THE SNOW SHADOW
OF VERMONT AND NEW HAMPSHIRE

BY

William H. Bauman III (1)
2803 Victoria Avenue
Bellevue, NE 68005

ABSTRACT

Through the use of snowfall data, melted precipitation data, synoptic weather maps, 850 mb analyses, and wind data from the Mt. Washington Observatory (Gorham, N.H.) a "snow shadow" area has been shown to exist. The snow shadow is an orographically induced phenomenon located in parts of Vermont and New Hampshire. It is caused by subsiding air on the western slopes of mountainous areas. It occurs during widespread precipitation events when the mean wind flow (from 850-mb to the surface) is east or southeast over New England.

1. INTRODUCTION

The "snow shadow" has grown to be a very well known phenomenon for students forecasting at Lyndon State College (LSC). It seemed that very often when the LFM "ground out" a considerable amount of moisture over New England, the North East Kingdom of Vermont (in particular LSC) received a disappointingly low snowfall total. Many areas in southern and western Vermont, as well as southern New Hampshire, received snowfall totals closer to what forecasters at LSC had hoped for. Moderate to heavy snow had been falling there for hours, while LSC remained cloudy or partly cloudy. As no prior research existed on the shadow effect in this area, a preliminary study of precipitation distribution and 850 mb wind direction for certain storms was undertaken.

2. BACKGROUND

The primary theory on the shadow effect was proposed by then Chairman of the Department of Meteorology at LSC, Joseph S. D'Aleo. He had hypothesized that the White Mountains of New Hampshire were "robbing" northeastern Vermont of moisture under certain wind flow conditions. The White Mountains are oriented in a general north-south direction from central New Hampshire to northern New Hampshire (see Figure 1). It was theorized that an east or southeast wind flow over the White Mountains might have an effect similar to that as shown in Figure 2. Assuming the air on the east side of the White Mountains is near saturation (since the shadow is predominant with moisture from coastal storms) it will cool moist adiabatically (6.5°C per 1000 meters) as it rises. As the air rises and condenses, heavy precipitation is likely to fall. As the air and condenses, heavy precipitation is

likely to fall. As the air reaches the west side of the White Mountains it will warm dry adiabatically (10°C per 1000 meters) as it sinks. In extreme cases this can cause heavy precipitation on the east side of the mountains and partly cloudy skies on the west side of the mountains. As the air flow continues over Vermont some of the higher peaks will cause uplift and heavier precipitation similar to the precipitation on the east side of the White Mountains. Finally, the air will get a further uplift when it reaches the Green Mountains in west central Vermont and causes more precipitation to fall.
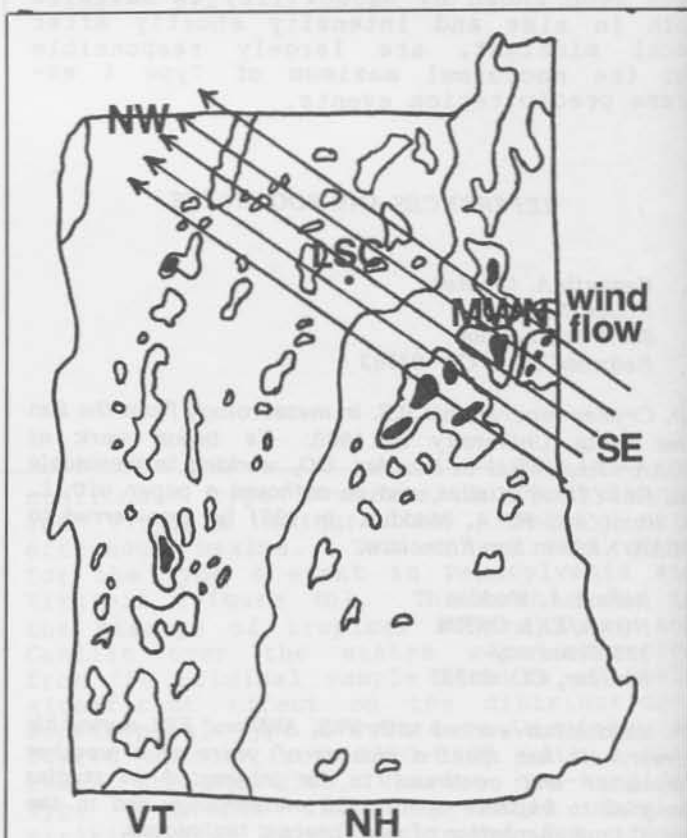

Figure 1. The mountains of Vermont and New Hampshire above 2000 feet (shaded areas above 4000 feet). Mt. Washington Observatory (MWN) in reference to Lyndon State College (LSC) and the "shadowing" wind flow over the White Mountains of New Hampshire.
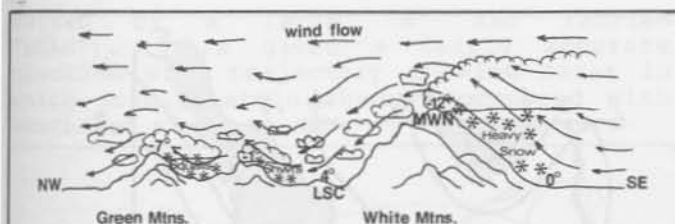
Figure 2 A side view of the wind flow as in Figure 1. Temperatures are in degrees Celsius.

3.   DATA

The first task to test this theory was to obtain snowfall data for Vermont and New Hampshire from the New England Climatological Data. The years 1965-1980 were chosen to study because of the availability of the data. Since St. Johnsbury (STJ), Vermont was the nearest snowfall reporting station to LSC it was used as a reference for snowfall. The shadow theory was initially tested by looking through the snowfall data for dates with a relative minimum of snowfall at STJ which occurred during widespread snowfall events. Once a series of dates for a possible shadow occurrence was gathered, the synoptic situations for these dates were studied. It soon became evident that the snowfall data would not suffice.

Snowfall depth is not only relative to the amount of moisture in the air but also to the temperature of the air. With STJ being somewhat warmer than some of the surrounding reporting stations the snow was wetter and would settle more rapidly making it appear as if there was a minimum snowfall at STJ.

To overcome this problem the next step was to obtain the melted precipitation data for the minimum snowfall dates. The data was obtained from the New England Climatological Data. It quickly became very evident whether or not a precipitation shadow was present. By plotting isohyets for these dates, a precipitation shadow was noted in several areas.

Nine dates (9 storms) studied showed very distinct shadows (see Figure 3). The melted precipitation for the 9 storms was totaled for each station and divided by the number of storms each station reported in to determine the average precipitation distribution. If reports were not received for at least 5 storms per station their data was omitted. Not only was there a shadow in northeast Vermont but also in west central New Hampshire and near Enosburg, Vermont (see figure 10 for station locations). In Figure 3, the shaded areas with minus signs received 0.5 inches of precipitation or less, which is 50 per cent less than on the east side of

the White Mountains (shaded areas with plus signs indicate 1.0 inches or more of precipitation). The storm tracks from these dates were studied and no correlation between shadow positions and the center of the surface storm track was found. The only conclusion to be made at this point was obtained from the Mt. Washington Observatory Bulletin climatological data. The mean wind direction atop Mt. Washington (MWN) for each storm was either east or southeast as was suggested earlier.

To further test the wind flow theory, a series of dates from four years of MWN climatological data (including only the months November through March) were chosen by the mean wind direction for each date. MWN was used as a reference point for the low level wind flow above the friction layer. The MWN observatory (elevation 6262 feet) is situated in the north central White Mountains due southeast of LSC (elevation 1000 feet). Any date with an east or southeast wind at MWN was chosen and the synoptic situation was studied. In many cases these winds were not associated with precipitation events. In some cases a high pressure area was moving off the North Atlantic coast and a southeast-
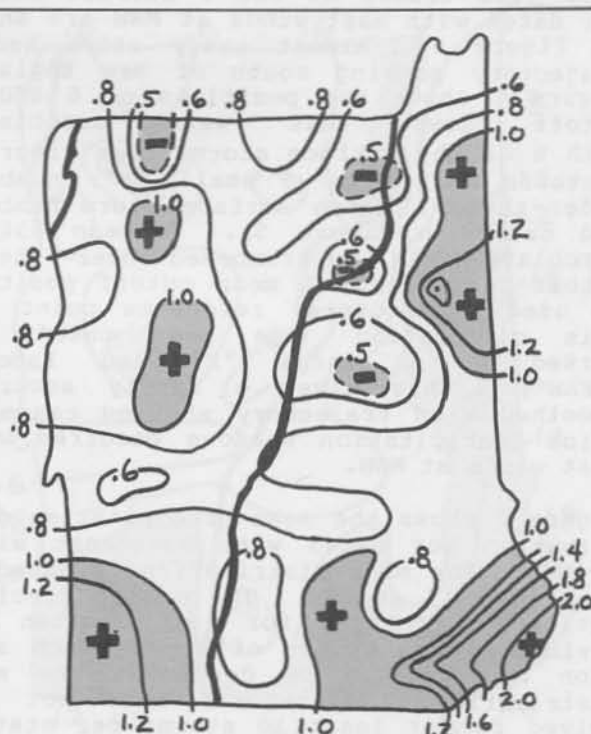

Figure 3 Mean precipitation distribution from nine storms with either east or southeast winds at MWN. Shaded areas with minus signs (less than 0.5 inch) indicate major shadows. Shaded areas with plus signs indicate 1.0 inches or more of precipitation. All values are in inches and tenths. The dates of the storms from which this map was derived are located in appendix A.

erly flow was predominant over New England with generally fair weather. A "condensed moisture shadow" can occur without precipitation. Occasionally a moist flow off the ocean causes low clouds and/or fog in many New England areas while northeastern Vermont could experience less cloudiness due to the subsiding air off the White Mountains. Most of the dates associated with precipitation involved coastal storms. In cases with precipitation and no coastal storm a shadow was rarely observed. These situations involved only frontal passages and/or light showery weather. These frontal situations produced light scattered precipitation rather than the widespread precipitation experienced with a coastal storm. All of the dates with some form of coastal storm were separated according to MWN wind direction: either east or southeast. Figure 4 shows the mean precipitation distribution for dates with east winds at MWN. The mean distribution is based on data from 10 storms. The melted precipitation was totaled for each station and divided by the number of storms each station reported in to determine the mean distribution. If reports were not received for at least 6 storms per station their data was omitted. The tracks of the 9 surface storms for dates with east winds at MWN are shown in Figure 5. Almost every storm had a trajectory passing south of New England. Figure 6 shows the positions of 6 850-mb cutoff lows that were associated with 6 of the surface storms from Figure 5 (cutoffs marked by a small "x"; numbers under the x's match surface storm numbers and dates in Figure 5). A mean 850-mb circulation is superimposed over the 6 cutoff positions. A mean cutoff position is used as a center reference point for this circulation (the mean cutoff is marked by a large "X" and labeled "MEAN"). This gives a fairly accurate smoothed wind trajectory showing cases in which precipitation shadows occurred with east winds at MWN.

Figure 7 shows the mean precipitation distribution for dates with southeast winds at MWN. The mean distribution is based on data from 15 storms. The melted precipitation was totaled for each station and divided by the number of storms each station reported in to determine the mean distribution. If reports were not received for at least 10 storms per station their data was omitted. The tracks of the 12 surface storms for dates with southeast winds at MWN are shown in Figure 8. Most of the trajectories of these storms were not south of New England (as in Figure 5). Most of these storms passed through New England and all but 2 were east of Vermont. Figure 9 shows the positions of 6 850-mb cutoff lows that were associated with 6 of the surface storms from Figure 8 (cutoffs marked by a small "x"; numbers
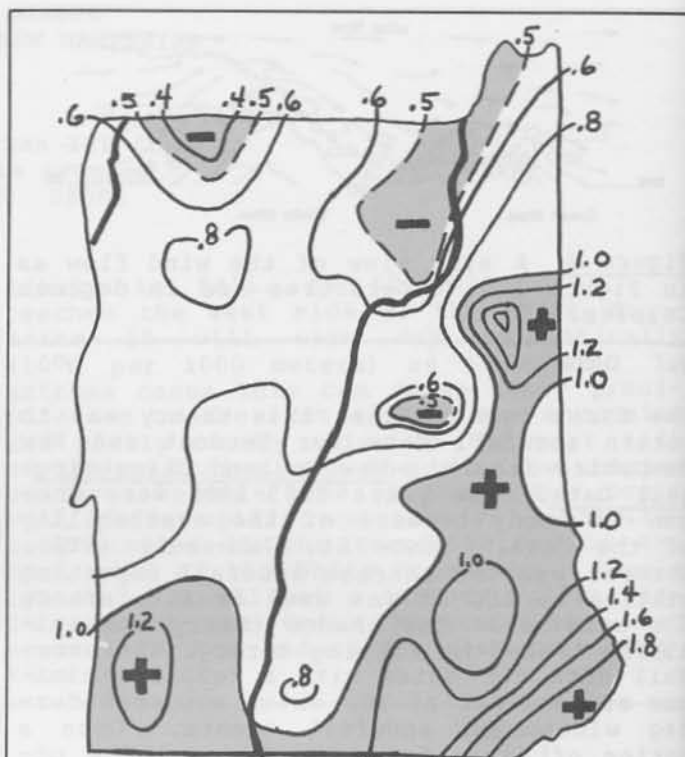

Figure 4 Mean precipitation distribution occurring when the winds at MWN were predominantly east. Shaded areas with minus signs (less than 0.5 inch) indicate the major shadows. Shaded areas with plus signs indicate 1 inch or more of precipitation. All values are in inches and tenths. The dates of the storms from which this map was derived are located in appendix A.
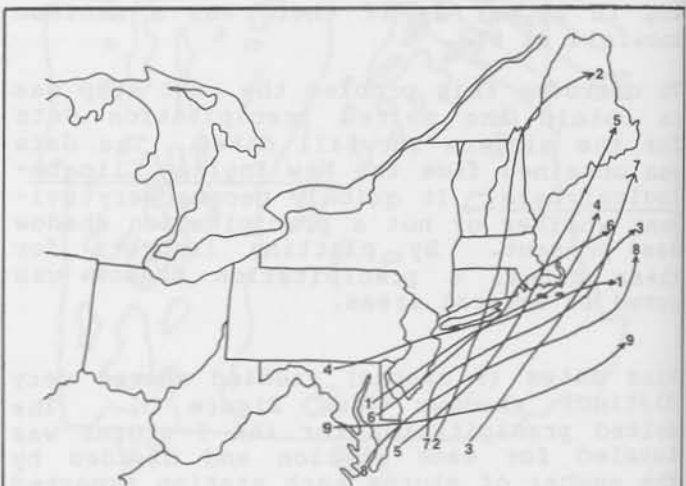

Figure 5 Tracks of 9 surface storms when the winds at MWN were predominantly east. The dates of the storms from which this map was derived are located in appendix A.

under the x's match surface storm numbers and dates in Figure 8). A mean 850-mb circulation is superimposed over the 6 cutoff positions. A mean cutoff position is used as a center reference point for this circulation (the mean cutoff is

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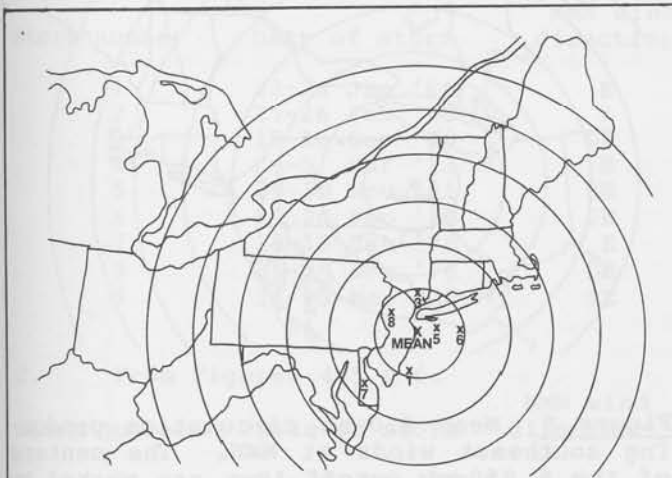

Figure 6 Mean 850-mb circulation producing east winds at MWN. The centers of the 6 850-mb cutoff lows are marked by an "x". Numbers under the x's correspond to numbers and dates of storms in Figure 4 and Figure 5.

In both Figures 4 and 7 the shaded areas with minus signs are where less that 0.5 inches of precipitation fell, which is 50 percent less than on the east side of the White Mountains (shaded areas with plus signs indicate 1.0 inches or more of precipitation). To make an accurate snow total comparison at each station, it can be assumed that the precipitation was all snow (not mixed with any other type of precipitation) and it was in a ratio of 1.0 inches of snow per 0.1 inches of melted precipitation.

With an east wind flow the snow shadow is very predominant near Enosburg, Vermont, in the northeast portion of Vermont, and near Woodstock, New Hampshire. With a southeast wind flow the snow shadow is very predominant only in the northeast portion of Vermont. In both wind flow situations, the areas being shadowed would have received from 4-5 inches of snow, while other areas of Vermont received up to 12 inches of snow and the White Mountains and coastal areas of New Hampshire received up to 19 inches of snow.

4. RESULTS

The differences between Figures 4 and 7 show a generally wider shadow positioned further west over northeastern Vermont under the influence of an east wind flow (see Figure 4 for east wind flow distribution map). This shadow extends out to

West Burke, Vermont which has a wind flow trajectory over 3200-foot mountains directly to its east, while to its southeast are scattered lower peaks and the Passumsic River Valley (elevations well below 1000 feet). Also under the influence of an east wind flow is the strong shadow near Enosburg, Vermont (see Figure 4 for east wind flow distribution map). East of Enosburg is Jay Peak (elevation 3861 feet) which is the northern edge of the Green Mountains. Southeast of Enosburg are some lower peaks (the highest being about 3300 feet). The important thing to note here is that the overall elevation to the southeast of Enosburg is lower than east of Enosburg resulting in a stronger shadow with an east wind flow over the higher terrain.

By comparing figures 5 and 8 it is obvious that the storm tracks are further inland when the winds at MWN are southeast. This results in higher precipitation amounts throughout the inland areas compared to the amounts that fall along the immediate coast.
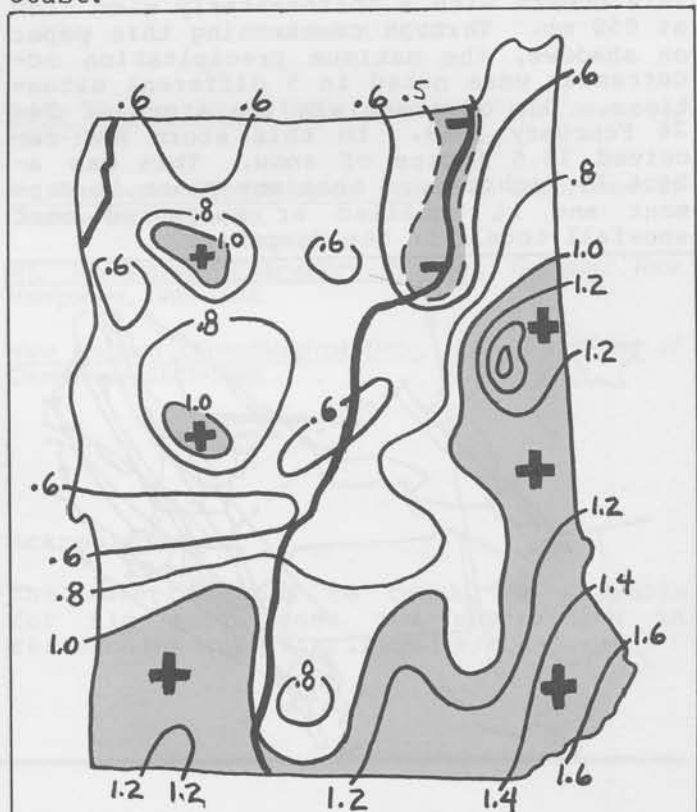

Figure 7 Mean precipitation distribution occurring when the winds at MWN were predominantly southeast. Shaded areas with minus signs (less than 0.5 inch) indicate the major shadows. Shaded areas with plus signs indicate 1 inch or more of precipitation. All values are in inches and tenths. The dates of the storms from which this map was derived are located in appendix A.

The best reference for predicting the wind flow that would cause a shadow is the 850-mb chart. From Figures 6 and 9, the wind direction at MWN is directly related to the 850-mb cutoff position. The more southerly the winds at MWN, the further west the 850-mb cutoff will be found (see Figure 6). Also, with the 850-mb cutoff north of the Great Lakes or east and northeast of New England a shadow would not exist since the component(s) of the wind would not be perpendicular to any mountain ranges.

5.   CONCLUSION

This preliminary study has shown a precipitation shadow does exist under certain wind flow conditions with widespread precipitation events in parts of Vermont and New Hampshire. The 850 mb chart, along with the surface storm track, and proper moisture conditions should aid in predicting where a shadow will occur.

It should also be noted that a snowfall (precipitation) maximum can occur in the "shadow areas" discussed in this paper. This occurs with a northeasterly wind flow at 850 mb. Through researching this paper on shadows, the maximum precipitation occurrences were noted in 5 different situations. One of these was the storm of 24-26 February 1969. In this storm STJ received 35.5 inches of snow. This was about 15 inches more than any place in Vermont and it equalled or surpassed most snowfall totals in New Hampshire.

Figure 9   Mean 850-mb circulation producing southeast winds at MWN. The centers of the 6 850-mb cutoff lows are marked by an "x". Numbers under the x's correspond to numbers and dates of storms in Figure 7 and Figure 8.
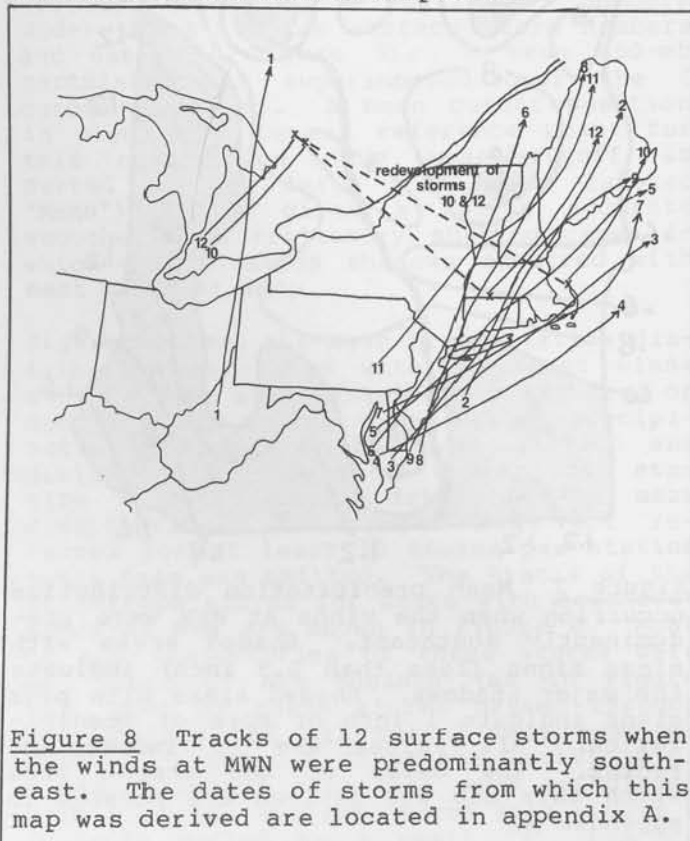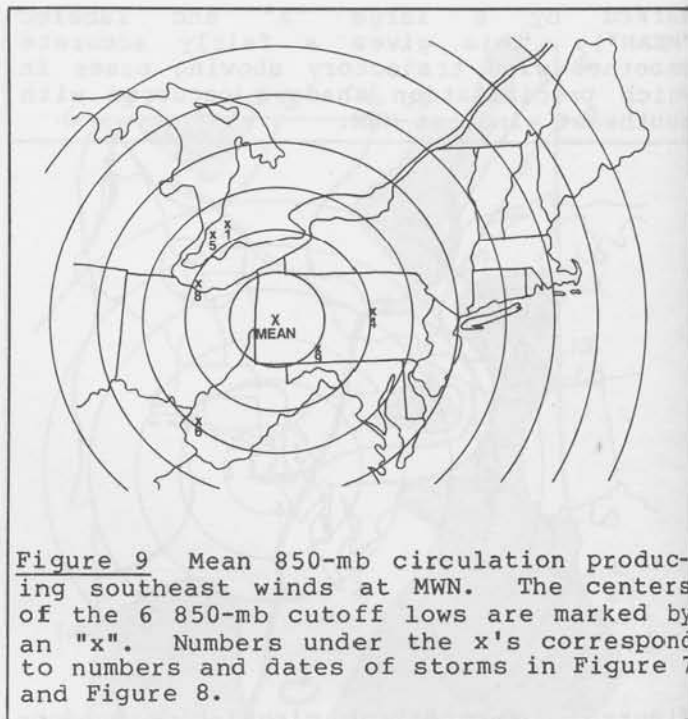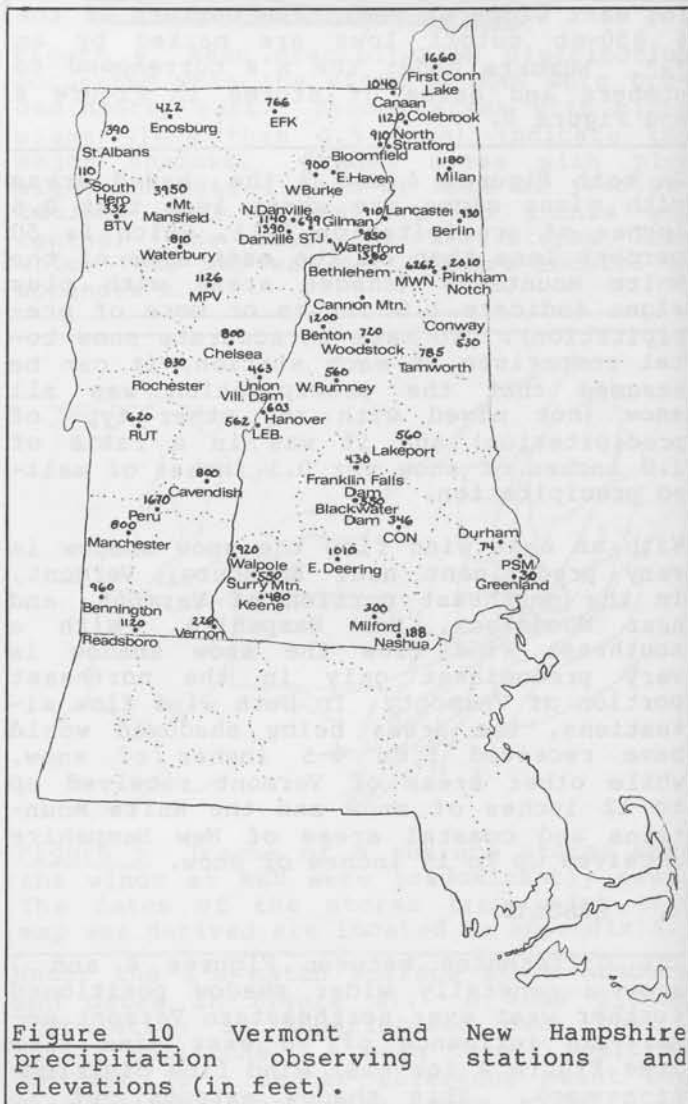

<u>Figure 8</u>   Tracks of 12 surface storms when the winds at MWN were predominantly southeast. The dates of storms from which this map was derived are located in appendix A.

<u>Figure 10</u>   Vermont and New Hampshire precipitation observing stations and elevations (in feet).

Appendix A

FOOTNOTES AND REFERENCES

1. From Figure 3:

Storm number	Date of storm	MWN wind direction
1	23-24 Jan '66	E
2	25-26 Feb '66	E
3	17-18 Dec '70	SE
4	4-5 Mar '71	E
5	29-30 Nov '71	SE
6	19-20 Feb '72	SE
7	14-15 Jan '78	E
8	25-26 Dec '78	SE
9	14-15 Mar '80	SE

2. From Figures 4,5 & 6:

Storm number	Date of storm	MWN wind direction
1	23-24 Jan '66	E
2	30-31 Jan '66	E
3	25-26 Feb '66	E
4	7-8 Nov '68	E
5	4-5 Mar '71	E
6	23-24 Mar '77	E
7	14-15 Jan '78	E
8	20-21 Jan '78	E
9	25-26 Feb '79	E
10	23-24 Feb '67	E

3. From Figures 7, 8 & 9:

Storm number	Date of storm	MWN wind direction
1	2-4 Nov '66	SE
2	14-15 Mar '80	SE
3	12-13 Mar '68	SE
4	17-18 Dec '70	SE
5	29-30 Nov '71	SE
6	3-4 Feb '72	SE
7	19-20 Feb '72	SE
8	10-11 Jan '77	SE
9	25-26 Dec '78	SE
10	13-14 Jan '79	SE
11	14-15 Jan '68	SE
12	24-25 Mar '79	SE
13	13-14 Feb '66	SE
14	24-25 Mar '79	SE
15	21-22 Jan '79	SE

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Acknowledgement

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Dennis McCarthy
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