# SURFACE WIND DIRECTIONS ASSOCIATED WITH SNOWFALL IN UPSTATE NEW YORK: UPDATE FOR 1994-2000

**Jerome B. Blechman**

State University of New York, College at Oneonta
Oneonta, New York

***Abstract***

*As an update to an earlier study by Blechman, hourly observations of snowfall, recorded November through April for the seasons 1994-95 through 1999-2000 at National Weather Service stations mostly in New York State, were used to identify the wind directions observed during those hours. The distributions of winds during snowfall found in the earlier study using data from 1981 through 1994 were different for each station, but were consistent with lake-effect snow at stations near the Great Lakes and coastal storm snowfall at stations near the ocean. In the 1994-2000 data these characteristics were essentially unchanged, even though observations after 1994 were made with Automated Surface Observing Systems (ASOS) instead of being manually done. When separating the seasons into those, which could be identified as El Niño, La Niña, or neutral, some differences from the previous study's results were found. In particular, at the stations not associated with lake-effect snow, years in which El Niño conditions prevailed were not more frequently snowy as they had been from 1981-94. However, the lake-effect stations continued to show fewer snowfall hours during El Niño, especially with southwest to west winds, a result, which was similar to that of the previous study.*

## 1. Introduction

In a recent paper (Blechman 2001), the relationships between occurrences of snowfall and wind direction were examined for several New York stations and Boston, Massachusetts. In that study, cold-season observations recorded hourly from 1981 to 1994 were used. The change to Automated Surface Observing System (ASOS) winds was cited as one of the reasons for stopping in 1994.

Now that several years of ASOS data are available, performing the same analyses as those done on the earlier data would allow comparisons to be made. The distributions of snowfall with wind direction found for 1981-94 varied from station to station but were generally consistent with the premise that the three stations near the Great Lakes should get snow with generally westerly winds while coastal stations should experience coastal storms and get snowfall with northeast winds. If using the data after 1994 does not fundamentally change those distributions of snowfall with wind direction, it could mean that the distributions are independent of the observation method and probably realistic.

One of the conclusions in Blechman (2001) was that fewer snowfall events with west and southwest winds occurred at the three stations normally considered subject to lake-effect snow during seasons characterized by El Niño conditions. Since strong climatic events, both La Niña and El Niño, have occurred in several seasons after 1994, another rationale for updating the study would be to test whether this relationship persisted. Moreover, during 1981-94 only two La Niña events had been observed, according to the criteria established by Trenberth (1997) so the results in the earlier paper could not be considered conclusive using that data. Now that further data are available and since that data are uniformly collected by ASOS, an opportunity exists to check the conclusions from the earlier study.

## 2. Method of Analysis

As in Blechman (2001), data for this study were obtained from Earthinfo, Inc. on compact disc for which the NOAA/National Climatic Data Center (NCDC) was the original source. Data available included the cold seasons through Spring 2000. The method used to match wind directions with "present weather" observations of any type of snowfall was the same one used in the earlier study.

Present weather is observed by ASOS using an instrument called a "Light Emitting Diode Weather Indicator" known as LEDWI. Light is passed from an emitter to a sensor two feet away and the resulting scatter analyzed for precipitation size. A sophisticated algorithm distinguishes between rain and snow. Other precipitation types are designated "unknown." The device has been highly successful, considering that major improvements have proven unnecessary since the ASOS program was initiated in the early 1990's. Recently a blowing snow algorithm was developed and implemented, but the focus of development for the LEDWI has been on identifying drizzle and freezing precipitation. In any case, at almost all the stations used in this study, observations were augmented by human observers so the observations of falling snow can be considered quite accurate.

Since 1981, some of the observing stations have been moved either during the change to ASOS or when new National Weather Service (NWS) facilities were built. In no case did the location change significantly. The most drastic change occurred at Albany in May of 1997 when the NWS Weather Forecast Office moved from the airport to the SUNY-Albany campus, only four miles south and at the same elevation.

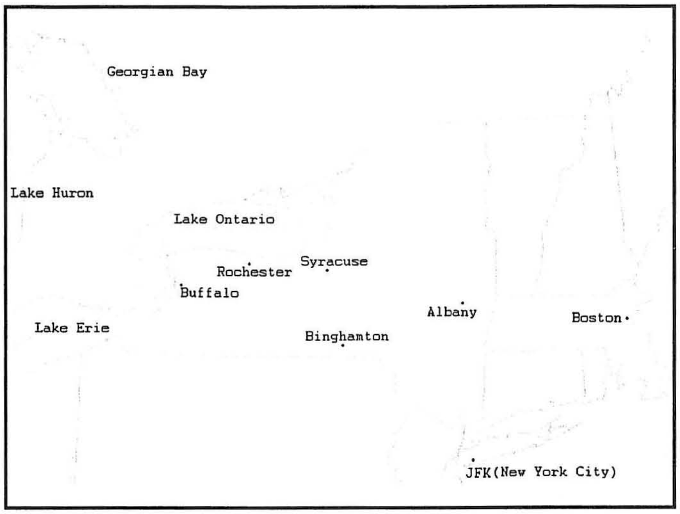



**Fig. 1.** Locations of stations used in this study.

Snowfall amount was not considered. If any type of snow was reported in an hourly observation, the observed wind direction from 0° to 360° during that hour was used. As in Blechman (2001), winds from the east were reported on the disk as 90°, winds from the south were reported at 180°, west winds were 270°, and north winds were 360°. A direction of 0° was used to report calm wind conditions.

Snowfall seasons were considered to begin on 1 November and end on 30 April so that the time periods for all stations were uniform. The stations used were the same as those in Blechman (2001), Buffalo, Syracuse, Rochester, Binghamton, and Albany in upstate New York, New York City (JFK airport station), and Boston, Massachusetts representing coastal stations. Figure 1, showing the locations of the stations, is reproduced from Blechman (2001).

## 3. Results

### *a. General*

In Table 1, basic statistics for the seven stations are summarized. In each case, the nineteen seasons' temperatures and snowfall amounts were averaged and departures from those averages (anomalies) are shown. The total snowfall hours are also included in Table 1 and the seasons are grouped by type, namely El Niño, La Niña, and neutral as defined by Trenberth (1997).

From Table 1, it can be seen that temperatures and snow (amounts and hours), are often inversely correlelated. As might be expected, warm winters tend to be less snowy and cold ones tend to have more snow, both in hours and amounts, although it's far from a perfect correlation. All seasonal types tend to have both warm winters and cold ones but most of the El Niño seasons at Buffalo, Rochester, and New York City tend to be warm and less snowy. La Niña and neutral seasons showed more complex relationships. Overall, Table 1 has no obvious interpretation although the El Niño data appears to contain some signal. When the snow observations were matched with wind directions, additional conclusions were reached by Blechman (2001). The question is, were those conclusions, reached using the 1981-94 data, still valid in 1994-2000?

### *b. Comparisons between 1981-94 and 1994-2000 data*

Figures 2a-g show the distributions of the number of hours with snowfall versus wind directions for all seven stations. These figures were designed to be compared directly with Figs. 2a-g of Blechman (2001). Since the 1994-2000 period had six seasons while the 1981-1994 period had thirteen, the vertical scale of number of hours reporting snowfall was approximately halved from the scale used in the earlier paper to make comparisons easier.

In the 1994-2000 period, each station had somewhere between 30% to 40% of the number of snowfall hours reported in the 1981-94 period. This was less than 6/13 (46%), mainly due to the fact that the last two seasons (1998-99 and 1999-2000) were quite deficient in snowfall. Just comparing Syracuse, Buffalo, and Rochester (Figs. 2a-c), Buffalo had the fewest number of snowfall hours during the 1994-2000 period, in contrast to the 1981-94 observations when Buffalo had the most. Boston and New York's observations were both reduced by approximately 40%. Binghamton had 32% of the snowfall hours they had in 1981-94 while Albany had 35%.

Despite changes in the total number of snowfall observations, the shapes of each distribution for the seven stations were remarkably similar to those found in the earlier study. The three lake-effect stations, Buffalo, Rochester, and Syracuse still showed large maxima with southwest, west, and northwest winds. Each distribution showed secondary maxima with east or northeast winds with almost exactly the same pattern shown by the 1981-94 data. New York City and Boston (Figs. 2d-e) were also strongly similar to their earlier patterns, even showing very little snowfall with calm winds (0°) just like in 1981-94. Albany's triple maxima (Fig. 2f) were again reproduced at north, northwest, and southeast winds. In 1994-2000, Albany also experienced a large number of calm wind snowfalls just as it did in 1981-94. Binghamton (Fig. 2g) did not show a calm wind maximum in either period but it did have a strong northwest wind maximum in observations in both periods.

While the directions associated with snow for Buffalo, Rochester, Syracuse, and Binghamton were discussed in Blechman (2001), an interesting suggestion about Albany's snow was made by one of this article's reviewers (Evans, personal communication 2002). Albany is located at the intersection of the Mohawk and Hudson river valleys. As any topographical map will confirm, these two valleys are oriented in directions which almost exactly match the snowfall maxima seen on Fig. 2f. The Hudson valley lines up with the south and north snowfall maxima, while the Mohawk valley reaches Albany from the northwest direction, about 290-300°. These three directions, south, north, and northwest, are the only ones to reach Albany with no downsloping. There may even be "channeling" of the lake effect bands in the Mohawk valley such as described by Niziol et al. (1995).

### *c. El Niño, La Niña, and neutral seasons*

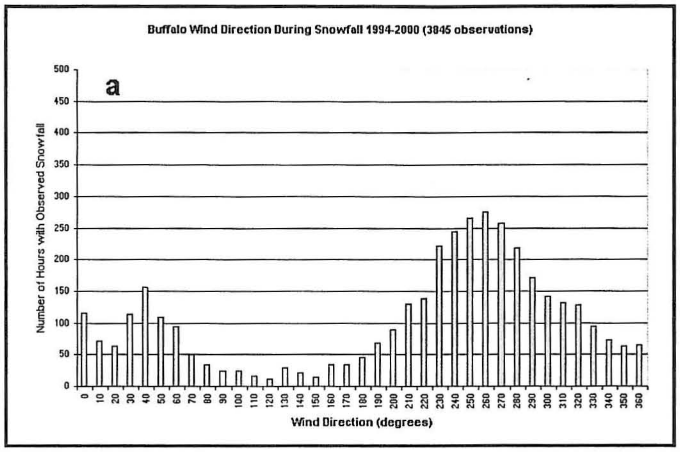
In Blechman (2001), the seasons were stratified into those meeting Trenberth's (1997) criteria for El Niño, La Niña, or neither condition (neutral). It was concluded in

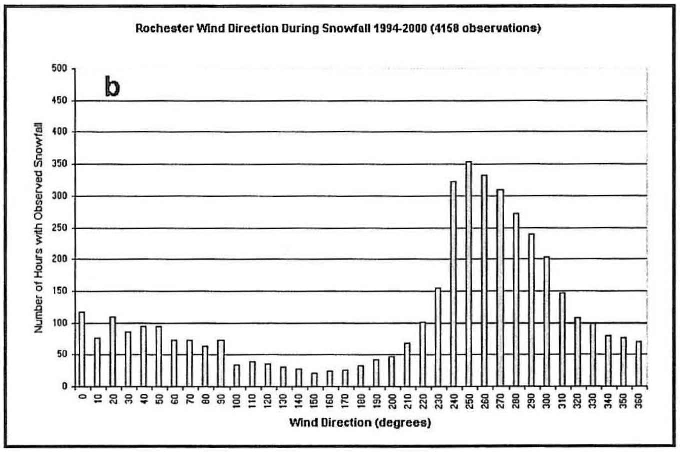
**Table 1.** Seasonal observations for the seven stations, arranged by type (El Niño, La Niña, Neutral). All anomalies are departures from the 1981-2000 averages shown on the first line. Snowfall in inches. Temperature in °F.

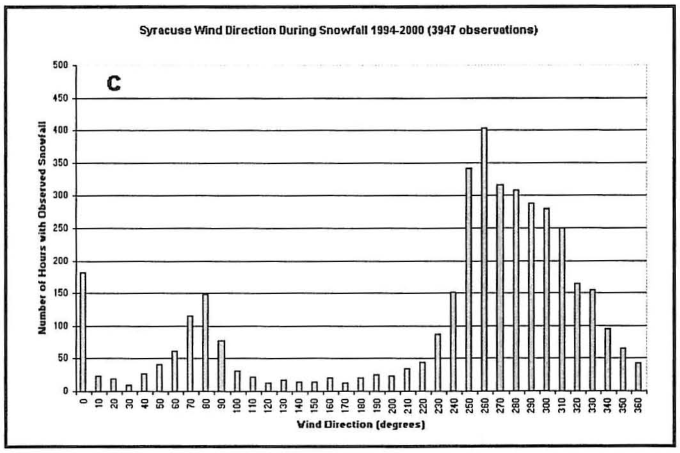
| | | | | | |
|---|---|---|---|---|---|
| **Buffalo** | 89.46 | 807.00 | 33.97 | | <—1981-00 averages |
| Season | Snowfall anomalies | Snow hours | Temperature anomalies | Type | |
| 1982-83 | -37.06 | 599.00 | 2.21 | El Niño | |
| 1986-87 | -21.96 | 759.00 | 0.83 | El Niño | |
| 1987-88 | -33.06 | 878.00 | 0.83 | El Niño | |
| 1991-92 | 3.14 | 884.00 | -0.54 | El Niño | |
| 1992-93 | 3.14 | 949.00 | -0.62 | El Niño | |
| 1993-94 | 20.34 | 977.00 | -2.19 | El Niño | |
| 1994-95 | -14.86 | 736.00 | 1.16 | El Niño | |
| 1997-98 | -15.56 | 517.00 | 2.31 | El Niño | |
| 8 El Niño seasons: | -11.98 | 787.38 | 0.50 | | |
| 1984-85 | 17.74 | 1000.00 | 0.27 | La Niña | |
| 1988-89 | -30.46 | 786.00 | -0.36 | La Niña | |
| 1995-96 | 51.64 | 920.00 | -4.17 | La Niña | |
| 1998-99 | 11.14 | 424.00 | 0.81 | La Niña | |
| 1999-2000 | -25.86 | 543.00 | 2.94 | La Niña | |
| 5 La Niña seasons: | 4.84 | 734.60 | -0.10 | | |
| 1981-82 | 22.94 | 865.00 | -3.35 | Neutral | |
| 1983-84 | 43.04 | 1010.00 | -1.94 | Neutral | |
| 1985-86 | 25.24 | 1142.00 | -0.43 | Neutral | |
| 1989-90 | 4.24 | 940.00 | -0.07 | Neutral | |
| 1990-91 | -31.96 | 699.00 | 3.12 | Neutral | |
| 1996-97 | 8.14 | 705.00 | -0.81 | Neutral | |
| 6 neutral seasons: | 11.94 | 893.50 | -0.58 | | |
| **Rochester** | 99.73 | 742.42 | 33.81 | | <—1981-00 averages |
| Season | Snowfall anomalies | Snow hours | Temperature anomalies | Type | |
| 1982-83 | -39.83 | 617.00 | 2.58 | El Niño | |
| 1986-87 | -32.63 | 530.00 | 0.21 | El Niño | |
| 1987-88 | -29.93 | 678.00 | -0.24 | El Niño | |
| 1991-92 | 10.87 | 801.00 | -0.93 | El Niño | |
| 1992-93 | 31.77 | 963.00 | -1.80 | El Niño | |
| 1993-94 | 23.87 | 961.00 | -3.27 | El Niño | |
| 1994-95 | -43.53 | 674.00 | 2.28 | El Niño | |
| 1997-98 | -0.13 | 575.00 | 2.59 | El Niño | |
| 8 El Niño seasons: | -9.94 | 724.88 | 0.18 | | |
| 1984-85 | -12.63 | 871.00 | 1.22 | La Niña | |
| 1988-89 | -24.13 | 662.00 | -0.65 | La Niña | |
| 1995-96 | 29.07 | 1117.00 | -3.53 | La Niña | |
| 1998-99 | 78.77 | 471.00 | 0.50 | La Niña | |
| 1999-2000 | 10.97 | 642.00 | 3.86 | La Niña | |
| 5 La Niña seasons: | 16.41 | 752.60 | 0.28 | | |
| 1981-82 | 28.57 | 781.00 | -3.11 | Neutral | |
| 1983-84 | 18.27 | 873.00 | -1.61 | Neutral | |
| 1985-86 | -29.03 | 743.00 | -0.37 | Neutral | |
| 1989-90 | 6.07 | 870.00 | 0.21 | Neutral | |
| 1990-91 | -31.43 | 598.00 | 2.67 | Neutral | |
| 1996-97 | 4.97 | 679.00 | -0.60 | Neutral | |
| 6 neutral seasons: | -0.43 | 757.33 | -0.47 | | |
| **Syracuse** | 124.82 | 735.21 | 33.21 | | <—1981-00 averages |
| Season | Snowfall anomalies | Snow hours | Temperature anomalies | Type | |
| 1982-83 | -58.82 | 564.00 | 1.43 | El Niño | |
| 1986-87 | -31.32 | 615.00 | 0.71 | El Niño | |
| 1987-88 | -13.42 | 797.00 | 0.28 | El Niño | |
| 1991-92 | 42.08 | 824.00 | -0.64 | El Niño | |
| 1992-93 | 65.88 | 835.00 | -1.22 | El Niño | |
| 1993-94 | 43.08 | 685.00 | -3.88 | El Niño | |
| 1994-95 | -57.92 | 503.00 | 1.27 | El Niño | |

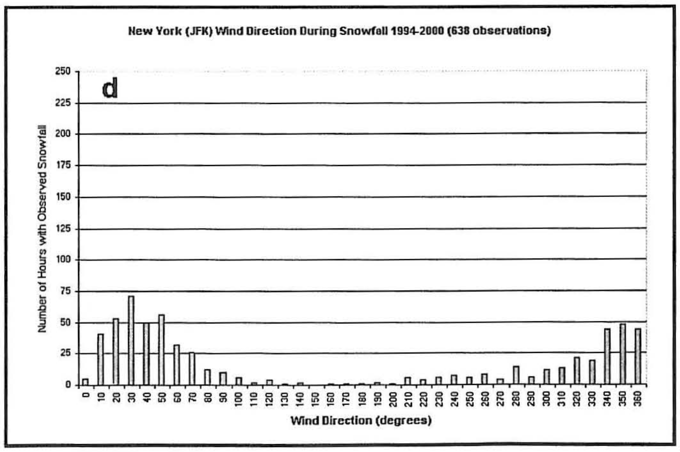
| | | | | | |
|---|---|---|---|---|---|
| 1997-98 | 8.68 | 617.00 | 2.51 | El Niño | |
| 8 El Niño seasons: | -0.22 | 680.00 | 0.06 | | |
| | | | | | |
| 1984-85 | -8.42 | 957.00 | 0.94 | La Niña | |
| 1988-89 | -32.72 | 631.00 | -0.17 | La Niña | |
| 1995-96 | 44.08 | 947.00 | -3.43 | La Niña | |
| 1998-99 | 41.88 | 465.00 | 1.32 | La Niña | |
| 1999-2000 | -39.02 | 643.00 | 1.72 | La Niña | |
| 5 La Niña seasons: | 1.16 | 728.60 | 0.08 | | |
| | | | | | |
| 1981-82 | 11.68 | 901.00 | -2.42 | Neutral | |
| 1983-84 | -11.22 | 912.00 | -2.80 | Neutral | |
| 1985-86 | -19.92 | 870.00 | 0.28 | Neutral | |
| 1989-90 | 37.18 | 849.00 | 0.54 | Neutral | |
| 1990-91 | -28.12 | 582.00 | 3.20 | Neutral | |
| 1996-97 | 6.28 | 772.00 | 0.36 | Neutral | |
| 6 neutral seasons: | -0.68 | 814.33 | -0.14 | | |
| | | | | | |
| **NYC (JFK)** | 20.85 | 115.68 | 41.19 | | <—1981-00 averages |
| Season | Snowfall anomalies | Snow hours | Temperature anomalies | Type | |
| 1982-83 | 11.25 | 90.00 | 2.46 | El Niño | |
| 1986-87 | 2.25 | 122.00 | -0.42 | El Niño | |
| 1987-88 | -1.15 | 118.00 | -1.04 | El Niño | |
| 1991-92 | -10.35 | 74.00 | 0.01 | El Niño | |
| 1992-93 | -0.85 | 139.00 | -0.95 | El Niño | |
| 1993-94 | 24.35 | 164.00 | -2.35 | El Niño | |
| 1994-95 | -12.95 | 69.00 | 1.64 | El Niño | |
| 1997-98 | -20.25 | 64.00 | 1.32 | El Niño | |
| 8 El Niño seasons: | -0.97 | 105.00 | 0.08 | | |
| | | | | | |
| 1984-85 | 6.45 | 140.00 | 1.25 | La Niña | |
| 1988-89 | -12.65 | 86.00 | -0.41 | La Niña | |
| 1995-96 | 48.15 | 256.00 | -2.52 | La Niña | |
| 1998-99 | -8.55 | 86.00 | 0.91 | La Niña | |
| 1999-2000 | -6.75 | 94.00 | 0.50 | La Niña | |
| 5 La Niña seasons: | 5.33 | 132.40 | -0.06 | | |
| | | | | | |
| 1981-82 | 4.05 | 125.00 | -1.57 | Neutral | |
| 1983-84 | 1.15 | 143.00 | 0.30 | Neutral | |
| 1985-86 | -1.55 | 142.00 | -0.45 | Neutral | |
| 1989-90 | -11.25 | 123.00 | -0.78 | Neutral | |
| 1990-91 | -0.45 | 94.00 | 2.15 | Neutral | |
| 1996-97 | -10.85 | 69.00 | -0.04 | Neutral | |
| 6 neutral seasons: | -3.15 | 116.00 | -0.07 | | |
| | | | | | |
| **Boston** | 42.87 | 252.21 | 38.00 | | <—1981-00 averages |
| Season | Snowfall anomalies | Snow hours | Temperature anomalies | Type | |
| 1982-83 | -10.17 | 229.00 | -0.07 | El Niño | |
| 1986-87 | -0.37 | 292.00 | -0.17 | El Niño | |
| 1987-88 | 9.73 | 210.00 | -1.08 | El Niño | |
| 1991-92 | -20.87 | 238.00 | 1.88 | El Niño | |
| 1992-93 | 41.03 | 390.00 | -0.88 | El Niño | |
| 1993-94 | 53.43 | 388.00 | -0.67 | El Niño | |
| 1994-95 | -27.97 | 199.00 | -0.33 | El Niño | |
| 1997-98 | -17.27 | 155.00 | -0.50 | El Niño | |
| 8 El Niño seasons: | 3.44 | 262.63 | -0.23 | | |
| | | | | | |
| 1984-85 | -16.27 | 256.00 | -0.35 | La Niña | |
| 1988-89 | -27.37 | 155.00 | -0.43 | La Niña | |
| 1995-96 | 64.73 | 494.00 | -1.10 | La Niña | |
| 1998-99 | -6.47 | 195.00 | 2.62 | La Niña | |
| 1999-2000 | -17.97 | 112.00 | 1.48 | La Niña | |
| 5 La Niña seasons: | -0.67 | 242.40 | 0.44 | | |
| | | | | | |
| 1981-82 | 18.93 | 311.00 | -0.40 | Neutral | |
| 1983-84 | 0.13 | 292.00 | 0.63 | Neutral | |
| 1985-86 | -24.77 | 199.00 | -0.78 | Neutral | |
| 1989-90 | -3.67 | 281.00 | -2.58 | Neutral | |

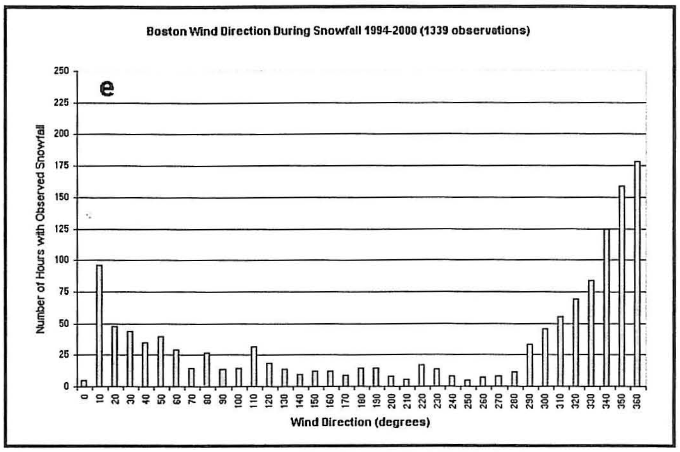
| | | | | |
|---|---|---|---|---|
| 1990-91 | -23.77 | 212.00 | 3.23 Neutral | |
| 1996-97 | 9.03 | 184.00 | -0.52 Neutral | |
| 6 neutral seasons: | -4.02 | 246.50 | -0.07 | |
| **Albany** | 60.42 | 338.84 | 33.19 | <—1981-00 averages |
| Season | Snowfall anomalies | Snow hours | Temperature anomalies Type | |
| 1982-83 | 14.48 | 307.00 | 2.15 El Niño | |
| 1986-87 | 20.18 | 309.00 | -0.21 El Niño | |
| 1987-88 | 9.78 | 336.00 | -0.48 El Niño | |
| 1991-92 | -29.72 | 349.00 | -0.45 El Niño | |
| 1992-93 | 33.78 | 466.00 | -0.95 El Niño | |
| 1993-94 | 27.68 | 430.00 | -3.38 El Niño | |
| 1994-95 | -29.52 | 213.00 | 2.29 El Niño | |
| 1997-98 | -12.22 | 281.00 | 2.24 El Niño | |
| 8 El Niño seasons: | 4.30 | 336.38 | 0.15 | |
| 1984-85 | -19.12 | 381.00 | 1.41 La Niña | |
| 1988-89 | -41.42 | 275.00 | -0.25 La Niña | |
| 1995-96 | 26.08 | 403.00 | -2.75 La Niña | |
| 1998-99 | -17.12 | 228.00 | 0.84 La Niña | |
| 1999-2000 | 1.68 | 188.00 | 1.62 La Niña | |
| 5 La Niña seasons: | -9.98 | 295.00 | 0.17 | |
| 1981-82 | 36.68 | 506.00 | -3.53 Neutral | |
| 1983-84 | 4.78 | 455.00 | -1.51 Neutral | |
| 1985-86 | 2.08 | 408.00 | -0.20 Neutral | |
| 1989-90 | -2.52 | 418.00 | 0.23 Neutral | |
| 1990-91 | -31.72 | 204.00 | 2.99 Neutral | |
| 1996-97 | 6.18 | 281.00 | -0.07 Neutral | |
| 6 neutral seasons: | 2.58 | 378.67 | -0.35 | |
| **Binghamton** | 80.74 | 767.47 | 32.15 | <—1981-00 averages |
| Season | Snowfall anomalies | Snow hours | Temperature anomalies Type | |
| 1982-83 | -0.44 | 697.00 | 2.54 El Niño | |
| 1986-87 | -1.94 | 708.00 | 1.17 El Niño | |
| 1987-88 | 0.86 | 888.00 | -0.78 El Niño | |
| 1991-92 | -24.74 | 920.00 | 0.30 El Niño | |
| 1992-93 | 40.06 | 977.00 | -1.89 El Niño | |
| 1993-94 | 38.96 | 950.00 | -3.19 El Niño | |
| 1994-95 | -27.94 | 711.00 | 1.44 El Niño | |
| 1997-98 | 11.26 | 469.00 | 2.25 El Niño | |
| 8 El Niño seasons: | 4.51 | 790.00 | 0.23 | |
| 1984-85 | -18.24 | 863.00 | 1.50 La Niña | |
| 1988-89 | -39.24 | 690.00 | -0.90 La Niña | |
| 1995-96 | 50.36 | 739.00 | -4.49 La Niña | |
| 1998-99 | -5.24 | 523.00 | 0.84 La Niña | |
| 1999-2000 | 1.66 | 528.00 | 1.15 La Niña | |
| 5 La Niña seasons: | -2.14 | 668.60 | -0.38 | |
| 1981-82 | -2.04 | 942.00 | -0.43 Neutral | |
| 1983-84 | -9.84 | 919.00 | -0.94 Neutral | |
| 1985-86 | -5.74 | 868.00 | -0.53 Neutral | |
| 1989-90 | -6.04 | 917.00 | 0.14 Neutral | |
| 1990-91 | -14.04 | 732.00 | 2.77 Neutral | |
| 1996-97 | 12.26 | 541.00 | -0.97 Neutral | |
| 6 neutral seasons: | -4.24 | 819.83 | 0.01 | |

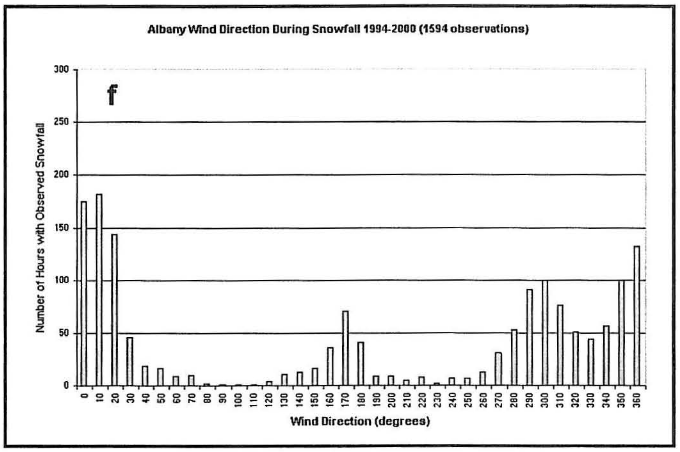


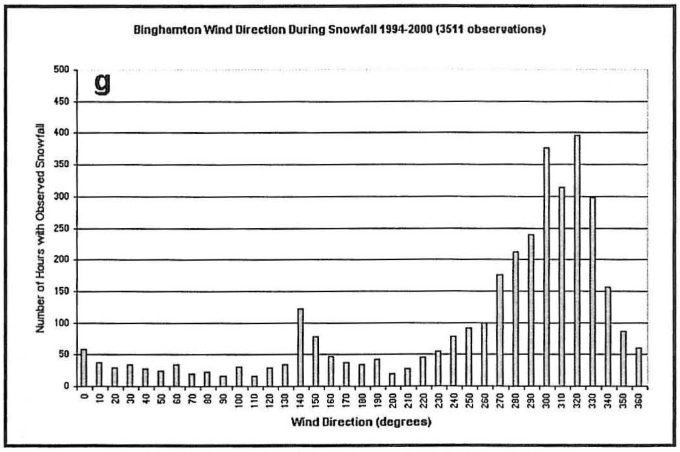
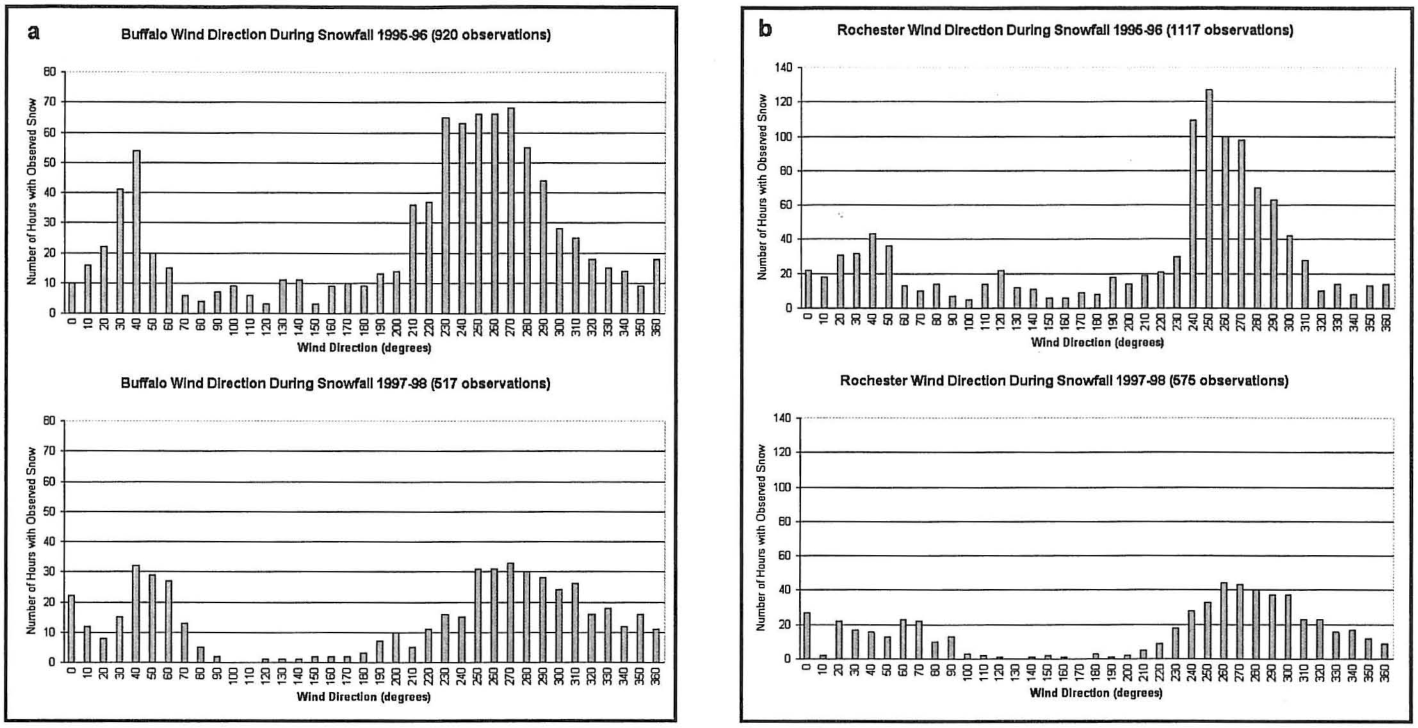




**Fig. 2.** Distribution of surface wind directions, 0° (calm) through 360° (north), during all hours in which snowfall was observed, November through April, 1994-2000. All stations except Boston are in New York State. (a) Buffalo, (b) Rochester, (c) Syracuse, (d) New York City (JFK airport station), (e) Boston, MA, (f) Albany, and (g) Binghamton.




the earlier paper that El Niño seasons had noticeably fewer snowfall hours at the three lake-effect stations with southwest, west, or northwest winds, the directions one would associate with lake-effect bands. El Niño appeared to increase the number of hours of snowfall at the two coastal cities, especially at Boston. Even at Albany and Binghamton, El Niño seasons showed more snow events with northeast winds, although many fewer events with west or northwest winds. From these results, it was suggested that during El Niño, coastal storms may have increased in number but that lake-effect events may have decreased. Only the latter appears to have occurred during El Niño in the period 1994 to 2000.

Figures 3a-c show distributions from the three lake-effect stations for two selected seasons during the 1994-2000 data. The weak La Niña of 1995-96 produced a large number of snow observations and is shown at the top of each figure. The very powerful El Niño of 1997-98 is shown at the bottom for contrast. In each case, it can be seen how few snow events occurred during that El Niño, compared to the La Niña, especially with westerly winds. This behavior turned out to be symptomatic of the data set in general.

To show the differences between seasonal types, the distributions of Figs. 2a-g were further organized in Figs. 4a-g. In addition, for clarity, the wind directions were grouped into 30° intervals, except for calm wind cases, which were in a separate category. Figures 4a-g may be roughly compared to the corresponding Figs. 4a-g in Blechman (2001). Data from all seasons, 1981-2000, are combined in Figs. 5a-g of this paper, which also uses the 30° intervals. Of the nineteen snow seasons used in total, eight were classified as El Niño, five were La Niña, and six were neutral.

Looking just at the three lake-effect stations (Figs. 4a-c), both Syracuse and Rochester from 1994-2000 showed

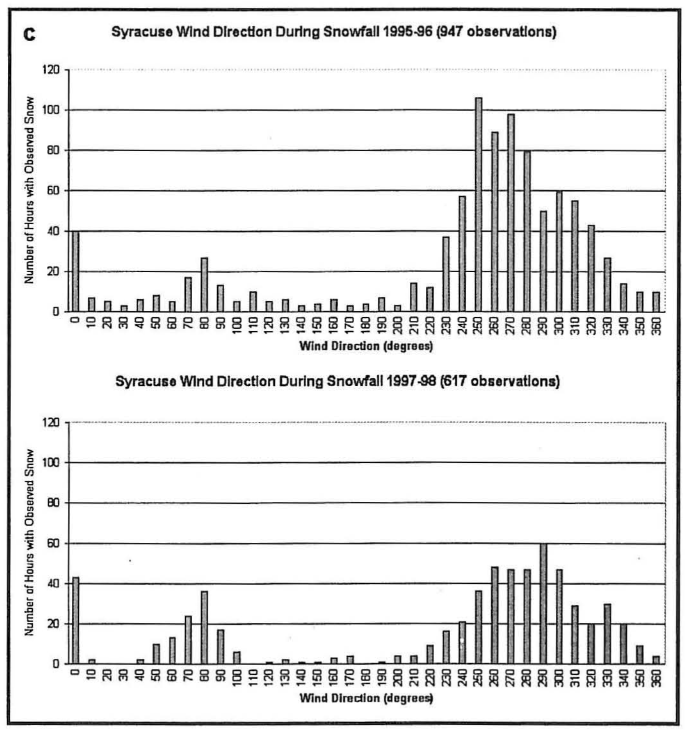
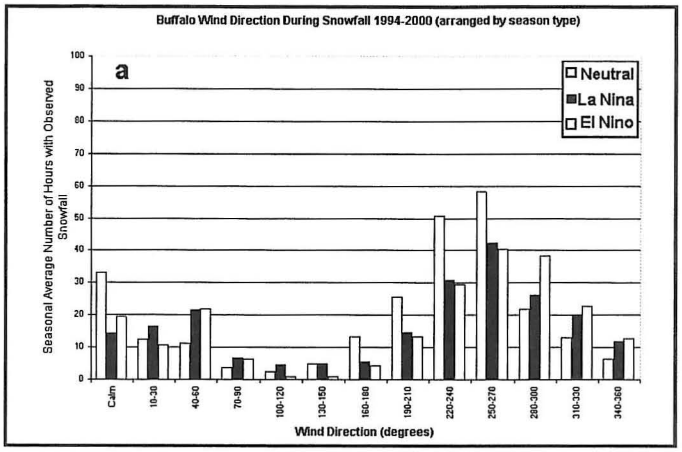
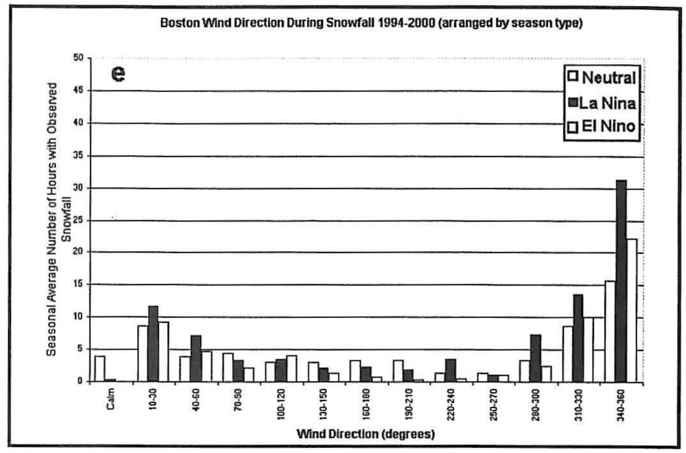
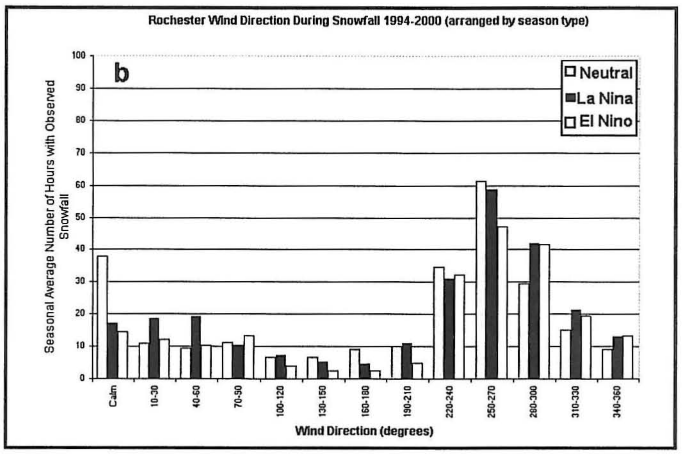


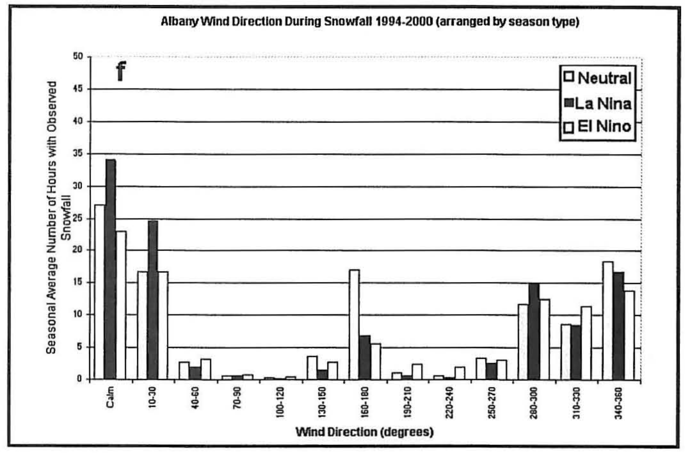

**Fig. 3.** Comparison of surface wind directions with snowfall as in Fig. 2, but for 1995-96 and 1997-98 only at (a) Buffalo, (b) Rochester, and (c) Syracuse.

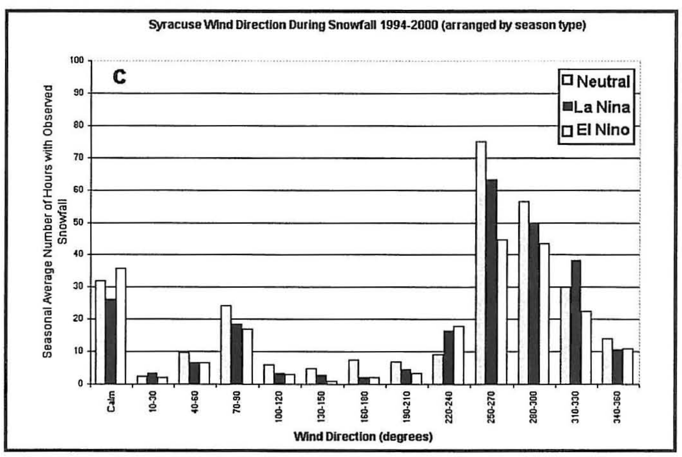
substantially fewer El Niño snow observations with west and northwest winds than the other two types as they did in 1981-94. Buffalo does not follow the pattern in one important aspect. It is not obvious that Buffalo's El Niño seasons had significantly fewer snowfall events with southwest winds than in La Niña. The neutral season was much stronger than the other two but there was only

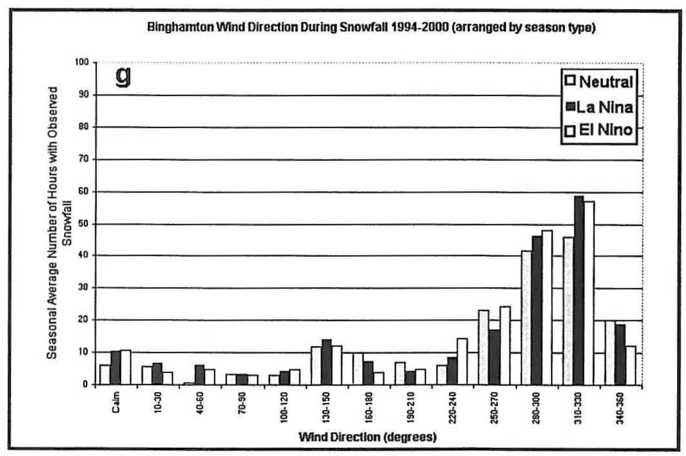


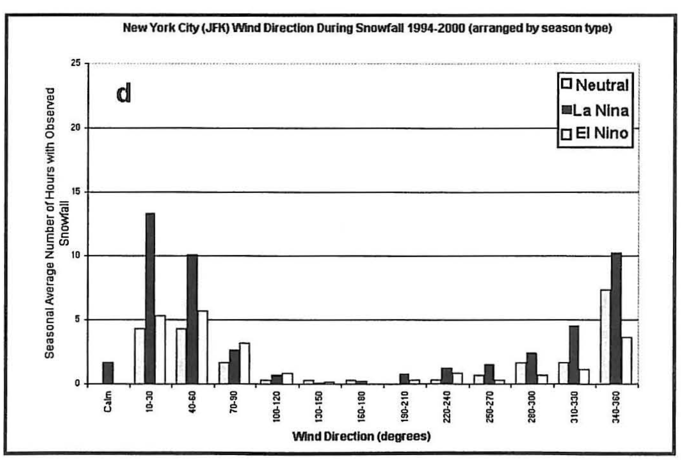
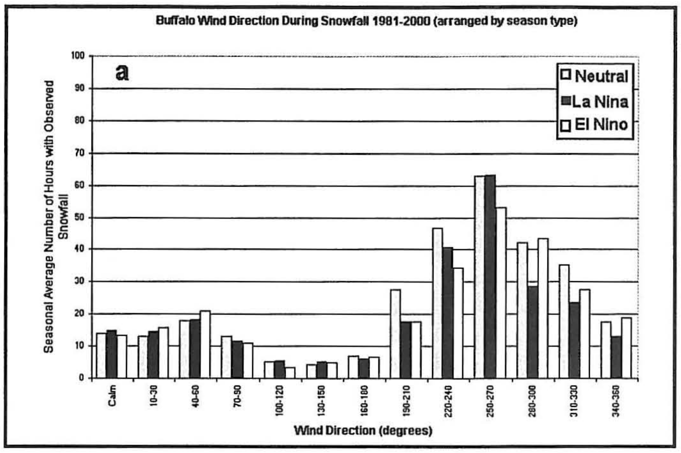
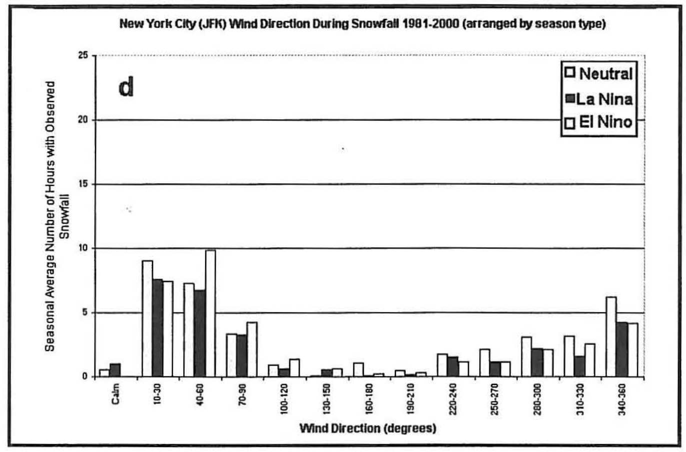
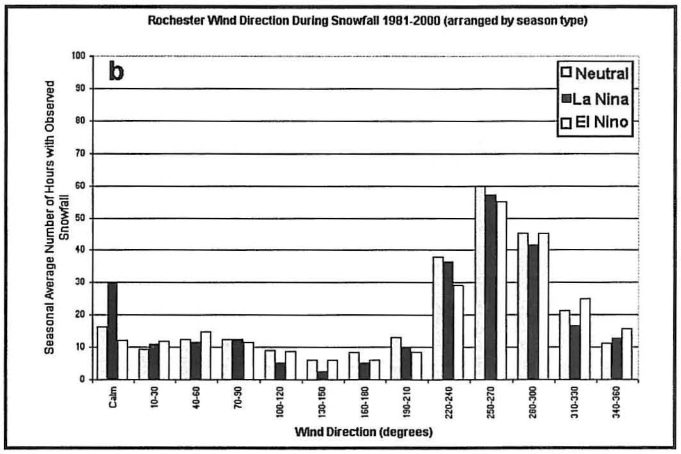
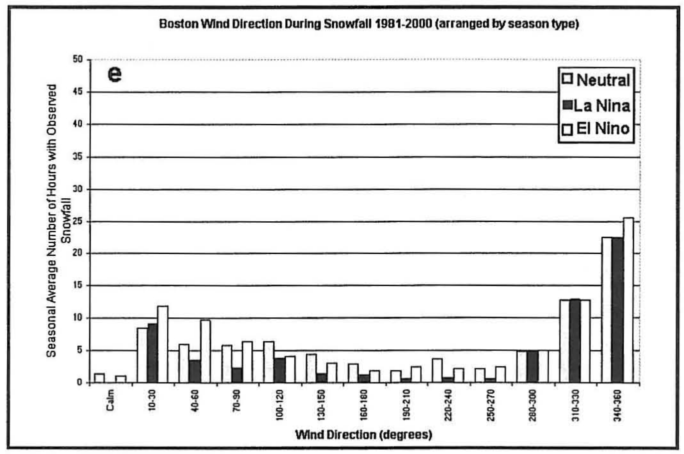



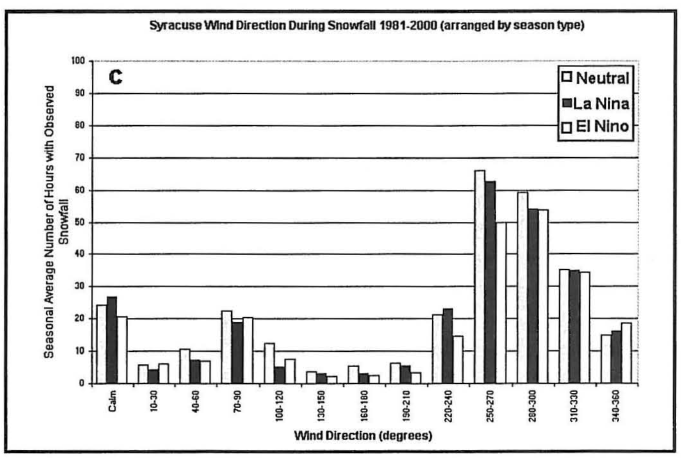

**Fig. 4.** Distribution of surface wind directions with snowfall, but seasonally averaged number of snow events classified for winters identified as neutral, La Niña, or El Niño during the period from 1994-2000. Note Y-axis scales reduced for New York City, Boston, and Albany.

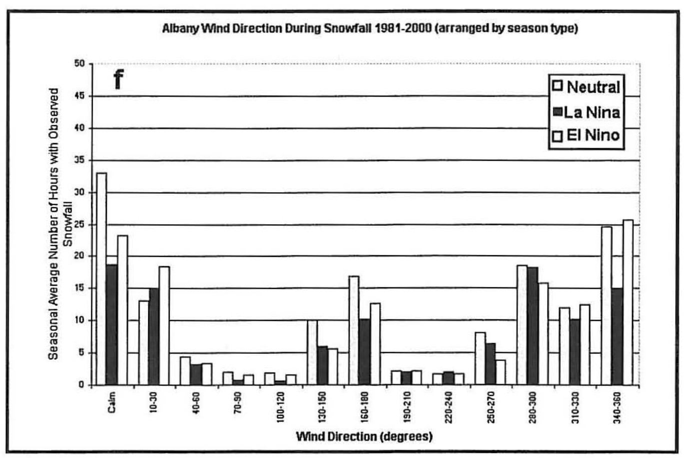


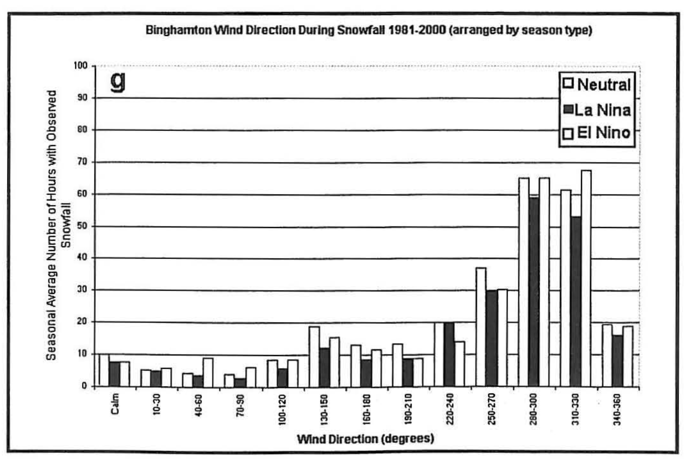




**Fig. 5.** Distribution of surface wind directions as in Fig. 4, but for the entire data set, 1981-2000.

one neutral season in 1994-2000. Actually, the level of neutral season snow events stayed consistent with the 1981-94 data. It was the El Niño and La Niña events which were both sharply lower in number with southwest winds at Buffalo. El Niño dominated with northwest winds, a feature that was suggested by the 1981-94 data, but is much more obvious in Fig. 4a here. Syracuse and Rochester show mostly similar patterns in the two periods studied.

New York City and Boston reveal similar patterns between the 1981-94 to 1994-2000 data sets (Figs. 4d-e). Neither city recorded snow in such large numbers of hours as the lake-effect cities. During the El Niños of 1994-95 and 1997-98, snowfall with north and northeast winds did not exceed the other types, a result that departed from the 1981-94 behaviors.

In the 1994-2000 data at Albany (Fig. 4f), large numbers of snow observations did not occur either with northeast winds during El Niño or with northwest winds during La Niña. This is in sharp contrast to the 1981-94 data. Again, snowfall events of all types were down substantially after 1994, except with north-northeast winds during La Niña. Binghamton (Fig. 4g) showed an even more dramatic drop in snow events of all types, with no obvious dominance of one type over another.The distribution was very similar to the one shown for the 1981-94 data in that no obvious maxima of any type stand out.

## 4. Summary and Conclusions

In a previous study (Blechman 2001), hourly snowfall events from Fall 1981 through Spring 1994, recorded at seven northeastern United States stations were identified and matched with the wind directions during those hours. Those results have now been updated using data from the seasons of Fall 1994 through Spring 2000.

Although only six cold seasons were used in this update, compared to thirteen in the previous study, the overall distributions of snow events with wind directions were quite similar to the earlier distributions (Fig. 2 of both papers). All stations had converted to ASOS by 1997 and the fact that the distributions did not significantly change suggests that those distributions represent real atmospheric signals, rather than statistical error associated with the change to automated observing systems.

Not all of the conclusions reached in the earlier study could be applied to the data after 1994. In particular, when separating the seasons into those meeting Trenberth's (1997) criteria for El Niño and La Niña, it was concluded in the previous study that 1981-94 El Niño seasons produced more snow hours at Boston, New York City, Albany, and Binghamton with northeast winds. In contrast, during the 1994-2000 period at those cities, the two El Niño seasons generated snowfall less frequently than the one neutral or three La Niña seasons.

The lake-effect cities, Buffalo, Syracuse, and Rochester, had results which more closely resembled those of Blechman (2001). At Syracuse in particular, but also to some degree at Rochester, southwest to west winds were associated with less snowfall during El Niño than the other two types. Overall, it appeared that, at lake-effect stations, there were again fewer snowfall events with southwest and west winds during El Niño. Buffalo also had less snow with southwest winds during El Niño than the one neutral season, but the La Niña results were somewhat different than those from 1981-94, especially in the last two seasons of the data set.

At all stations, the last two La Niña events of 1998-99 and 1999-2000 were times of fewer snow observations than previous La Niñas. This may be a short-term fluctuation in snowfall events or it may be an indication of longer-term climatic change. Nevertheless, at the lake-effect stations, the minor changes of snow with wind direction from 1981-94 to 1994-2000 support the conclusion reached in Blechman (2001), namely that La Niña and neutral winters have more snow observations with westerly type winds than El Niño winters. That relationship held true with both the 1981-94 data and in the ASOS data from 1994-2000. Since the greatest differences between the various seasonal types occur with southwest, west, and northwest winds, it is further concluded that those differences are due to fewer lake-effect snowfalls during El Niño conditions.

## Acknowledgments

The author appreciates the efforts of the two reviewers, Mike Evans of the NWS Forecast Office in Binghamton, and an anonymous reviewer. Their comments greatly improved this paper. NWS personnel Jeff Tongue (KOKX), Steve Francis (KBUF), Steve McLaughlin (KBUF), Steve Pertgen (KALB), and Dave Henry (KBOX) provided vital information on observation methodology, ASOS, and weather station histories.

## Author

Jerome B. Blechman holds the rank of Professor at the State University of New York, College at Oneonta. He teaches undergraduate courses in Introductory Meteorology, Climatology, Synoptic Meteorology, Remote Sensing, and Environmental Science. He received his B.S. degree in Meteorology from New York University in 1973, his M.S. and Ph.D. degrees, also in Meteorology, from the University of Wisconsin-Madison in 1975 and 1979 respectively. After a brief posting as Project Associate in the Center for Climatic Research, he accepted his teaching position at SUNY-Oneonta in 1982.

## *References*

Blechman, J. B., 2001: Surface Wind Directions Associated with Snowfall in Upstate New York. *Natl. Wea. Dig.*, 25:3,4, 19-27.

Niziol, T. A., W. R. Snyder and J. S. Waldstreicher, 1995: Winter weather forecasting throughout the eastern United States. Part IV: Lake-effect snow. *Wea. Forecasting*, 10, 61-77.

Trenberth, K. E., 1997: The definition of El Niño. *Bull. Amer. Meteor. Soc.,* 78, 2771-2777.