The Influence of Terrain on the Severe Weather Distribution across Interior Eastern New York and Western New England

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ABSTRACT

Forecasters have surmised that prominent mountain ranges and river valleys in eastern New York and western New England (e.g., Hudson and Mohawk River valleys; Adirondack, Catskill, Green, and Berkshire Mountains) affect convective initiation and subsequent severe weather distribution. The purpose of this research is to document the climatology of severe weather in this region with respect to the terrain and the synoptic-scale flow direction. The area of study was subdivided into overlapping 0.5° grid boxes, and the number of severe weather reports from the database (1950–98) was tabulated for each box. These severe weather reports were then normalized and contoured over a terrain map. A logarithmic correction factor was applied to the data in order to minimize potential population bias effects. The results of this correction were compared with cloud-to-ground (CG) lightning strikes (independent of population bias) from 1989 to 1998 (1990 missing) for severe weather days in the same region. The severe weather and CG lightning database also was stratified by 700-hPa flow direction into northwest and southwest flow regimes to see if subtle terrain influences on the severe weather distribution could be detected. Regions where the CG lightning and severe weather stratifications agree well include the southern Adirondacks, Berkshires, and the Litchfield Hills of northwest Connecticut. Regions where discrepancies exist between the two stratifications include the Catskills and the mid–Hudson valley. The results of both severe weather and lightning stratifications show that there are preferred regions of upstate New York and western New England for both CG lightning and severe weather to occur depending on the 700-hPa flow direction.

1. Purpose

Although severe weather may be less frequent in the northeastern United States than in some other regions of the country, it does occur and it poses a forecast challenge. The purpose of this paper is to present the results of a severe weather climatology for wind, hail, and tornadoes over interior eastern New York and western New England (Fig. 1). Experienced local forecasters have long suspected that major regional topographical features such as the Adirondack, Berkshire, Catskill, and Green Mountains, the north–south-oriented Hudson and Housatonic River valleys, and the west-northwest–east-southeast-oriented Mohawk River valley influence the distribution of severe weather. To test this supposition we will present the results of the severe weather climatology stratified by the 700-hPa wind direction. An attempt is also made to correct the climatology for population bias. As an independent check on the population bias correction, we will also show the distribution of cloud-to-ground (CG) lightning flashes for the more recent years when such data were available.

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2. Introduction

Articles from the recent (2001) American Meteorological Society monograph *Severe Convective Storms* (e.g., Davies-Jones et al. 2001; Doswell and Bosart 2001; Fritsch and Forbes 2001; Johnson and Mapes 2001; Moller 2001; Wakimoto 2001; Wilhelmson and Wicker 2001) have provided an extensive review of the state-of-the-art understanding of observational, theoretical, and numerical aspects of severe convective storms. This paper addresses the possible influence of terrain features on the distribution of severe weather. An early

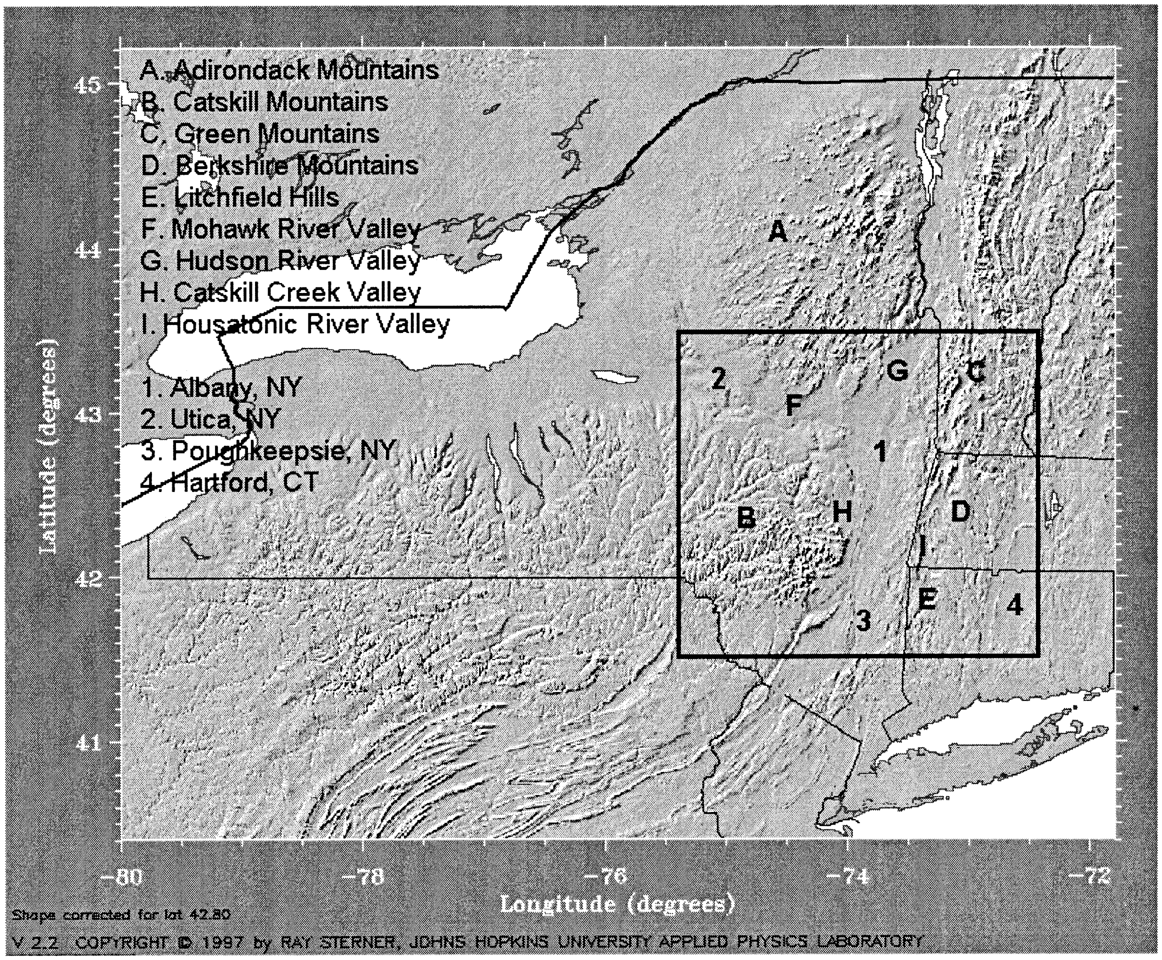


FIG. 1. Terrain map of New York and New England with important terrain and political features labeled. Area of study is enclosed in the black box.

study by Kuo and Orville (1973) demonstrated using radar data that various sides of the Black Hills in South Dakota were favored for convective development as a function of the orientation of the flow direction to the terrain. Riley and Bosart (1983) presented the results of a case study of the damaging Windsor Locks, Connecticut, F4 tornado of 3 October 1979 that suggested terrain played a role in the severe weather development. They showed that terrain-channeled southerly flow up the north–south-oriented Connecticut River valley helped to focus the convergence of warm, moist unstable air into the region where the storms became severe. Bracken et al. (1998), in a study of the 29 May 1995 Memorial Day F3 tornado in Great Barrington, Massachusetts, also suggested that the north–south-oriented Hudson and Housatonic River valleys contributed to the funneling of warm, moist, and unstable southerly flow. This resulted in enhancement of the low-level vertical wind shear profiles (right-turning hodograph) and atmospheric destabilization, thereby creating a more favorable environment for tornado development on a day in which the large-scale flow regime favored severe weather. In Europe, Schmid and Lehre (1998) showed that the local terrain of Switzerland can modify the vertical wind shear profile in such a way that convective evolution is affected as storms move through the region. These (and other) studies, and the knowledge that local forecasters have often observed that terrain-channeled southerly flow up the Hudson River valley can be very effective at transporting higher equivalent potential temperature (θ_e) air poleward, provide the motivation for this research.

Relatively few climatological studies of conditions associated with severe weather and/or tornadoes in the Northeast have been done in the past. David (1976) presented a climatology of synoptic conditions associated with New England tornadoes. He found that the highest number of tornadoes occurs in July in this region, and that tornado events can occur with both northwest flow and southwest flow aloft. Johns and Dorr (1996) showed that strong and violent tornado (F2–F5 intensity) episodes tend to occur approximately every 2 yr on average over eastern New York and New England. They confirmed the results of David (1976), including the July maximum and the two major synoptic setups. More recently, Maglaras and LaPenta (1997) developed a severe weather forecast equation for the Albany National Weather Service (ALY WFO) forecast area in which they combined severe weather parameters [convective available potential energy (CAPE), storm-relative helicity, energy helicity index, etc.] into a statistical regression equation to determine the potential for severe storm development [background information on these and other severe weather indices and forecast procedures can be found in, e.g., Peppler (1988), Hart and Korotky (1991), and Davies-Jones et al. (1990)].

A secondary goal of this research is to explore the effect of applying a population correction on the severe weather database in an attempt to separate topographic effects on the distribution from population density biases. It has been well documented that the severe weather database has a strong population density bias. For example, Snider (1977) showed that there was a statistically significant correlation between population density and tornado reporting in Michigan. Paruk and Blackwell (1994) compiled a severe thunderstorm climatology for Alberta, Canada. They developed a scheme in which they attempted to correct for some of the population bias in the severe weather reporting database. Doswell et al. (1999) illustrated that as the number of spotters increased after 1950, the number of tornadoes reported annually increased as well. He thus inferred that as population increases, frequency of severe weather reporting likewise increases. The authors of this paper followed the Paruk and Blackwell (1994) methodology for developing a population density correction scheme to be discussed in more detail in section 3.

In recent years CG lightning climatologies have also proved very useful in uncovering the regional and diurnal distribution of thunderstorms of all types (see, e.g., Camp et al. 1998; Hodanish et al. 1997). As discussed in the previous paragraph, a significant problem with mapping the distribution of reported severe weather is that these reports are subject to population bias problems and that no ideal scheme exists to remove completely the effects of population bias from the data. As an independent check on our population bias correction we will also stratify reported CG flashes on days with severe weather as a function of the 700-hPa flow direction. Although the CG flash dataset only begins in 1989, it has the advantage that it does not suffer from a population bias problem.

3. Data and methodology

a. Data

Severe weather reports were obtained from the severe weather report database at the Storm Prediction Center (SPC) for the years 1950–98, except 1982 (at the time this research was done, 1982 was missing from the database and, thus, is not used in any calculations in this study). Sounding data for Albany, New York (ALY), were obtained from the Radiosonde Data of North America CD-ROM, produced by the National Oceanic and Atmospheric Administration/Forecast Systems Laboratory (NOAA/FSL). Terrain maps were obtained online from the *Color Landform Atlas of North America* (compiled by R. Sterner of The Johns Hopkins University's Applied Physics Laboratory; http://fermi.jhuapl.edu/states/states.html). Population density data were obtained online from the United States Census Bureau summary tape files (http://www.census.gov). Block level population data were retrieved from this source (census blocks are sometimes irregular, small geographic units, bounded by streets, railroads, bodies of water, and other features), as well as the centroid latitude and longitude of each census block. Archived CG lightning strike data from the National Lightning Detection Network (NLDN) on severe weather days from 1989 to 1998 (1990 missing) was also used in this study (Krider et al. 1976; Orville et al. 1987; Orville 1991; Cummins et al. 1992).

b. Methodology

The area of study for this project was defined from 41.5° to 43.5°N and 72.5° to 75.5°W (Fig. 1). All reported severe weather, including high and/or damaging wind ($>$25.7 m s^{-1}), large hail ($>$1.91 cm), and tornadoes, that occurred in this area during 1950–98 was tabulated. A total of 3384 reports for the 49-yr period examined were tabulated including 2611 wind reports, 581 hail reports, and 192 tornado reports (Fig. 2). A corresponding ALY sounding was selected for each event; 1200 UTC soundings were used for severe weather reports before 1800 UTC, while the 0000 UTC soundings were used for reports after 1800 UTC. Thus, each severe weather report was paired with an ALY sounding in this objective manner, regardless of how many severe weather reports occurred on a particular day. It is understood that there is often ample time for the flow direction to change between when a severe weather report occurs and the closest sounding time. However, given that radiosondes are only launched every 12 h, this was the best method available for determining the wind direction associated with each individual severe weather report. The observed 700-hPa wind direction at ALY associated with each severe weather report in the region was used to stratify the reports into southwest and northwest flow regimes. The data were stratified by the 700-hPa wind direction because this was the first mandatory pressure level that is clearly above the underlying terrain.

Various stratifications were considered, such as southwest (northwest) flow defined as 700-hPa wind directions from 180° to 250° (290°–360°), or the approximate orientation of the Mohawk valley (280°) as the division between northwest and southwest flow. It was determined that terrain influence on severe weather reports

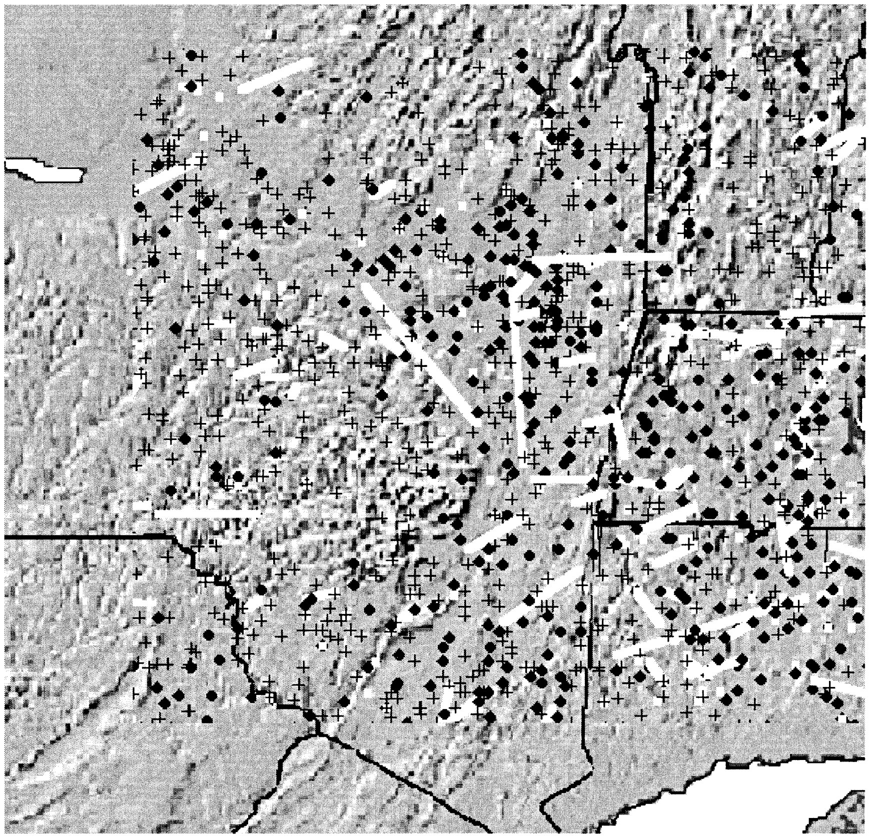


FIG. 2. All severe weather reports from 1950 to 1998 in area of study overlaid on terrain. Black plus sign, black dots, and white lines indicate high wind reports, hail reports, and tornadoes, respectively. (The terrain map is available online at http://fermi.jhuapl.edu/states/states.html.)

was most clearly represented by defining southwest (northwest) flow as 180°–260° (280°–360°). West flow was defined as a 700-hPa wind direction between 261° and 279°. The west flow stratification results resembled a combination of southwest and northwest flow plots and, thus, will not be presented in this paper. Next, the area of study box was divided into 0.5° × 0.5° grid boxes, overlapping every 0.25°. Although the overlapping boxes resulted in severe weather reports being counted in more than one grid box, it increased the number of points for smoother contouring. Aside from this, results of the study were not affected in any way. A severe weather day was defined as any day with at least one severe weather report in the entire area of study, and the number of severe weather reports was summed and grouped as northwest or southwest flow based on the 700-hPa wind direction in the ALY sounding. Last, the number of severe weather reports per severe weather day for northwest and southwest flow was plotted at the center of each grid box and contoured. For example, a grid box that had a ratio of severe weather reports per northwest flow severe weather day of 0.1 indicates that 1 out of every 10 northwest flow severe weather days had severe weather occur in that grid box.

Subsequent to grouping of severe weather reports by flow regime, a population correction was performed following the methodology of Paruk and Blackwell (1994). First, the area average population density was computed for each grid box by summing the population of all census blocks whose centroid fell within that box, then dividing by the area of the grid box. Population density was plotted against the number of severe weather reports per severe weather day in each box, and an equation for the best fit logarithmic curve (nonlinear) was computed from the scatterplot. The correction factor for each grid box was computed by dividing the value of the regression equation at the highest population density by the value of the regression equation at the population density of that particular grid box. This correction factor then was multiplied by the number of severe weather reports per severe weather day in the box. The grid box with the highest population density has a correction factor of 1, while all other grid boxes have a correction factor higher than 1. Although we appreciate that there are problems with correcting a dataset that likely contains other errors, the Paruk and Blackwell (1994) scheme is a simple attempt to account for substantial variations in population density and its effects on reports of severe weather events.

The CG lightning strike data were then stratified in

TABLE 1. Mean and standard deviation of temperature, dewpoint (°C), and SWEAT index at various levels for each category of severe weather report. Here, N is the total number of reports in the dataset of each type, and n is the number of soundings for which all data required for computations was reported.

Category	500-hPa temperature (°C) (mean/std dev)	500-hPa dewpoint (°C) (mean/std dev)	700-hPa temperature (°C) (mean/std dev)	700-hPa dewpoint (°C) (mean/std dev)	850-hPa temperature (°C) (mean/std dev)	850-hPa dewpoint (°C) (mean/std dev)	SWEAT index (mean/std dev)
All reports (N = 3384)	−10.6/3.7; n = 2698	−21.2/7.6; n = 2649	4.7/3.3; n = 2752	−0.6/5.3; n = 2744	14.7/3.7; n = 2763	10.5/4.0; n = 2759	240/70; n = 2492
Wind reports (N = 2611)	−10.3/3.7; n = 2096	−20.6/7.4; n = 2069	4.9/3.3; n = 2154	−0.3/5.3; n = 2149	14.9/3.8; n = 2163	10.7/4.0; n = 2160	242/68; n = 1920
Hail reports (N = 581)	−12.0/3.2; n = 450	−24.3/7.6; n = 436	3.7/2.9; n = 446	−1.5/5.0; n = 445	14.2/3.4; n = 447	9.5/3.7; n = 447	226/69; n = 427
Tornado reports (N = 192)	−11.4/3.9; n = 152	−20.8/8.6; n = 144	4.0/3.5; n = 152	−1.4/5.5; n = 150	13.8/3.5; n = 153	9.9/4.0; n = 152	250/68; n = 145

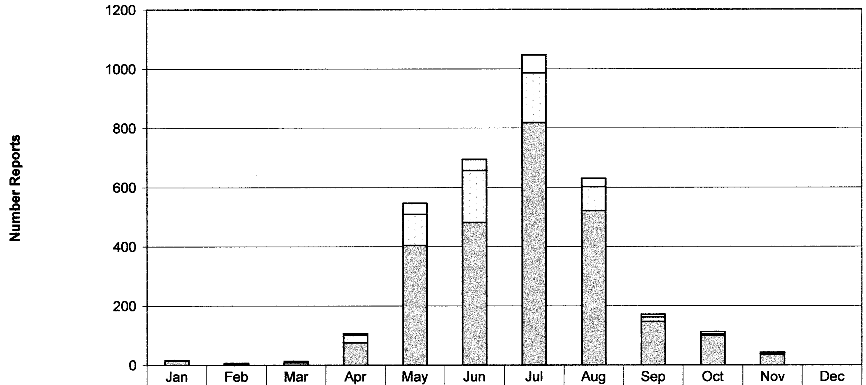
the same manner as severe weather reports in order to see if a similar signal appeared in a dataset with no population bias. A 10-yr period of the lightning data was chosen from 1989 to 1998. The consistency of the lightning data available was best after 1989, and because 1998 was the end of the time period for the severe weather reports used in the study, the lightning data were used up to this point also (future work will include expanding both the severe weather and lightning databases to include the most recent years). All lightning data for the year 1990 were missing from the archive at the time this research was completed, and thus there are only 9 yr of data in the period 1989–98. Only CG lightning strike data on days when severe weather occurred were stratified. The total number of CG lightning strikes is 421 007, with 128 736 on northwest-flow severe weather days and 292 271 occurring on southwest-flow severe weather days (there are roughly twice as many southwest-flow severe weather days as there are with northwest flow, and there are roughly twice as many southwest-flow strikes as with northwest flow). The number of lightning strikes per northwest- and southwest-flow severe weather day was tabulated for each grid box in the area of study, and the results were contoured and overlaid on a terrain map.

c. Data credibility

For perspective purposes, we show in Table 1 the mean temperature and dewpoint temperature at 850, 700, and 500 hPa for all severe weather reports and for each individual category. These values were taken from the closest sounding to each report. While it is recognized that this may not be representative of the storm environment, it should be pointed out that 38% of reports occurred within 2 h of 1200 UTC or 0000 UTC. Since such a large fraction of reports occurred in this time frame, the mean values presented in Table 1 are somewhat weighted toward values of the larger-scale environment in which the severe weather occurred, especially at levels well above the boundary layer such as 700 and 500 hPa where large-scale temperature and moisture changes tend to take place on timescales longer than 2 h. There is also the possibility that some of the individual soundings could be convectively contaminated in association with storm passage near the 0000 or 1200 UTC nominal sounding time. Despite these caveats, we feel that the data presented in Table 1 are reasonably representative of severe weather environments in the northeastern United States.

The data from Table 1 indicate that severe weather in eastern New York and western New England tends to occur with 850-hPa (500 hPa) temperatures in the 13°–15°C (−10° to −12°C) range and with temperature–dewpoint temperature spreads at 850 hPa (500 hPa) between 3° and 4°C (10° and 12°C). Hail reports are associated with the steepest 850–500-hPa lapse rates, mostly because of colder mean 500-hPa temperatures (−24.3°C).

For further comparison, we show the severe weather threat (SWEAT) index (David and Smith 1971; Miller et al. 1971; David 1976; Miller and Maddox 1976) for each category of severe weather report. The SWEAT index calculation was based on a reduced sample size of 2492 because of missing mandatory-level data. The SWEAT index was chosen for comparison because it combines measures of moisture, lapse rate, and vertical shear in a very simple way. The results from Table 1 indicate that the SWEAT index thresholds of 240 and 250 for all events and tornadoes, respectively, are relatively low as compared with typical SWEAT index values for severe weather over the plains and southeastern United States as given in the above references (a SWEAT index of 250 generally is considered borderline for strong convection). S. Weiss and R. Johns of SPC (2002, personal communication) have indicated that the comparatively low SWEAT index values for northeastern U.S. severe weather events may reflect seasonal variations in an index (see also Table 2 in David 1976) that is sensitive to the value of the 850-hPa dewpoint temperature. Therefore, since vertical profiles associated with severe weather in the northeastern United States tend to be less unstable and have less 850–500-hPa directional shear (David 1976) as compared with similar air masses over the plains, lower mean SWEAT indices over the northeastern United States would be



	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Tornado Events	0	0	4	5	37	37	61	28	9	8	3	0
Hail Events	2	0	0	25	105	176	168	81	15	5	4	0
Wind Events	14	6	9	76	404	481	818	521	147	99	36	0

Month

Wind Events Hail Events Tornado Events

FIG. 3. Number of severe weather reports by month in area of study, broken down by event type.

expected as shown in Table 1. A more thorough analysis of the severe weather environments in our area of study would likely involve the calculation of various parameters related to CAPE and vertical wind shear. However, the focus of this paper is to document any preferences for severe weather with respect to flow regime and terrain in the area of study. The ALY sounding data are unlikely to be fully representative of this diverse geographic region with respect to severe weather parameters that are sensitive to relatively small changes in low-level temperature, moisture, and wind.

4. Results

Figure 2 shows the distribution of all severe weather reports (3384) from 1950 to 1998 overlaid on a terrain map of interior eastern New York and western New England. It is clear that there are far fewer reports in the highest mountainous areas than in the more densely populated valleys. Within the valleys there are high concentrations of reports collocated with major cities, such as Albany (ALB) and Utica (UCA). Despite our attempt to correct for population density, it is unclear how much the severe weather report distribution is affected by population density variations and how much is a result of the underlying topographical variations.

Initially, a general climatology of severe weather reports was compiled to determine the seasonal distribution of severe weather in the area of study. These results are shown in Fig. 3. They concur with the findings of previous research, in that there was a maximum of severe weather reports of all types during the summer season. There are over twice as many high-wind reports as hail and tornado reports combined. There is a distinct minimum of severe weather during the winter months, with very few hail and no tornado reports from December through February.

The next step was to compare the wind at various levels for each type of event by constructing wind roses and comparing these wind roses with climatological wind roses for ALY. Since 1997 the ALY WFO and the Albany International Airport surface observing site (ALB) have not been collocated, and different abbreviations will be used to refer to the radiosonde launch site at the ALY WFO (ALY) and the surface observing site (ALB). Figure 4 shows surface wind roses for ALB (UCA) from March 1993 to March 1997 (July 1995 to May 1997). Each hourly surface observation for these two stations was binned and plotted on the wind rose. The funneling effects of the local terrain stand out dramatically. At UCA, there are two prevailing wind directions: west-northwest (down the Mohawk valley) and east-southeast (up the Mohawk valley). At ALB, there are three prevailing wind directions: south (up the Hudson valley), west-northwest (down the Mohawk valley), and north (down the Hudson valley). Higher in the atmosphere, these effects are less noticeable (not shown), but near and just above the surface the terrain funneling is an important effect.

Wind roses at ALY for 850, 700, and 500 hPa for all types of severe weather events, as well as for climatology, are shown in Fig. 5. The wind roses for all types of severe weather reports are substantially different from the climatology wind rose, in that there are prevailing wind directions with a higher number of soundings, whereas the climatology wind rose shows a rounded peak of soundings from southwest to northwest flow at all three levels (Fig. 5e). A weighted climatology wind rose was created by multiplying the sounding in each month by the percentage of severe weather reports that occur in the region in that month (not shown). This weighted climatology looked markedly similar to the simple unweighted wind rose.

The wind rose for all reports combined (Fig. 5a) looks

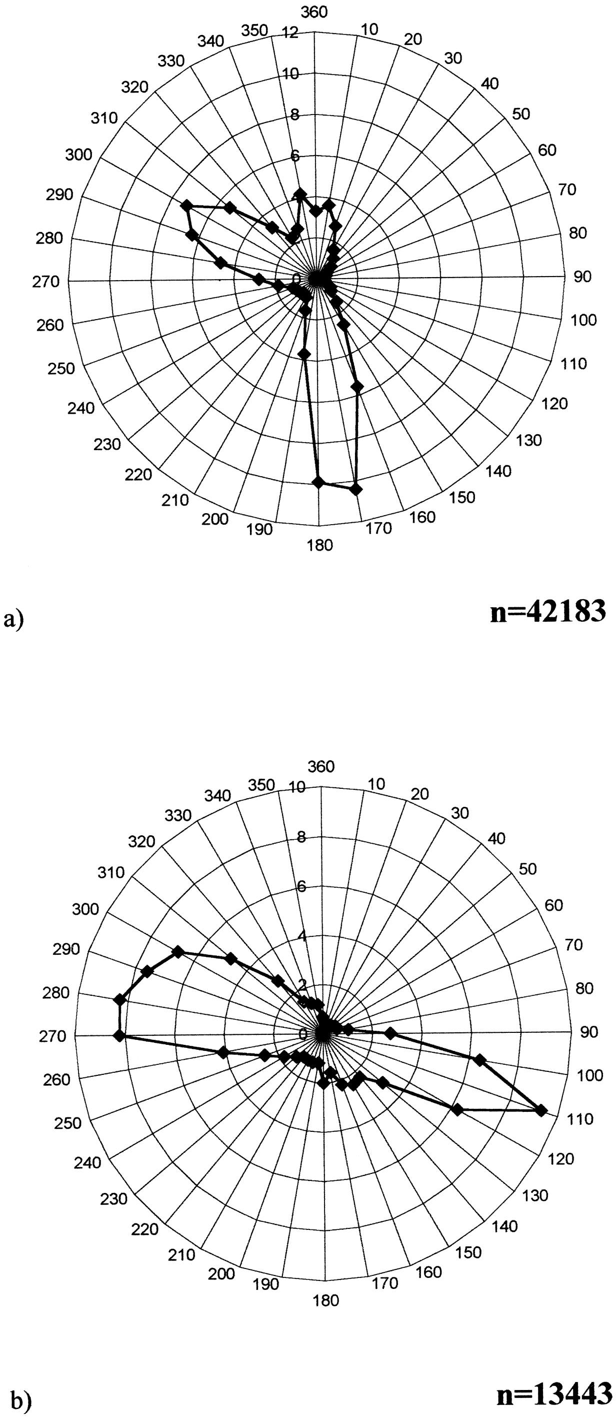


FIG. 4. Surface wind roses for (a) ALY, and (b) UCA, for Mar 1993–Mar 1997 and Jul 1995–May 1997, respectively. Azimuthal axis represents wind direction (°), and radial axis represents wind speed (m s^{-1}).

nearly identical to the wind rose for high-wind reports (Fig. 5b), because there are so many more wind reports in the database than hail and tornado reports. There is a maximum number of reports occurring with southwest or west-southwest flow at all levels for both all reports (Fig. 5a) and high-wind reports (Fig. 5b), likely indicative of an approaching trough. There is also a weak maxima of soundings with south flow at 850 hPa. Figure 5b also shows a weak peak at 310° at 700 and 500 hPa, indicating that some reports may occur under northwest flow.

Figure 5c shows the wind rose for hail reports. In this figure, the magnitude of the northwest-flow peak is much closer to the magnitude of the southwest-flow peak than for either wind or tornado reports. For example, at 700 hPa there is a maximum of approximately 65 reports at 250°, and there is also a maximum of over 60 reports at 280°, or west-northwest flow (Fig. 5c). This is not the case for wind reports, for which there are almost 100 more reports at 250° than at 280° (Fig. 5b). There is also a small peak of northerly flow at 850 hPa associated with hail events (Fig. 5c). Recall from Table 1 that hail reports are associated with the coldest and driest air at the midlevels in the mean, consistent with northwest (as opposed to southwest) flow. Figure 5d shows the wind rose for tornado reports. Most noticeable in this plot is the maximum of tornado reports that occur with west-southwest flow at all levels, suggestive of a synoptic-scale trough approaching from the west.

Figure 6 shows contour plots of the number of total reports, uncorrected and corrected for population bias, per severe weather day for northwest and southwest flow. Plots similar to Fig. 6 were also created for each type of severe weather individually, but they are not shown, because significant differences were not present between the high-wind and hail stratifications, and because there were too few tornadoes in the area of study for the tornado stratification to give useful results. In the uncorrected plots, both northwest- and southwest-flow days show a maximum of severe weather events at the juncture of the Hudson and Mohawk valleys, near ALB. There is also a maximum farther south near the city of Poughkeepsie, New York (POU), and minima in the surrounding mountain ranges, in both flow stratifications. This result may indicate that there are dominant population effects despite the stratification by flow direction. The plots that have been adjusted for population density show some differences from the uncorrected plots. The maximum near ALB for both northwest and southwest flow is brought more in line with the values in the surrounding regions. While it is understood that the correction factors may have incorrectly inflated values in places with small population density, it does appear that the terrain influences have been better isolated by the (nonlinear) correction scheme. The northwest- and southwest-flow plots look somewhat different from each other after the correction has been applied. On southwest-flow severe weather days, the highest concentration of reports lies at the juncture of the Hudson and Mohawk valleys and extends west-northwestward up the Mohawk valley. On northwest-flow severe weath-

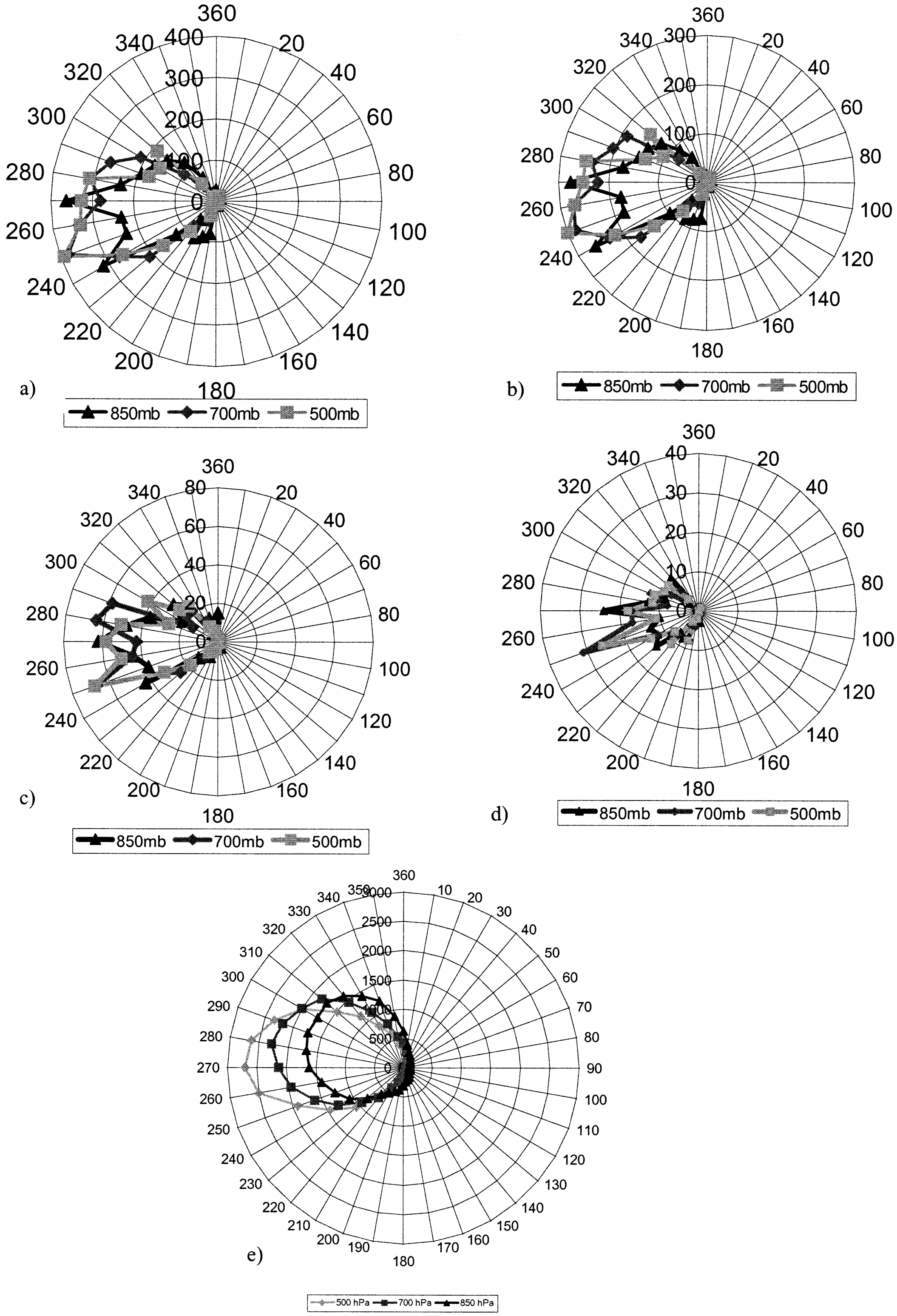


FIG. 5. Wind rose plots of ALY soundings for (a) all severe weather reports, (b) high-wind reports, (c) hail reports, (d) tornado reports, and (e) climatology 1950–96. Azimuthal axis represents wind direction in degrees, and radial axis represents number of severe weather reports.

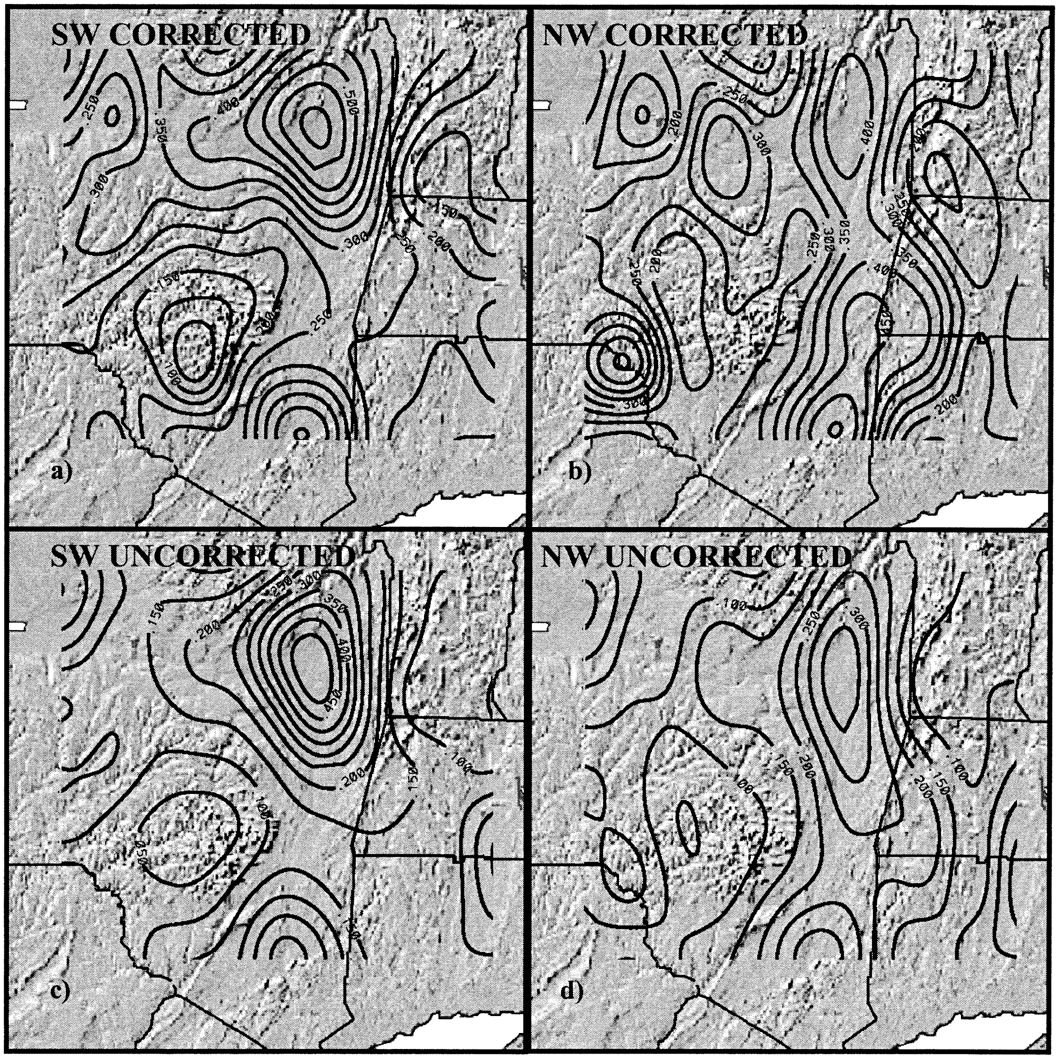


FIG. 6. Number of reports per severe weather day for (a) southwest flow, population corrected; (b) northwest flow, population corrected; (c) southwest flow, uncorrected; and (d) northwest flow, uncorrected. Contour interval is 0.05.

er days, the maximum over the ALB area becomes less pronounced in relation to the maximum farther south in the mid–Hudson valley eastward into the Berkshires. In both the northwest- and southwest-flow (corrected and uncorrected) plots, there is a north–south maximum near the Hudson valley. It is difficult to determine whether this is due to population bias, or whether there does tend to be more severe weather in the valley for all flow directions, until one examines the CG lightning data.

Figure 7 shows the contour plots for the CG lightning data stratification. While it cannot be assumed that frequency of CG lightning strikes on severe weather days is directly related to the number of severe weather reports, one can still draw some useful conclusions by comparing the two figures. The CG lightning data illustrate the distribution of convection on severe weather days across the region, and this is closely related to severe weather occurrence, so some comparisons may still be made. On southwest-flow severe weather days, a relative maximum of CG strikes is found south of Albany in the mid–Hudson valley, extending northward into the southeast flank of the Adirondacks. A minimum of strikes is found over the northeastern Catskills and eastern slopes of the Greens. Although the maximum of CG strikes south of Albany extends eastward toward the Berkshires, it is smaller and farther west than the CG lightning strike maximum on northwest-flow severe weather days that crosses the Berkshires (Fig. 7b).

It is possible that the large bull's-eye of severe weather reports on southwest-flow days in the mid–Hudson valley (west of Connecticut) seen in Fig. 6a is partially a reflection of population bias, because this feature is displaced to the north in the CG lightning data (Fig. 7a). However, the maximum of reports at the junction of the Hudson and Mohawk valleys (near ALB) does appear in the CG lightning data and is unlikely to be a

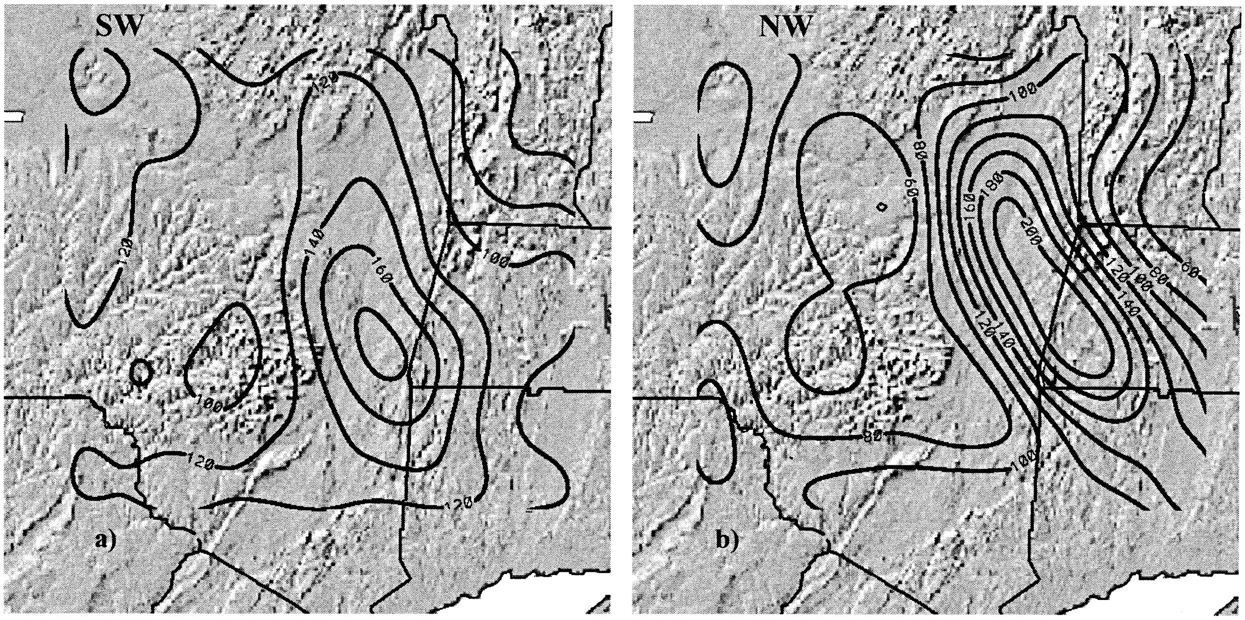


FIG. 7. Number of lightning strikes per severe weather day for (a) southwest flow and (b) northwest flow.

complete artifact of population bias. On northwest-flow severe weather days, the highest frequency of CG strikes by far occurs east of ALB southeastward into the Berkshires (Fig. 7b). A very steep gradient of lightning flashes surrounds this region, which suggests that there is a climatological preference for lightning to occur as storms move through this corridor on northwest-flow severe weather days. This flash gradient correlates well to the maximum of corrected severe weather reports in this region on northwest-flow days southeast of ALB into the Berkshires (Fig. 6b). As on southwest-flow severe weather days, this northwest-flow maximum in the mid–Hudson valley may partially reflect a population bias, given that the CG lightning data do not show a strike maximum in this region, but instead show an elongated northwest–southwest-oriented maximum from near the southeastern foothills of the Adirondacks to the western slopes of the southern Berkshires. There

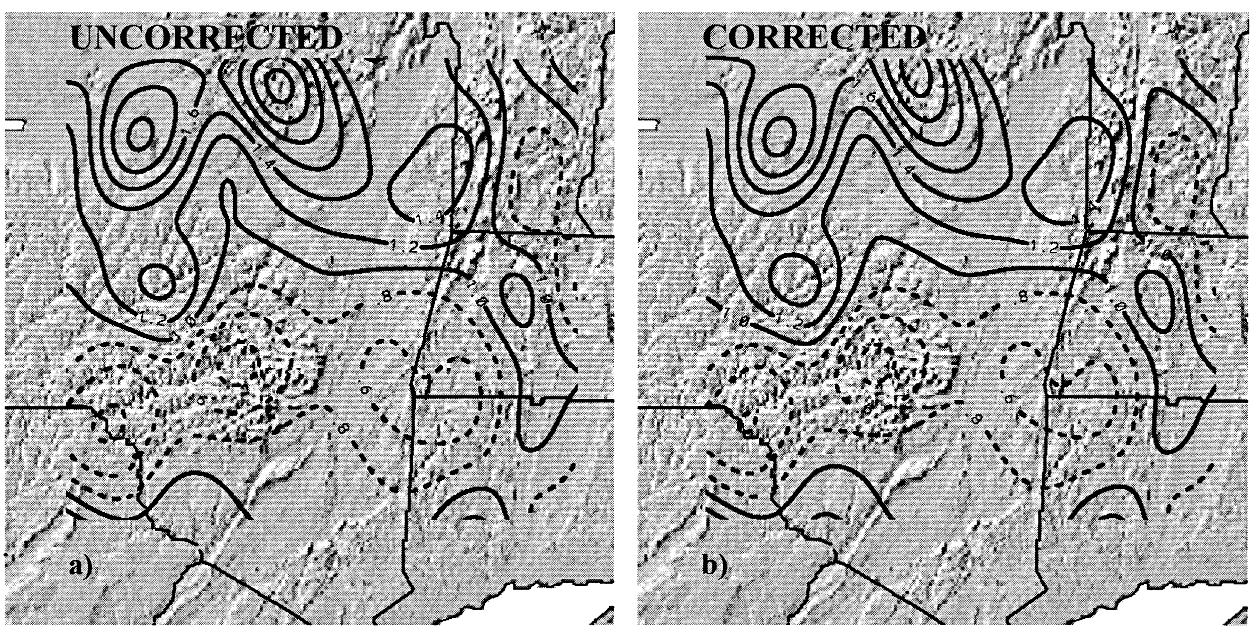


FIG. 8. Ratio of number of reports per severe weather day southwest flow to number of reports per severe weather day northwest flow, for (a) uncorrected and (b) population corrected plots.

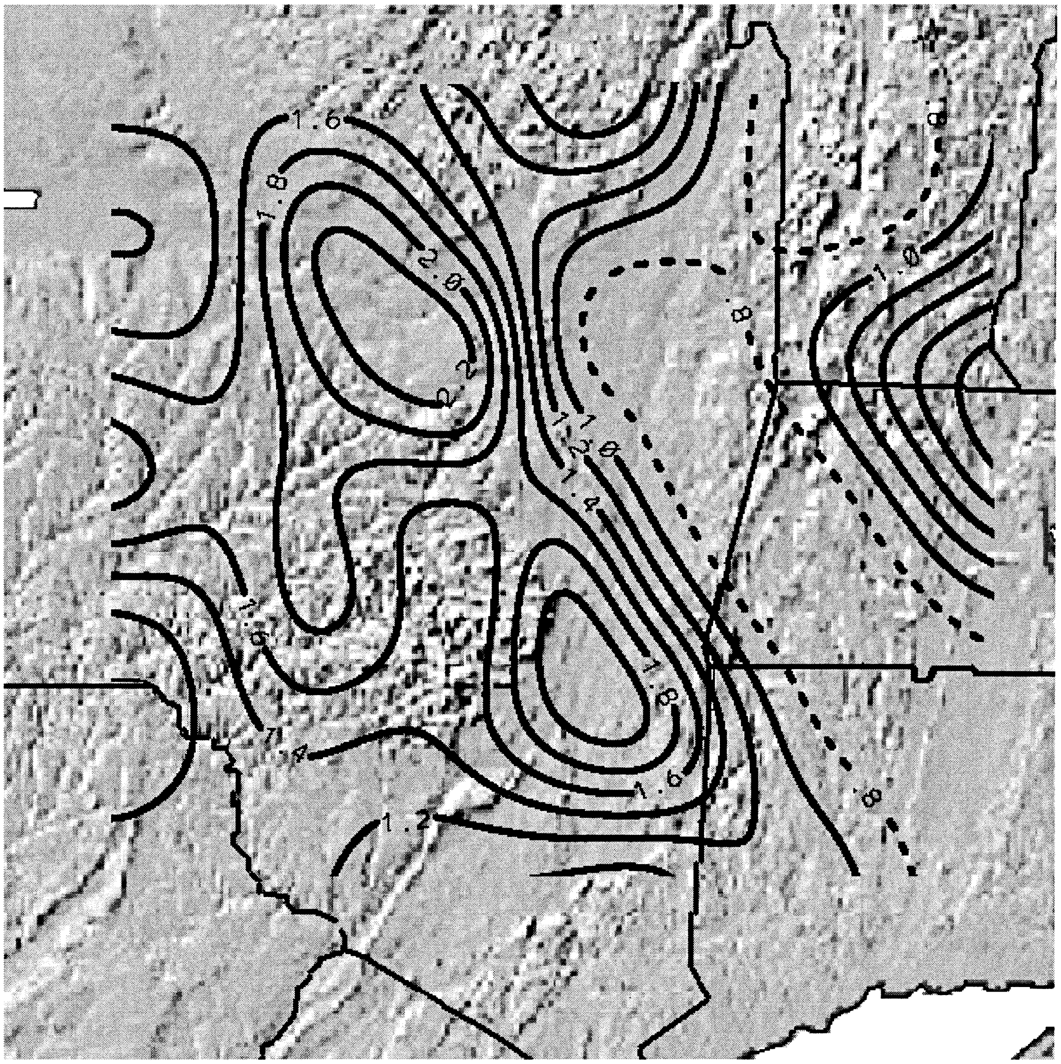


FIG. 9. Ratio of number of lightning strikes per severe weather day southwest flow to number of lightning strikes per severe weather day northwest flow.

is also a relative minimum of CG lightning strikes from the central Catskills northward into the southern Adirondacks on northwest-flow severe weather days.

Figure 8 shows the ratio of southwest to northwest flow for reported severe weather for the uncorrected (Fig. 8a) and corrected (Fig. 8b) schemes. Areas in which more events occur on southwest- (northwest) flow severe weather days have a ratio greater (less) than 1. The corrected and uncorrected plots look similar, which indicates that the paucity of reports in sparsely populated areas is not dependent on flow direction. It is clear that there is a tendency for severe weather reports on northwest-flow severe weather days to occur preferentially south of the Mohawk valley into the Catskills and Berkshires. Conversely, the tendency for severe weather reports to occur preferentially on southwest-flow severe weather days lies from the Mohawk valley northward into the Adirondack and Green Mountains.

Last, Fig. 9 shows the ratio of southwest to northwest flow for CG lightning strikes. The CG lightning flashes are much more frequent along an axis extending from the southern flanks of the Adirondacks southeastward into the mid–Hudson valley on southwest-flow severe weather days than on northwest-flow severe weather days. Other southwest-flow CG hotspots can be found along the eastern Vermont–Massachusetts border and over the western Catskills. On northwest-flow severe weather days, CG lightning flashes occur more often in the southern Berkshires, and northwest Connecticut than on southwest-flow days. This result agrees with the severe weather report stratification shown in Fig. 8, in that there is a tendency for CG lightning on the southern flank of the Adirondacks and near the Massachusetts–Vermont border (in the southern Berkshires and into northwest Connecticut) on southwest- (northwest) flow severe weather days. The biggest discrepancies between the CG lightning and severe weather stratifications are in the Catskills (where the severe weather stratification indicates a northwest-flow bias, and the CG lightning strike stratification indicates a southwest-flow bias), and the region in upstate New York just west of the Vermont–Massachusetts border (where the CG lightning stratification indicates a northwest-flow bias, and the severe weather stratification indicates a southwest-flow bias). Another discrepancy lies in the mid–Hudson valley, west of Connecticut. The severe weather stratification indicates that this region has a ratio of near 1.0, indicating little preference for severe weather depending on flow direction. The CG lightning data has a ratio of 2:1 in this region, which would suggest that there is a bias for more CG lightning to occur here on southwest-flow severe weather days than on northwest-flow severe weather days. In most parts of the area of study, the CG lightning strike ratio for southwest to northwest flow on severe weather days is greater than 1, indicating that, on average, more CG lightning tends to occur on southwest-flow severe weather days in much of the region. It is unclear how these discrepancies and similarities would change if a larger sample of CG lightning data were available.

5. Conclusions

This study has provided evidence that the distribution of severe weather is affected by the underlying terrain and its orientation relative to the 700-hPa flow direction in eastern New York and western New England. Based upon the areas where the CG lightning strike and severe weather stratifications agree, it appears that on southwest-flow (northwest flow) severe weather days, severe weather is more likely from the Mohawk valley west of ALB northward into the southern Adirondacks (in the southern Berkshires and Litchfield Hills of Connecticut). It is also apparent that there is a strong population bias in the dataset, and that performing a logarithmic (nonlinear) population density correction on the data only partially corrects for this bias in the data, as there is no way to unambiguously separate the terrain and population influences. By constructing a ratio of severe weather reports for southwest to northwest flow on severe weather days we have evidence that sparsely populated areas underreport severe weather at the same rate independent of flow direction. The results of the CG lightning stratification help to isolate which relative maxima and minima in the severe weather stratification may be largely due to population effects and which are more likely to be due to terrain influences. In areas where the results of the lightning and severe weather stratifications agree well (such as along the Vermont–Massachusetts border and the Berkshires into the Litchfield Hills), the severe weather distribution likely has some terrain influences, whereas in areas where the results differ significantly (such as in the Catskills, eastern New York State east of ALB, and populated areas of the mid–Hudson valley), it is more difficult to conclude that the population bias is not affecting the distribution of severe weather reports. From the CG lightning strike data, one can draw the conclusion that severe convection is dependent on the relationship of the large-scale flow to the underlying terrain. Because severe weather occurrence is closely related to convection, the results from the CG lightning data analysis lend support to the conclusion that severe weather occurrence is also affected by the local terrain (especially since only CG lightning strikes on severe weather days were considered in the stratification). Examination of the CG lightning data makes it easier to discern which severe weather maxima may be largely due to population (e.g., Catskills), and which may actually be preferentially preferred areas for convection and/or severe weather in the area depending on the flow direction (e.g., Berkshires and northwest Connecticut).

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