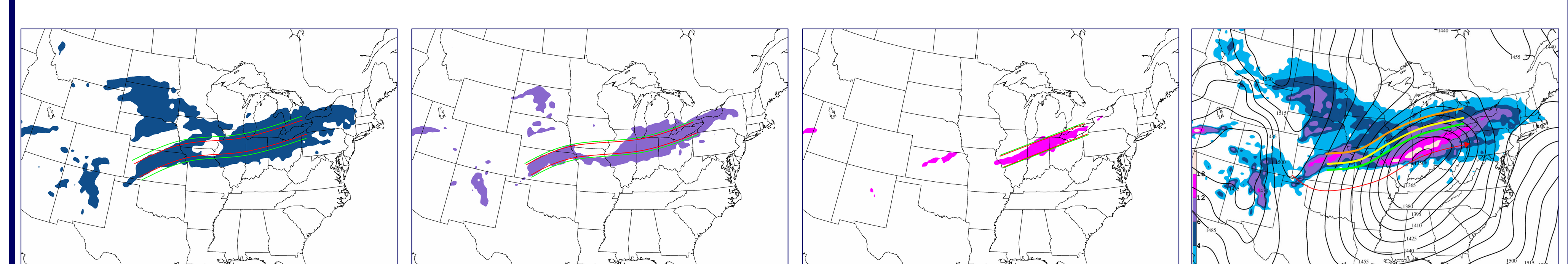


4" isohyet of snowfall for the 48-h period ending at 1200 UTC 14 February 2007 based upon COOP station data from NCDC. Median (red contours) and 90th percentile (green contours) band widths of W/E cases are shown.

6" isohyet of snowfall for the 48-h period ending at 1200 UTC 14 February 2007 based upon COOP station data from NCDC. Median (red contours) and 90th percentile (green contours) band widths of W/E cases are shown.

12" isohyet of snowfall for the 48-h period ending at 1200 UTC 14 February 2007 based upon COOP station data from NCDC. Median (red contours) and 90th percentile (green contours) band widths of W/E cases are shown.

850-hPa analysis of geopotential heights (gpm, black) and isohyets of snowfall (in., shading) for the 48-h period ending at 1200 UTC 14 February 2007. 30th percentile (green), median (yellow), and 90th percentile (brown) distances between 850-hPa feature and the storm track (red arrow) for W/E cases are shown.



NAM212 4" isohyet of snowfall for the 48-h period ending at 1200 UTC 14 February 2007. Median (red contours) and 90th percentile (green contours) band widths of W/E cases are shown.

NAM212 6" isohyet of snowfall for the 48-h period ending at 1200 UTC 14 February 2007. Median (red contours) and 90th percentile (green contours) band widths of W/E cases are shown.

NAM212 12" isohyet of snowfall for the 48-h period ending at 1200 UTC 14 February 2007. Median (red contours) and 90th percentile (green contours) band widths of W/E cases are shown.

NAM212 48-h forecast of 850-hPa geopotential heights (gpm, black) and isohyets of snowfall (in., shading) for the 48-h period ending at 1200 UTC 14 February 2007. 30th percentile (green), median (yellow), and 90th percentile (brown) distances between 850-hPa feature and the storm track (red arrow) for W/E cases are shown.

Conclusions - Future Research

- Banded snow events in the Midwest lend themselves to be organized into three distinct categories: NW/SE, SW/NE, and W/E.
- SW/NE bands are the strongest and widest, followed by W/E and NW/SE bands.
- In all banded snow types, variance decreases with increasing snow amount category.
- Tracks of lower-tropospheric (850-700 hPa) features are more consistent in relation to the axis of heaviest snowfall (cf. surface and 500-hPa features).
- Expand the period of study to include more years (~25 yrs) and examine the relationship between the strength of organized bands and their accompanying surface/upper-level features.
- Investigate other process-oriented parameters (Qs convergence maxima) and their correlation to the axis of heavy snowfall.
- Use the climatology for the development of an analog system. This system would examine model forecasts and identify past cases that mimic key aspects of the forecast. From the identified past cases, probabilistic forecasts of snowfall potential (e.g., probability of 4 in or more snowfall) can be developed.

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