

A COMPARISON BETWEEN MEAN MONTHLY TEMPERATURE AND MEAN MONTHLY SNOWFALL IN NEW YORK STATE

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Abstract

Winter mean monthly temperature and snowfall records were correlated to assess the relationship, if any, between these two parameters in New York State. Since high single-storm snowfall totals tend to occur when temperatures are low both from synoptic scale systems and from mesoscale "lake-effect" storms, temperature and snowfall should show a strong negative correlation. As expected, correlations were found to be strongly negative in western and central New York to the lee of Lakes Ontario and Erie, but were surprisingly weak in nearby areas. Correlations were uniformly strongly negative in southeastern New York and northeastern Pennsylvania, apparently because higher winter temperatures were associated with more rain and less snow. At Rochester in western New York, weak correlations were found despite large snowfall amounts. In addition, a small area northwest of the Catskill Mountains showed very weakly negative correlations. It was speculated that the western Catskill Mountain region is in a peculiar situation where neither lake effect nor coastal storms affect the area as much as in other parts of the state.

1. Introduction

In the northeastern region of the United States, often the most extreme weather of the year is heavy snow, usually from a rapidly deepening synoptic-scale low pressure system just off the coast. Much has been written about coastal snowstorms (colloquially called "Nor'easters") and their ability to produce copious snowfall. In western and central New York State, once the snow from a coastal storm has tapered off, the advent of lake-effect snow may add many inches of additional snow to the storm total. Muller (1966) documented "snowbursts" from lake effect which caused snowfall from 45 to 75 inches to the lee of Lake Ontario. In another lake-effect situation, Sykes (1966) reported on an event producing up to 100 inches during several days in January of 1966.

Many studies of lake-effect snow have been performed (e.g., DeLisi and Przybylinski 1992; Niziol et al. 1995; Peace and Sykes 1966), but since Muller (1966), few climatic analyses of the snowbelts have appeared. Wilson (1977) examined the effect of Lake Ontario on the surrounding area, but for all precipitation, snow and rain, warm season and cool season. A complete snow climatology of the region will not be attempted here. Instead, a simple analysis correlating mean monthly temperature with monthly snowfall will be employed to examine the characteristics of snowfall records, with attention to the sources, i.e., coastal storms and lake effect.

2. Analysis Method

Monthly mean temperature and snowfall data were extracted from a compact disk "NCDC Summary of the Day." Most

station records began in 1948, although some began earlier (a few of them start much earlier). The years 1948 to 1988 were used because that 41-year period was the most common one available on the disk. Also, stopping at 1988 allowed some data to remain independent so hypotheses developed from this pilot study may be checked in a future study. Data from winter months only, December, January and February (DJF) were used so the 41-year period consisted of 123 months. Almost none of the stations had a perfectly complete record of both temperature and snowfall and stations with large gaps or many missing values were discarded. Some data gaps were tolerated and in cases where one or more temperature records existed with no corresponding snowfall records (and vice versa) those months were omitted. Therefore, many of the stations show fewer than 123 points.

The DJF snowfall averages for each station were extracted from the observed daily snowfall on the compact disk and plotted on a map (Fig. 2). These averages, of course, neglect the snow occurring in other months. November can be a big lake-effect month and March can have quite intense coastal storms like the Superstorm of 1993 (Kocin et al. 1995). Since the usual meteorological convention of "winter" is December, January and February, this analysis is restricted to those months.

Next, the mean monthly temperatures were correlated with the DJF monthly snowfall. The monthly mean maximum and minimum temperatures, calculated using daily values were used to find the mean monthly temperatures. Grouping them by months, the appropriate averages were calculated from the months on record which were then subtracted from each monthly value. For example, the 41-year December average was subtracted from each December value to get departures from this average. This was done to make the values comparable since average January temperatures were lower than those of December or February and using departures avoided that bias. The same procedure was used on monthly snow totals and the two resulting series, temperature departures from means and snowfall departures from means were correlated using a sample correlation coefficient (Hoel 1971):

$$r = (n\sum xy - \sum x \sum y) / \sqrt{[n\sum x^2 - (\sum x)^2][n\sum y^2 - (\sum y)^2]}^{1/2} \quad (1)$$

In (1), designed for programming simplicity, r is the sample correlation coefficient, x and y are the series of monthly temperature and snowfall departures and n is the number of temperature-snowfall value pairs.

Due to the finite number of observations, the sample correlation coefficient, r , may not accurately represent the true correlation coefficient. Due to sampling error, the true correlation coefficient, one theoretically calculated from an infinite number of points, may in fact be zero, even when r is negative. To estimate the likelihood that the true correlation coefficient for these data would be less than zero, the Fisher's Z transformation

was used. Following the treatment found in Dowdy and Wearson (1983), an estimate for r was found for which one could say with 95% confidence that the true correlation coefficient would be less than zero. This estimate depended on the number of value pairs and the sample correlation coefficient. For the stations listed in Table 1, n was as low as 87 and as high as 123. For all stations, no matter how many value pairs, whenever $r \leq -0.18$, the sample correlation coefficient passed the Fisher's Z transformation test at the 95% level or better, i.e., one could be at least 95% confident that the true correlation coefficient was less than zero if the sample correlation coefficient was less than -0.18 .

This procedure assumed that each station's data were normally distributed, not a terrible assumption for monthly data but less acceptable for snowfall than for temperature. It was also assumed that the monthly values were independent of each other, i.e., no month's temperature (or snowfall) depended on the previous month's observation, a condition which was probably not always true. Reducing n , the number of independent observations, would probably not decrease the confidence limit substantially since the three stations with less than 100 value

pairs all had strongly negative correlations. Moreover, it was not obvious how many monthly observations were actually independent. Namias (1952) found some month-to-month persistence in winter, but it was small. Given the two preceding considerations, the total number of value pairs in each record was used in this study. In any case, most of the conclusions were based on comparisons between the coefficients, rather than their values in an absolute sense.

The sample correlation coefficients are listed in Table 1 and shown in Fig. 3.

3. Results

The stations found to have reasonably complete records, allowing reliable analyses are shown in Fig. 1. Unfortunately, most stations available on the compact disk were incomplete in either temperature or snowfall. Figure 2 shows the average snowfall found for the three-month (DJF) period. Of course, the DJF snowfall does not include the substantial snow which occurs at some places during November and March. Nevertheless, the DJF snowfalls shown in Fig. 2 easily indicate the effects of Lakes Ontario and Erie in producing heavy snow. There is a "corridor" of lower snow totals from Mount Morris (MTM) in western New York to north-central Pennsylvania. Also, there is a minimum snow total area around Oneonta, with only 39 inches of snow from December through February. This minimum, nestled nicely between the Adirondack maximum to the north and the Catskill maximum to the south is consistent with the personal experience of the author and many of the students at SUNY-Oneonta. Lake-effect snow squalls are rarely more than flurries by the time they reach Oneonta. Oneonta gets 28% less snowfall in DJF than Cooperstown, only 22 miles to the north. Also, snow from coastal storms appears to be less intense at Oneonta than at points to the southeast. For example, Walton, in the Catskills, gets 69 inches on average during

Table 1. Results of correlations of December-January-February (DJF) mean temperature departures from monthly averages with those of corresponding snowfalls. Also, DJF winter snowfall totals in inches. Unless otherwise noted as PA, all stations from New York State. ✓ indicates the correlation coefficient passed the Fisher's Z transformation test at or above the 95% level.

Station	Number of points (n)	Avg. DJF snowfall	Correlation Coefficient (r)	
Addison	92	32	-0.28	✓
Albany	118	49	-0.17	
Binghamton	114	55	-0.26	✓
Boonville	117	150	-0.36	✓
Bradford, PA	110	64	-0.34	✓
Buffalo	123	65	-0.51	✓
Carmel	87	28	-0.39	✓
Clarion, PA	108	31	-0.49	✓
Cooperstown	119	54	-0.26	✓
Erie, PA	118	58	-0.49	✓
Franklinville	102	80	-0.38	✓
Fredonia	119	57	-0.52	✓
Gloversville	117	56	-0.24	✓
Liberty	114	52	-0.36	✓
Massena	120	48	-0.27	✓
Montrose, PA	117	54	-0.35	✓
Mount Morris	96	28	-0.40	✓
New York City	117	19	-0.42	✓
Norwich	115	48	-0.25	✓
Oneonta	100	39	-0.16	
Oswego	118	102	-0.51	✓
Penn Yan	94	28	-0.25	✓
Peru	110	41	-0.13	
Rochester	119	67	-0.0001	
Stillwater res.	104	127	-0.31	✓
Stroudsburg, PA	117	31	-0.44	✓
Syracuse	118	78	-0.43	✓
Tupper Lake	117	64	-0.29	✓
Walton	121	69	-0.26	✓
Watertown	119	59	-0.33	✓
Williamsport, PA	118	30	-0.42	✓

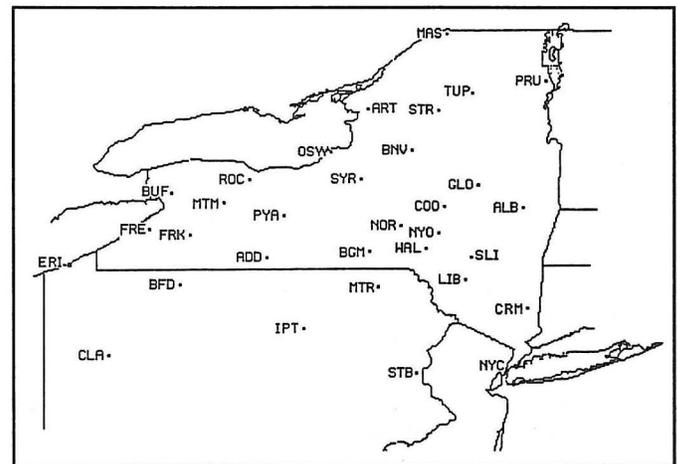


Fig. 1. Stations used in this study. Key to decoding the three-letter identifiers: ADD: Addison, ALB: Albany, BGM: Binghamton, BNV: Boonville, BFD: Bradford PA, BUF: Buffalo, CRM: Carmel, CLA: Clarion PA, COO: Cooperstown, ERI: Erie PA, FRK: Franklinville, FRE: Fredonia, GLO: Gloversville, LIB: Liberty, MAS: Massena, MTR: Montrose PA, MTM: Mount Morris, NYC: New York City, NOR: Norwich, NYO: Oneonta, OSW: Oswego, PYA: Penn Yan, PRU: Peru, ROC: Rochester, SLI: Slide Mountain (snowfall only), STR: Stillwater Reservoir, STB: Stroudsburg PA, SYR: Syracuse, TUP: Tupper Lake, WAL: Walton, ART: Watertown, IPT: Williamsport PA. (Unless otherwise noted as PA, all stations are in New York State.)

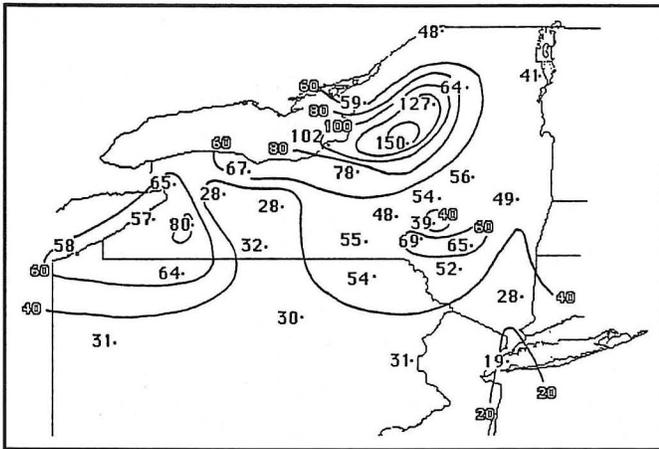


Fig. 2. Total average snowfall in winter, defined as December, January and February. Most stations from 1948 to 1988. Contour interval is 20 inches (20, 40, 60, 80, 100, 120 and 140). Note that Slide Mountain (SLI) is included to better define the Catskill snowfall maximum, although no correlation coefficient was calculated due to data gaps. Values actually located at the station dots.

this three-month period. Albany averages 49 inches and even Liberty, well to Oneonta's south averages 52 inches, 13 inches more than Oneonta.

Lake-effect snowstorms are most likely to develop when there is a strong contrast of lake water and air temperature, among other factors (Dockus 1985). Therefore, winter months with colder than average temperatures might result in greater than average snowfall in the lake-effect belts, over the long term, anyway. Those other factors, like ambient humidity, surface pressure troughs, fetch, etc. can make or break any particular situation, but over the course of 41 winters, one might expect temperature to be negatively correlated with snowfall. It turns out that the majority of the strongly negative correlations in upstate New York are near the lakes (see next paragraph). This suggests the possibility that lake-effect snow is greater during colder-than-average months.

Figure 3 shows the DJF temperature-snowfall correlations. Two areas of correlations were strongly negative in western and northern New York, east of the lakes. The Lake Ontario snowfall maximum in these data occurred at Boonville, probably due to a combination of cold temperatures, upslope and proximity to the open lake water. These last two factors likely also contributed to the Lake Erie snowbelt, maximized at Franklinville on this map. The weak correlation area in western New York corresponds roughly with lower DJF average snow totals (Fig. 2).

Some of the least negative correlations on the map are at Oneonta and Albany. It is well known that lake effect is quite local. Squalls and flurries occasionally reach the Catskills and beyond, but their contribution, typically 0.1–0.5 inches per event, probably would not strongly influence the correlations. On the other hand, coastal storms, often accompanied by rain in near-coastal areas due to the warming effect of the ocean, produce substantial snows inland. Figure 2 shows that Carmel receives 28 inches per winter, compared to New York City's 19. Aided by upslope from the Catskill Mountains, Walton and Slide Mountain show 69 and 65 inches, almost twice Oneonta's 39. It is apparent from Fig. 2 that Oneonta, on the downslope side of the Catskills and far from the Great Lakes, does not get abundant snowfall either from coastal cyclones or from

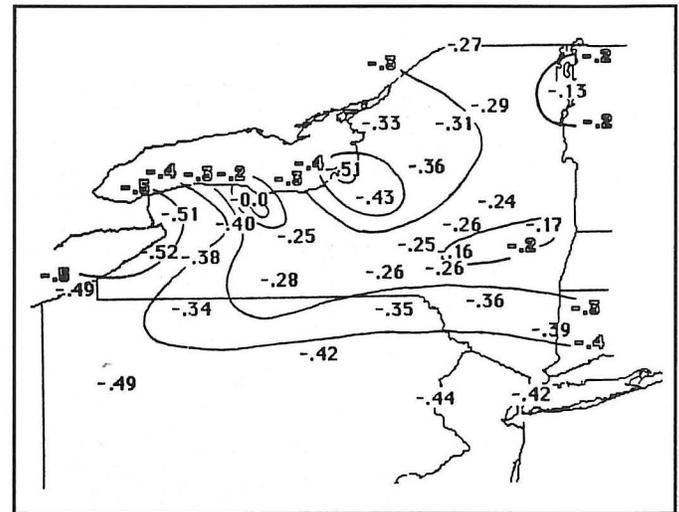


Fig. 3. Results of winter temperature and snowfall correlations. Correlation coefficient contour interval is 0.1 (-0.1, -0.2, -0.3, -0.4 and -0.5). Station values actually located at the decimal points.

lake effect. Kocin's (1995) analysis of snowfall from the 12–14 March 1993 Superstorm even shows a minimum just west of the Catskills.

To illustrate the differences between areas in New York, bar graphs were created from the factors used to calculate the correlation coefficient (1), namely temperatures (x), snowfall (y) and the combination of the two (xy). For negatively correlated values, the signs of x_i and y_i would be opposite so xy would be negative. These graphs are shown in Figs. 6–11. Note that while the ordinate is labeled "Year," the only months plotted were January, February and December, in that order. For example, the first tick on all graphs represents January, 1948 while the last one represents December, 1988. If either the temperature or snowfall was missing (or both missing), a zero bar was plotted, although in the correlation coefficient calculation missing values were simply omitted.

In Fig. 6, the data are shown for Fredonia where the correlation coefficient of -0.52 was the lowest in this study. As can be expected from that correlation, the temperatures and snowfall amounts show a fairly clear inverse relationship (top graph). The bottom graph indicates that most of the Temperature²-Snowfall bars are negative, and the bars of largest magnitude are on the negative side as well. Other graphs in lake-effect areas are very similar, even if Lake Ontario was the source rather than Lake Erie. Oswego in Fig. 7 is an example. However, lake-effect snow from Lake Erie is strongly affected by ice conditions which progress during the winter. On average, by the end of January, Lake Erie is approximately 90% covered with ice in contrast to Lake Ontario which is only about 20% covered by that time (Assel et al. 1983). Figure 4 shows the change that occurs in the normal ice cover on Lake Erie during January. In contrast, Lake Ontario stays mostly ice-free during that time (Fig. 5) and for the entire winter (Assel et al. 1983). It is remarkable that Fredonia should show such a large negative correlation when much of that relationship is probably occurring only during the first part of the winter.

Rochester's graphs (Fig. 8) are shown since this city seemed to show anomalous behavior with a correlation of -0.0001, even though Rochester is close to Lake Ontario and shows considerable snowfall during DJF (Fig. 2). However, the bottom

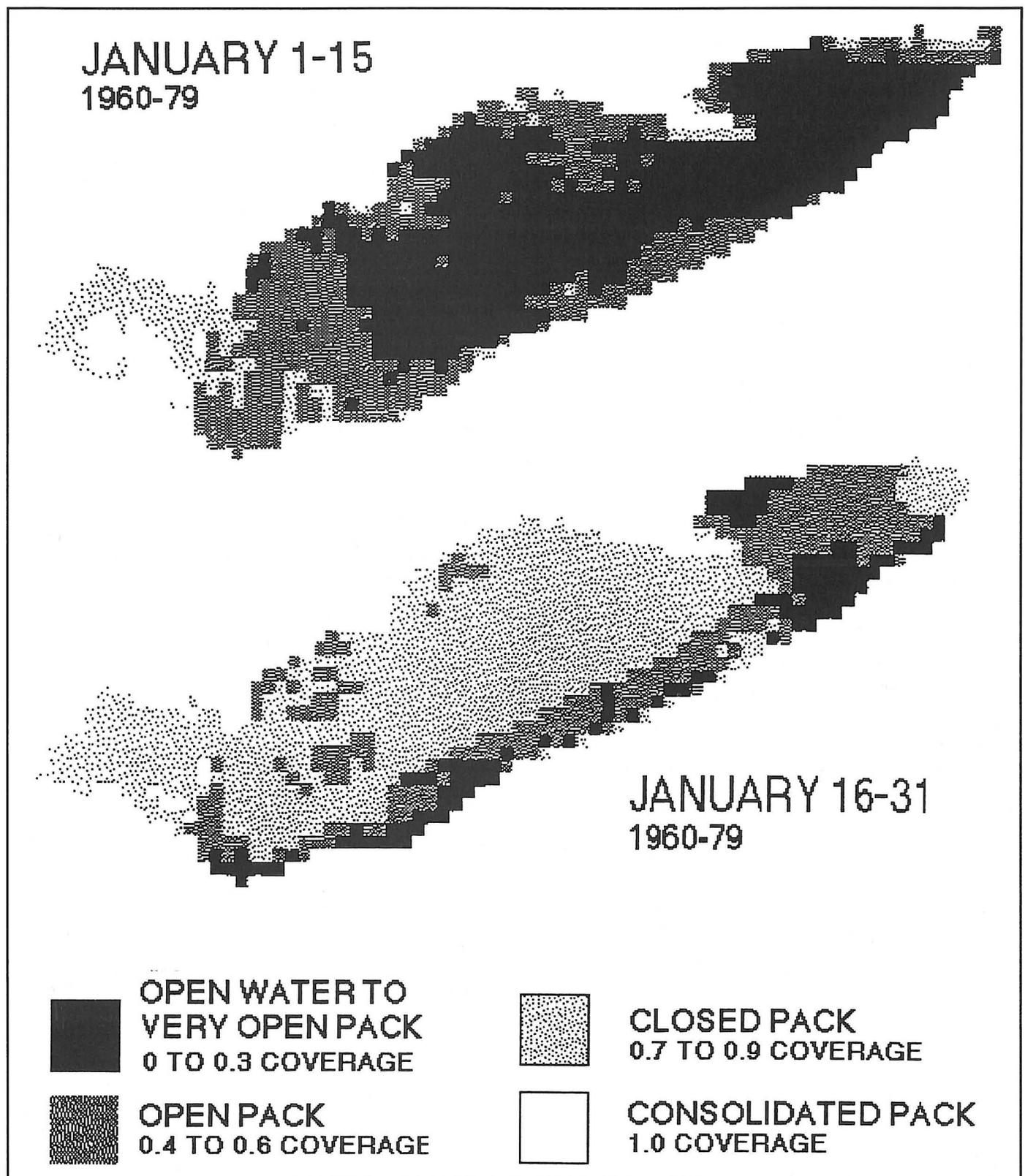


Fig. 4. Normal ice cover on Lake Erie for the periods from Jan 1-15 (top) and from Jan 16-31 (bottom). Data collected during the years from 1960-79. Figure adapted from the Great Lakes Ice Atlas, available from the Great Lakes Environmental Research Laboratory (GLERL), Ann Arbor, Michigan 48104.

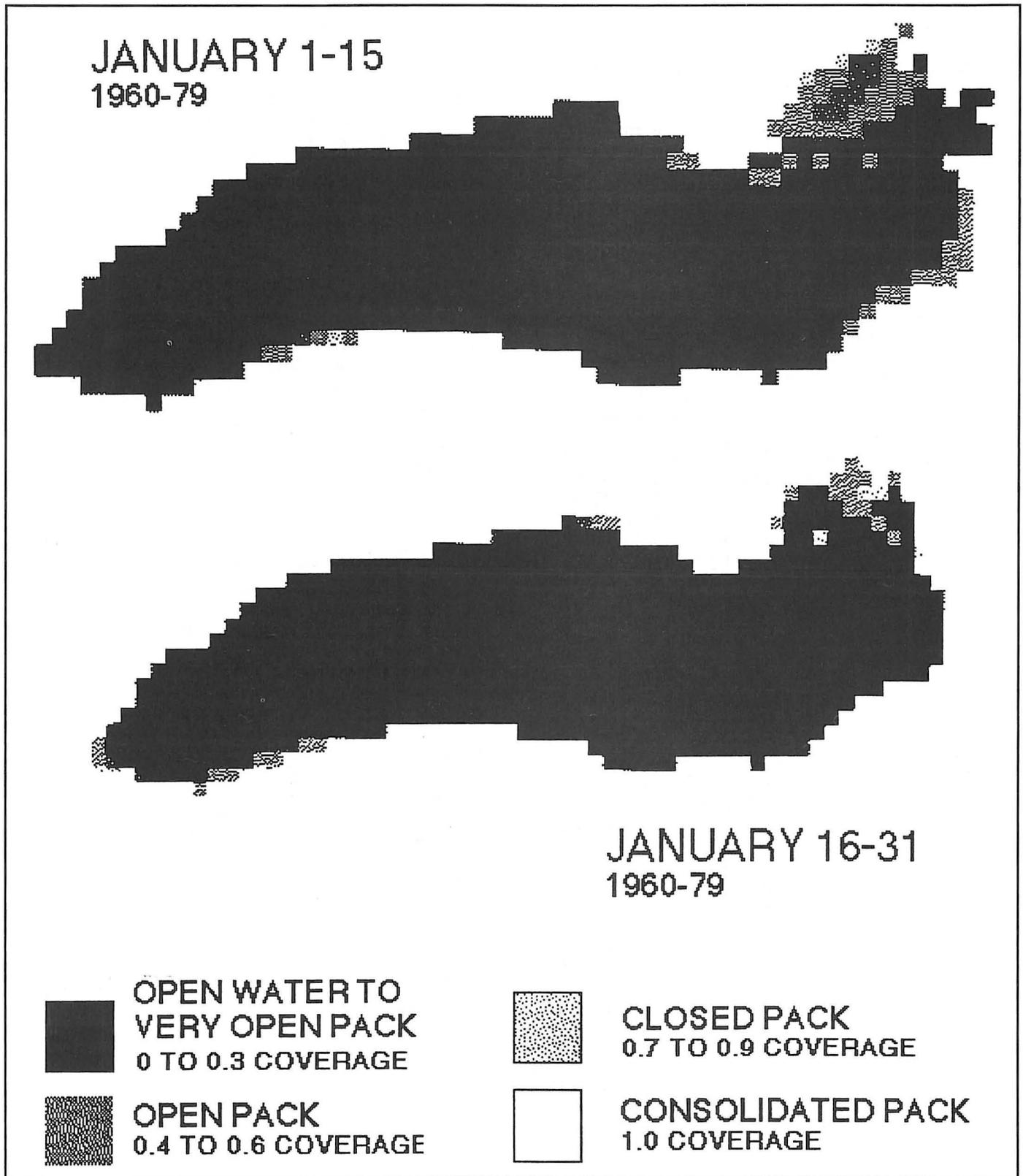


Fig. 5. Same as Fig. 4, but for Lake Ontario.

graph of Fig. 8 shows several large, positive bars which apparently influence the correlation. Without the five largest of those bars, the correlation falls to -0.15 , more consistent with other correlations in that region but still weak. Curiously, those five bars are fairly evenly split between months which were cold and dry (three months) and those which were warm and snowy (two months). Fredonia showed quite a different pattern (Fig. 6). The six largest bars were all negative and of those, five occurred during cold but snowy conditions, i.e., lake effect. Rochester's winters are characterized by strong snowfall with an average DJF snow of 67 inches, but warm, snowy months are almost as likely as cold snowy ones, very unlike the behavior shown in nearby lake-effect areas just west and just east. It may be that Rochester does not experience frequent lake-effect snow but given its proximity to Lake Ontario, no explanation is obvious from this data.

Oneonta's correlation was -0.16 and Oneonta's graphs (Fig. 9) were quite different than those of Oswego, Fredonia or Rochester. Plotted using the same scale as the others, Oneonta's bottom graph of temperatures times snowfall looks quite tame. Only one value exceeded $+100$, in February 1979. In Oneonta's snowiest months, with snowfall above average by 41, 39 and 32 inches, the average temperatures were only slightly above or below the means at $+0.8^{\circ}\text{F}$, -1.3°F and -1.8°F . In Oneonta's coldest months at -12°F , -9°F and -8°F , snowfall was less than average by -11 , -8 and -6 inches. According to Fig. 9, when it gets cold in Oneonta, it just gets cold and dry. Oneonta does not receive a consistent or measurable lake effect.

Cooperstown, NY shows a behavior qualitatively similar to that of Fredonia and Oswego, namely a few large positive Temperature*Snow bars but mostly negative ones, some very strongly negative (Fig. 10). Cooperstown shows fewer snowy events than lake-effect locations but the combination of snow and cold appears to be well established. It appears that at least occasionally, lake-effect snow does dominate Cooperstown's climate. Niziol et al. (1995) discussed two cases in which the east-west oriented Mohawk Valley apparently was the focus for lake-effect snow to reach far from Lake Ontario. Cooperstown is not in the Mohawk Valley, but its snowfall record suggests that some of that far-reaching lake effect does impact the village. Considering Oneonta's substantially smaller average snowfall and weak temperature-snowfall correlation, Cooperstown would appear to be as far from the Mohawk Valley as lake effect can reach on a regular enough basis to affect the monthly totals.

The lake-effect scenario depends on it being cold enough to snow, even during warmer months. In southeast New York, near the Atlantic Ocean, average winter temperatures hover around freezing or just above (Ruffner and Bair 1981). Warmer than normal temperatures probably result in winter rains, rather than snows. Colder than normal temperatures could come from more coastal snowstorms being followed by strong Arctic air. Therefore, again one expects a negative correlation in that when it snows more, it gets cold and when it gets warm, it rains.

With a low average DJF snowfall of 19 inches, New York City would not be expected to show large departures from the snowfall mean and the bottom graph of Fig. 11 certainly shows very low amplitude bars (note the diminished snowfall scale on the upper graph). Most of them were negative. The upper graph temperatures show many strong departures from the means, both positive and negative. They were about evenly divided but cold months with more snow occurred slightly more often than warm months with less snow. New York City does not get anything resembling lake effect and its record is consistent with the coastal snowstorm-Arctic air explanation.

4. Summary and Conclusions

Monthly records of winter temperatures and snowfall at stations in New York and Pennsylvania from January 1948 through December 1988 were correlated. Coherent areas of strongly negative correlations were found in the extreme western part of this region and in the central New York-Tug Hill Plateau area, possibly due to lake-effect snowfall. A broad region of strongly negative correlations was found across northern Pennsylvania and southeastern New York, consistent with the hypothesis that higher winter temperatures result in rain rather than snow.

Two areas of weak correlation were found. One such area extended from Rochester southeastward. Another, more localized region was centered on the western Catskills region around Oneonta. To attempt to explain the weak correlations, individual records of temperature and snowfall were shown for a sampling of stations in the strong lake-effect areas, those upstate stations in weak correlation areas and a downstate station, New York City. The lake-effect records were characterized by large snowfall excursions from the mean and almost universally opposing temperatures, i.e., the signs of the temperature and snowfall observations were almost always opposing. The New York City record showed very small snowfall excursions (since not much snow falls in New York City) but also almost complete opposition between the temperatures and snowfalls. Upstate stations with weak correlations fell into two categories. Rochester, which should have substantial lake-effect snow, had very strong snowfall excursions, typical for a lake-effect station. However, Rochester exhibited several strongly non-lake effect months, with low temperatures correlated with low snowfall or high temperatures correlated with high snowfall. Even with these removed, Rochester's correlation was only weakly negative.

Oneonta, on the other hand, combined snowfall totals and excursions much like downstate areas with its weak correlation. Oneonta's extreme month temperatures and snowfalls tended to be positively as well as negatively correlated. Cooperstown, only 25 miles to the north of Oneonta showed a pattern more characteristic of lake effect. The minimum of snowfall around Oneonta may occur since this station is just beyond the range for measurable lake-effect snowfall while coastal snows may be diminished by downsloping from the Catskill Mountains. This wind-driven explanation, however, cannot be proven with the correlation analysis.

A wind analysis is the logical next step to explain the Oneonta minimum in lake-effect snow correlations in upstate New York. While downsloping may be part of the answer for the western Catskill Mountains, the minimum in west central New York may be related to the wind direction over Lake Ontario during cold air outbreaks. Also, the influence of Lake Huron and especially Georgian Bay snowbands is an important mechanism to investigate and may answer this question about the lake-effect pattern. Finally, this study should be extended to include other months, especially November for lake effect and March for coastal storms.

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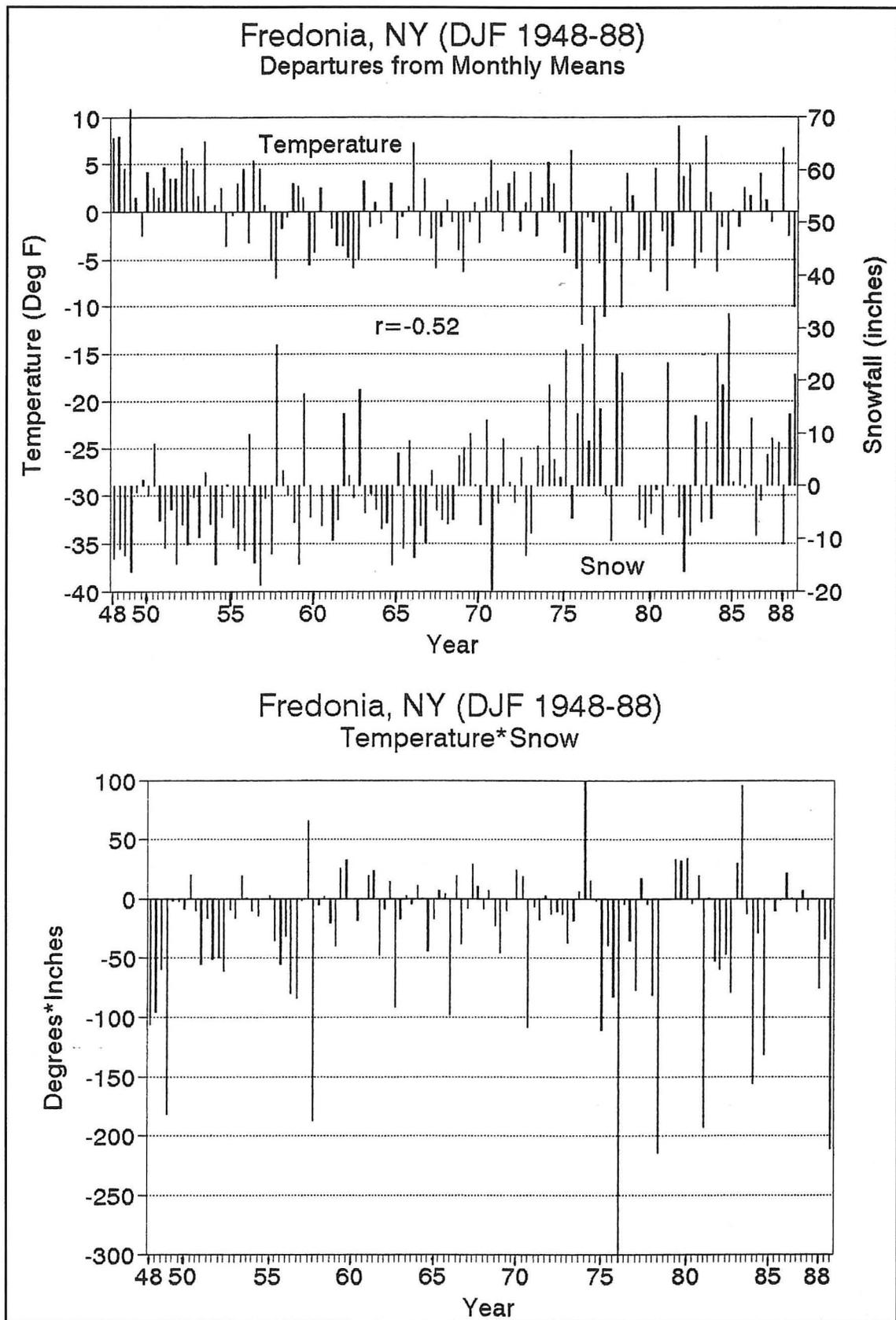


Fig. 6. Top: Monthly observations of temperature and snowfall in winter for Fredonia, N.Y. Monthly means removed (see text). Tick marks represent months January, February and December in that order for the years marked. Larger tick marks represent the January of marked years. Bottom: Product of temperature and snowfall observations. X-axis same as top.

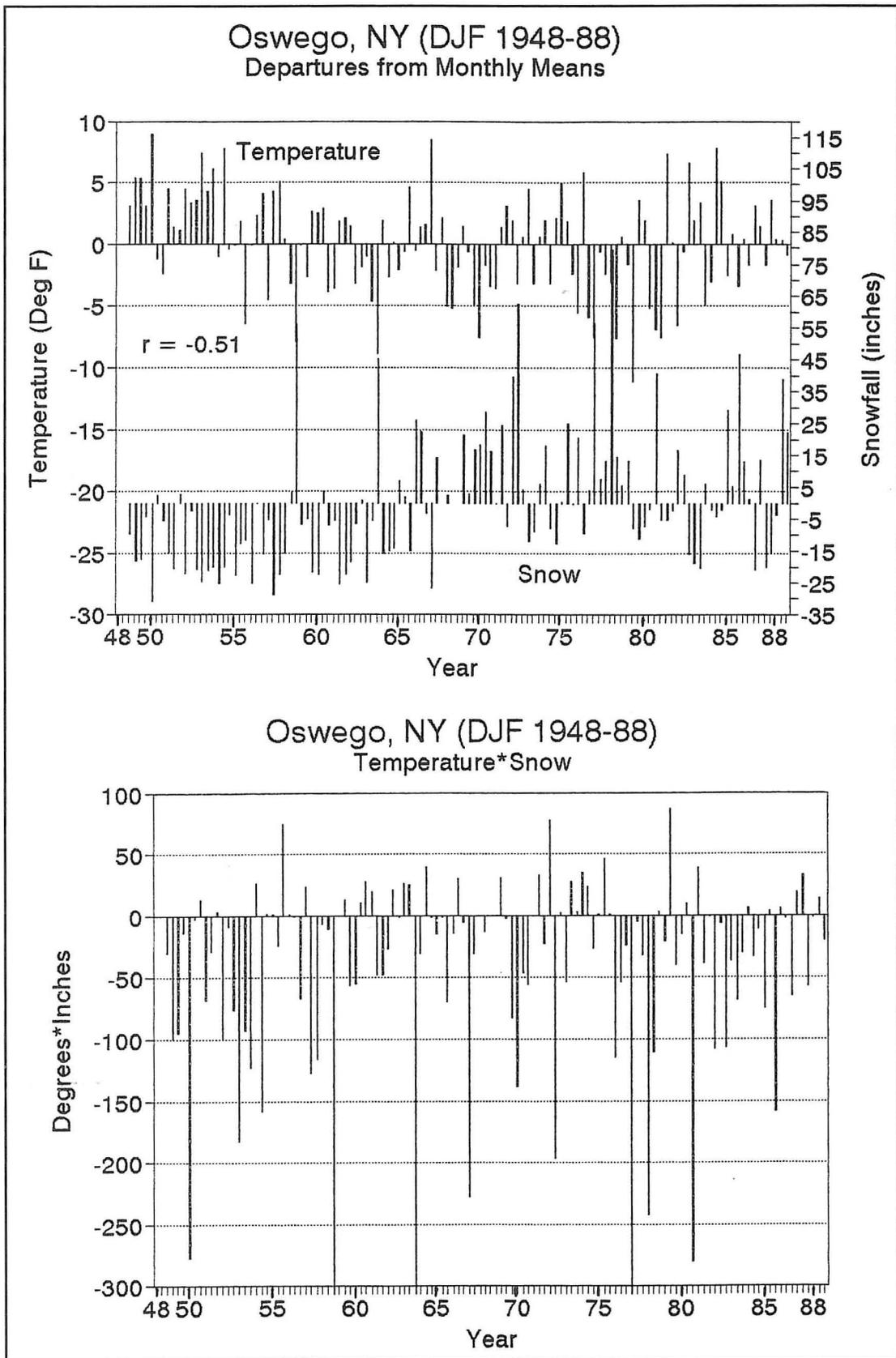


Fig. 7. Same as Fig. 6, but for Oswego, N.Y.

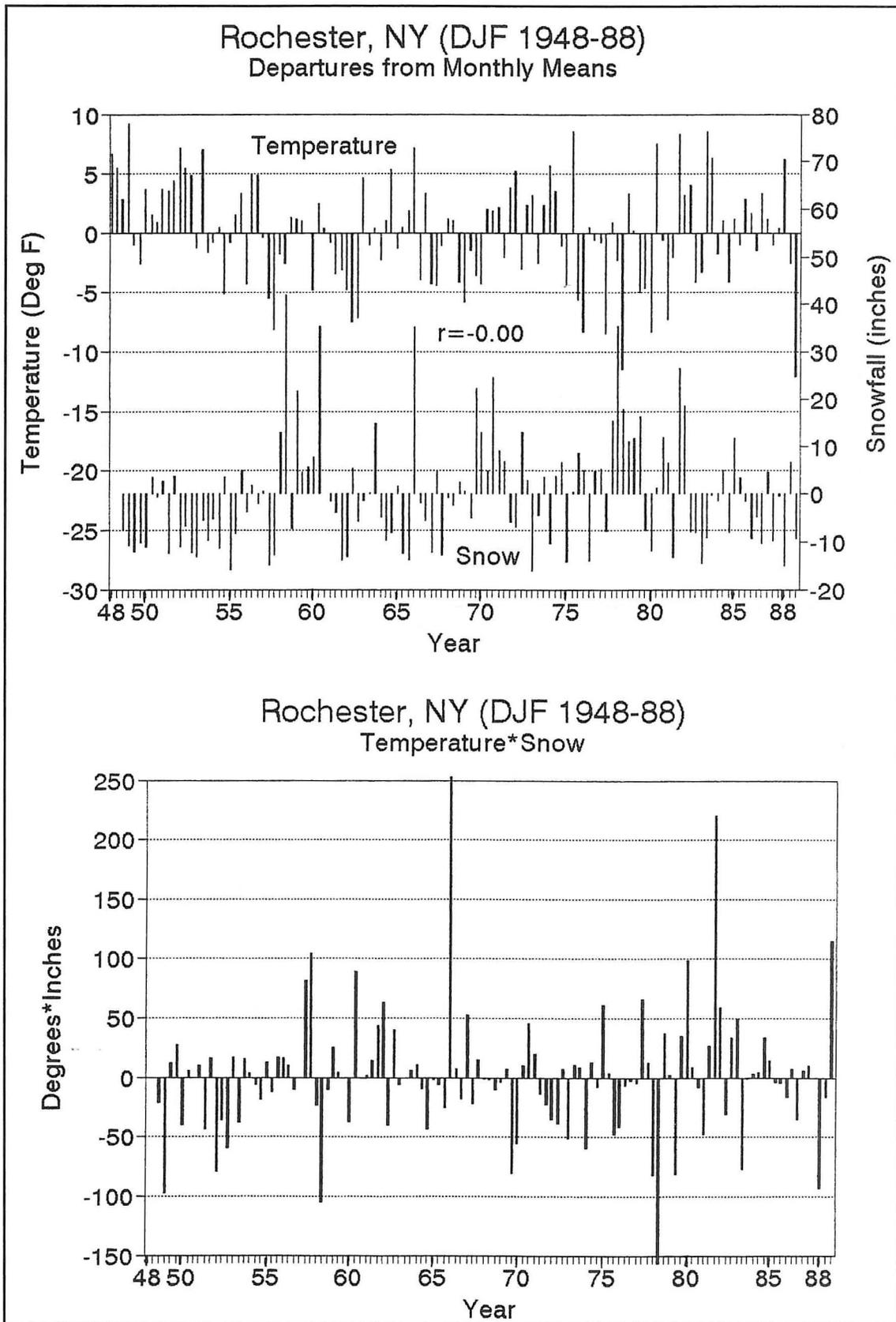


Fig. 8. Same as Fig. 6, but for Rochester, N.Y.

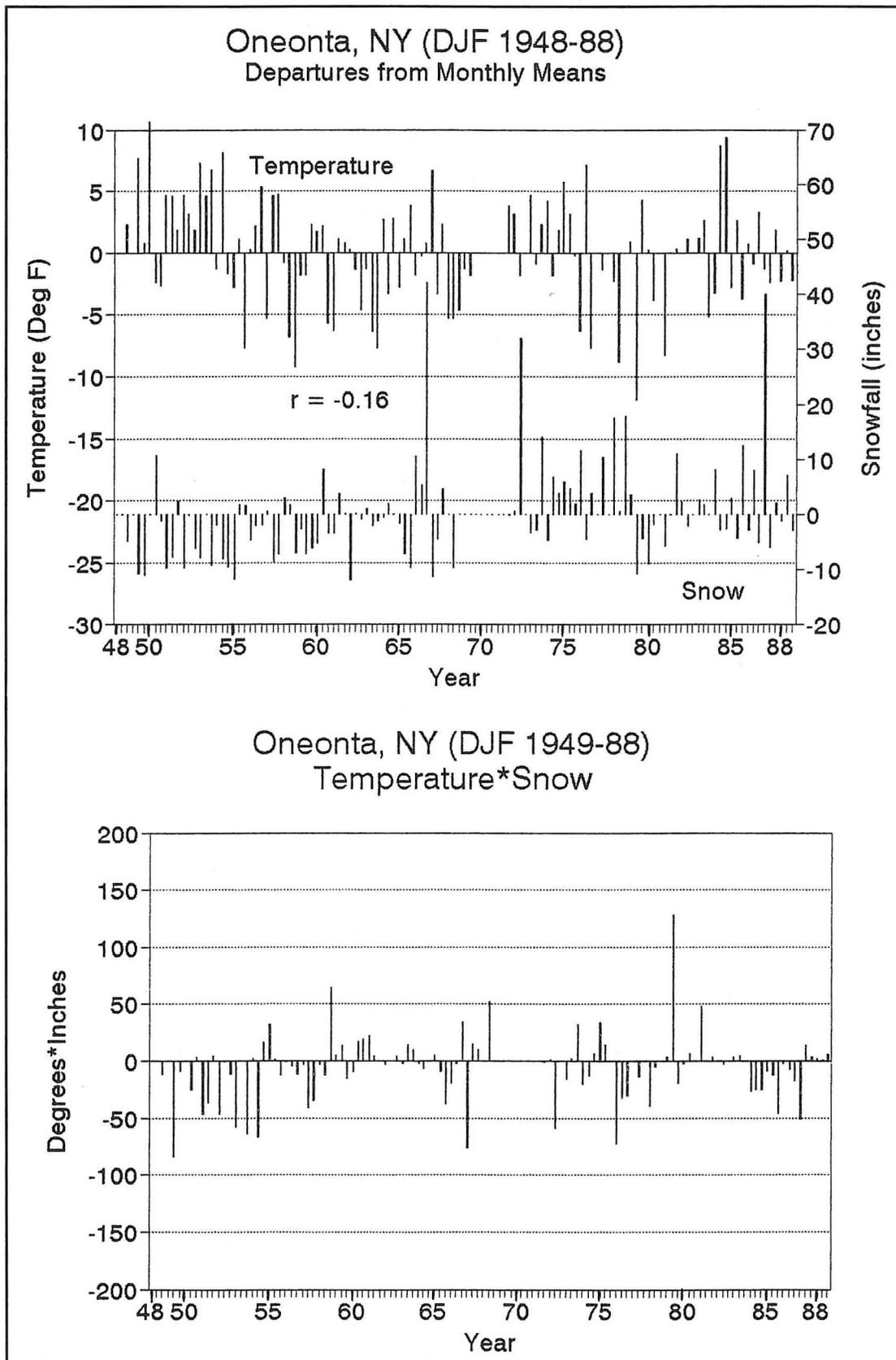


Fig. 9. Same as Fig. 6, but for Oneonta, N.Y.

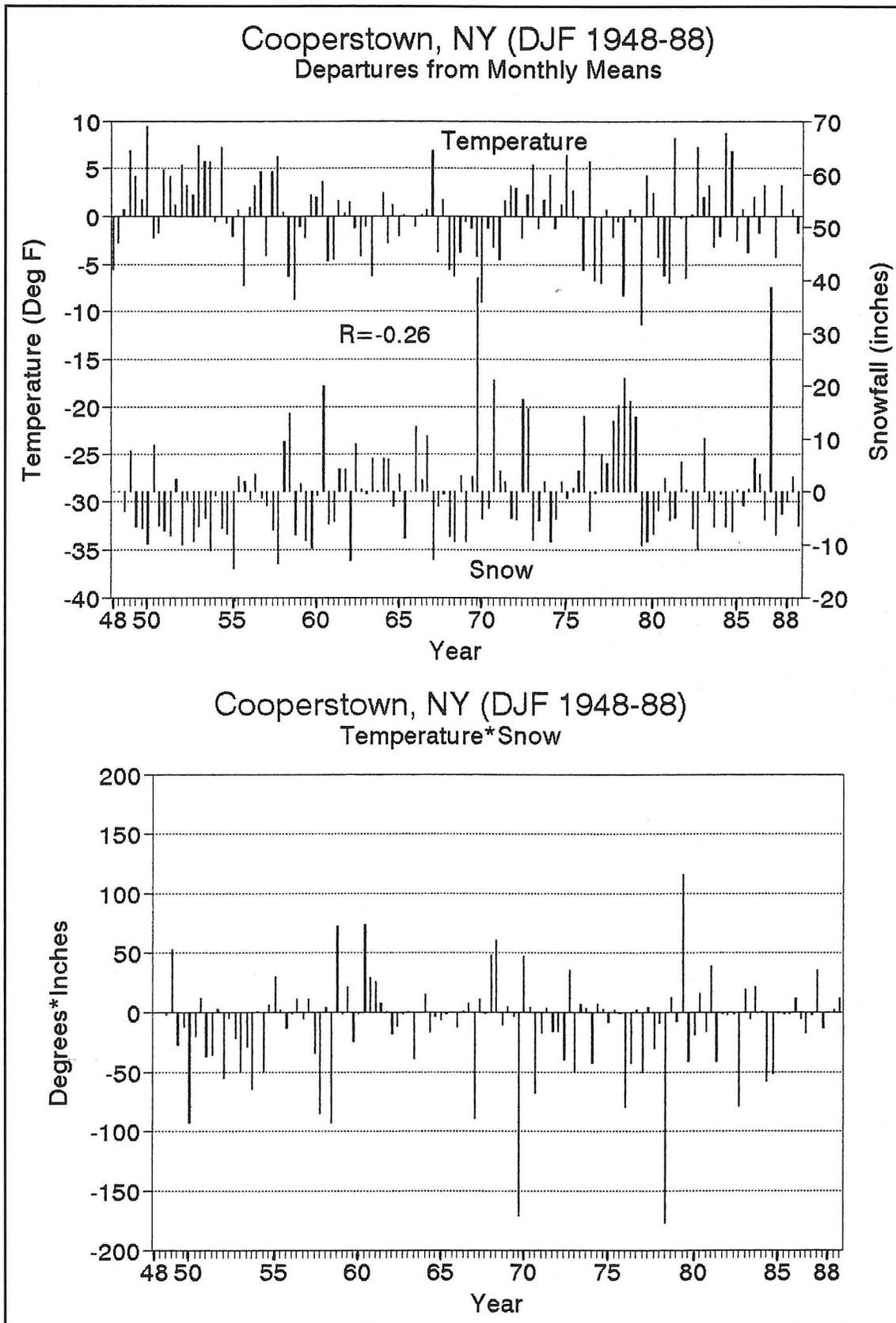


Fig. 10. Same as Fig. 6, but for Cooperstown, N.Y.

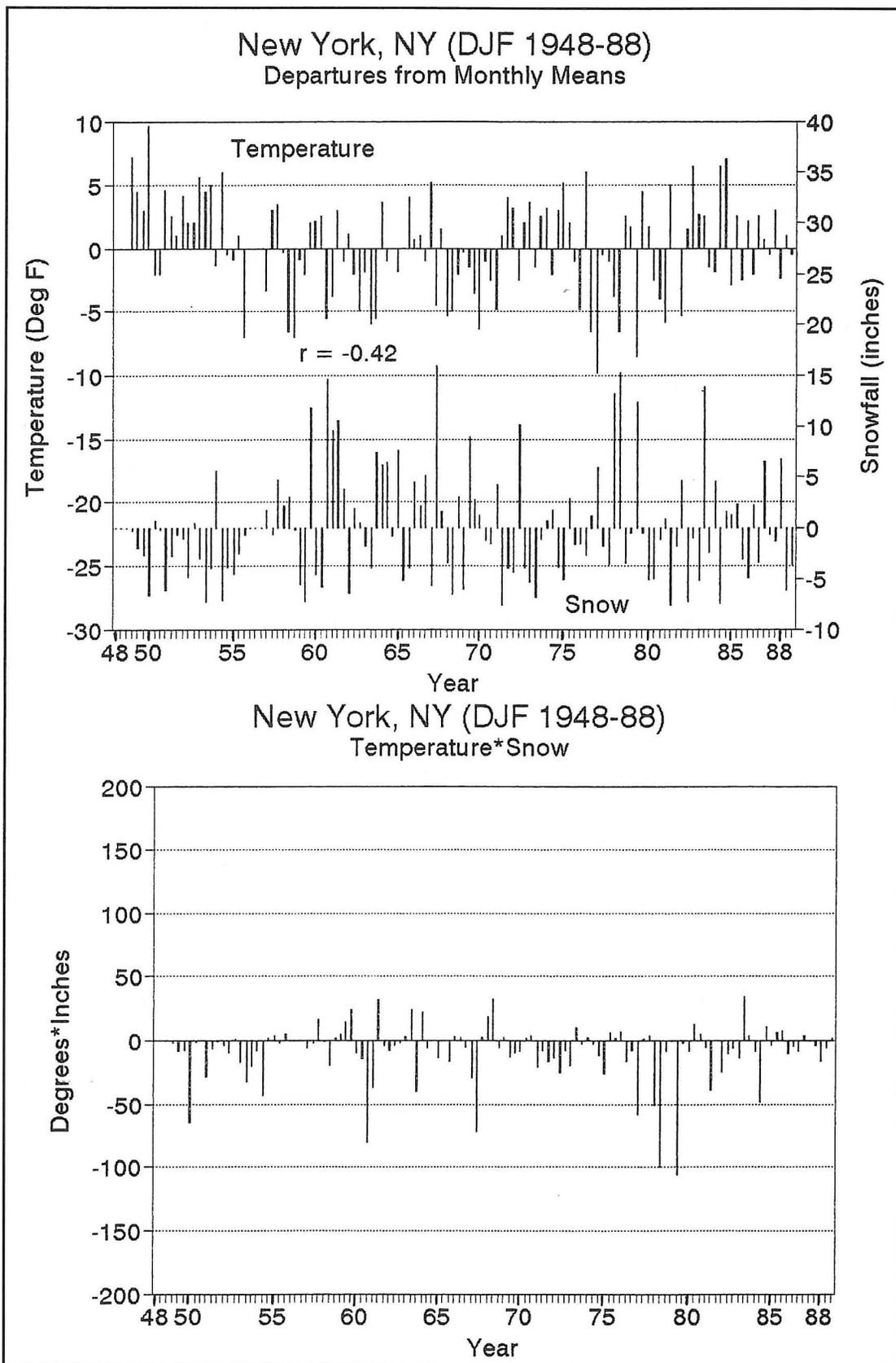


Fig. 11. Same as Fig. 6, but for New York, N.Y.

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