Some Local Climate Trends in Four Cities of New York State

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ABSTRACT

From historical weather records, a preliminary assessment was made of local climate changes in four major urban areas of New York State. Particular emphasis was placed on cold season precipitation and possible relationships to man's activities. Total snowfall was found to have increased significantly from about 1940, the start of a period of sharp increases in urbanization and industrialization. The relationship was merely coincidental, with the underlying cause of snowfall increases due to natural causes, apparently in part to a corresponding decline in ambient temperature. A few climate trends appeared linked to anthropogenic causes, particularly in New York City.

1. Introduction

Man's activities have been suspected of affecting local climate for many decades. In 1929 Ashworth published an article on increases in rainfall due to smoke and hot gases from factories. Studies of climate change have been numerous in the last decade. The findings provide rather convincing evidence that urbanization can affect local weather and climate. Changes in local temperature, precipitation, winds, cloudiness, atmospheric turbidity and visibility have all been documented (e.g., Bornstein, 1968; Changnon, 1968; Lawrence, 1969; Hobbs *et al.*, 1970; Huff and Changnon, 1973; Landsberg, 1974; METROMEX, 1974, 1978).

Most of the studies have focused on summer or yearly climate. Huff and Changnon (1973) analyzed seasonal precipitation trends in and downwind of eight urban areas of the United States and found 1) significant precipitation enhancement associated only with the six larger cities and 2) greater summertime increases. Frederick (1970) compared "cool" season precipitation (October–March) with "warm" season precipitation at 22 Weather Bureau Stations in the eastern United States (1912–61). He found that while warm season precipitation was randomly distributed according to day of the week, cold season precipitation was not; furthermore, there was a minimum of precipitation on Saturdays, Sundays and Mondays. Frederick suggested that man's activities in connection with urbanization patterns were responsible for the non-random distribution. Specific cases of locally-induced light snowfalls have also been reported (e.g., Culkowski, 1962; Agee, 1971).

Causes usually cited for urban-induced precipitation, if evident at all, are increased heating and thermal buoyancy, altered surface roughness, release of cloud-nucleating particles (giant condensation and/or ice nuclei), and the emission of water vapor and other gases.

The object of this study was to determine from historical weather data whether any discernible changes in climate—particularly snowfall—in New York State might have been brought about by urbanization. Four urban cities—New York City, Buffalo, Syracuse and Albany—were chosen for study. Where possible they were compared with both rural control stations and downwind stations to better separate the effects of the city on the climate from natural climatic variations.

2. Approach

Perhaps the most powerful method of studying local climate changes involves an intensive measurement network operated over a lengthy period of time in a given area [e.g., the METROMEX Project at St. Louis, Illinois (Braham, 1977; Changnon *et al.*, 1977)]. Second, the case study approach can be fruitful in somewhat unique areas like Washington, DC, where numerous weather stations and extensive recorded variables for analysis exist (Harnack and Landsberg, 1975). Analysis of historical weather record data for a station, while often less definitive, is simple, inexpensive and generally recommended for preliminary assessments. The latter method was employed here, bolstered by control stations and cities with records dating back to 1900. Obviously, small-scale urban effects and interstation anomalies, if they exist, would not be detected. Trends ob-

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TABLE 1. Urban areas and rural controls.

Urbanized areas				Rural controls
City	Counties in urbanized area	Area (km²)	1970 population density (number km⁻²)	Town
Albany	Albany, Rensselaer, Schenectady	3620	166	Gloversville 55 km NW
Syracuse	Onondaga	2056	230	Baldwinsville 16 km NW
Buffalo	Erie	2740	406	Fredonia 58 km SW
New York City	Bronx, Kings, Nassau, New York, Queens, Richmond, Rockland, Westchester	3128	3340	Mohonk (New Paltz) 92 km NNW

served and conclusions reached must be viewed accordingly.

The four urban cities mentioned each have a first order National Weather Service (NWS) station and these were used to establish the 75-year weather data-bases. Each station, in general, is centrally located within the county or counties indicated in Table 1. Weather data from control stations consisted of NWS cooperative observations from adjacent rural towns relatively remote from the city locations. Non-weather data (e.g., population, manufacturing wage earners, etc.) were compiled for the entire urbanized area listed; this better reflects the overall demographic picture and incorporates the pronounced shift of people and light industry to the suburbs after 1945–50.

As shown in Table 1, the four urban areas vary considerably in population density as well as climate type. New York City is obviously the most urbanized region and unique in that the area is influenced by the Atlantic Ocean. Buffalo's climate is affected by the Great Lakes. In addition, it has approximately twice the population of the Syracuse and Albany areas. These inland cities are both relatively less urbanized, particularly Albany.

Many different weather parameters were included

TABLE 2. Urban area climate trends.

Station	Element	Overall mean	Slope–decade change (1900–39) Period I	Slope–decade change (1940–75) Period II	Correlation coefficient Period I	Correlation coefficient Period II	Scatter s Period I	Scatter s Period II	Student t-test significance of means from period I to period II (0.05 level)
NYC	TEMP	12.2°C	+0.19	+0.02	0.53	0.10	0.31	0.24	Yes
NYC	SNOW	71.4 cm	−6.9	−3.6	−0.43	−0.20	15.0	18.3	No
NYC	PREC	110 cm	+0.48	+2.5	0.09	0.21	5.6	12.4	Yes
NYC	PREC-W	56.9 cm	+0.53	+0.38	0.10	0.05	5.8	8.6	
NYC	PREC-C	53.1 cm	0	+2.5	0	0.45	3.3	5.3	
NYC	DAYS-1	9.9	−0.57	+0.25	−0.47	0.11	1.1	2.5	No
BUF	TEMP	8.6	+0.08	−0.08	0.25	−0.22	0.34	0.39	Yes
BUF	SNOW	204	−14.7	+13.0	−0.56	0.40	23.1	31.0	Yes
BUF	PREC	86.6	−5.6	+1.5	−0.76	0.26	5.1	6.1	Yes
BUF	PREC-W	42.4	−3.3	+2.5	−0.72	0.63	3.3	3.3	
BUF	PREC-C	44.2	−2.2	−0.89	−0.57	−0.18	3.3	5.3	
BUF	DAYS-1	4.0	−0.53	+0.16	−0.43	0.28	1.2	0.58	Yes
SYR	TEMP	8.7	+0.53	−0.19	0.78	−0.54	0.40	0.31	No
SYR	SNOW	231	−6.9	+21.6	−0.39	0.68	15.5	24.9	Yes
SYR	PREC	91.7	+2.2	+1.9	0.33	0.19	5.8	10.2	Yes
SYR	PREC-W	47.8	+0.03	+2.4	0	0.29	4.3	8.1	
SYR	PREC-C	43.9	+2.2	−0.53	0.67	−0.19	2.3	3.0	
SYR	DAYS-1	4.9	−0.44	+0.31	−0.35	0.21	1.1	1.5	Yes
ALB	TEMP	8.9	+0.28	−0.17	0.71	−0.57	0.29	0.27	Yes
ALB	SNOW	135	−5.8	+21.3	−0.47	0.90	11.7	11.2	Yes
ALB	PREC	85.3	+3.3	+0.48	0.63	0.06	4.3	8.4	Yes
ALB	PREC-W	47.0	+0.91	−1.5	0.27	−0.28	3.6	5.3	
ALB	PREC-C	38.4	+2.1	+2.0	0.66	0.47	2.5	3.8	
ALB	DAYS-1	5.4	+0.34	−0.11	0.54	−0.08	0.51	1.6	No

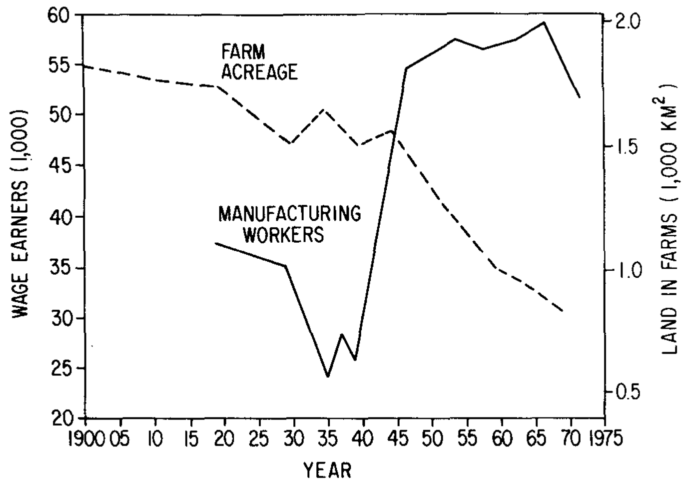

FIG. 1. Number of manufacturing wage earners and farm acreage in Syracuse (1900–75).

in the study to aid in verification of trends. The principal variables were as follows:

TEMP	average annual temperature
SNOW	total snowfall in a calendar year
PREC	total precipitation (rain and melted snow) in a calendar year
PREC-W	warm season precipitation; includes months May–October
PREC-C	cold season precipitation; includes months January–April and November and December
DAYS-1	total number of days in a year with precipitation > 1.0 inch (2.54 cm).

The urbanization variables included area population, number of manufacturing workers, number of motor vehicles, farm acreage and airline traffic.

All the variables were analyzed as a function of time, and linear regression lines were fit to the time series data. Five-year running means were used. The data trends were determined for the time period 1900–75 and for the subintervals 1904–39 (period I) and 1940–75 (period II). Period I data represent a time of minimal urbanization effects for each station. In the context of this study, period II is most important in that it marks the dramatic increase in urbanization from about 1940 that occurred in New York State and elsewhere (e.g., see Fig. 1 for Syracuse).

The standard correlation coefficients of each linear regression line (trend or slope) was determined, as well as the scatter s as given by Panofsky and Brier (1968)

$$s = [\Sigma(\hat{y} - y)^2/n]^{1/2},$$

where $\Sigma(\hat{y} - y)^2$ is the sum of the squared deviations from the trend line. Parallel lines at a distance equal to the scatter would include 68% of the data points

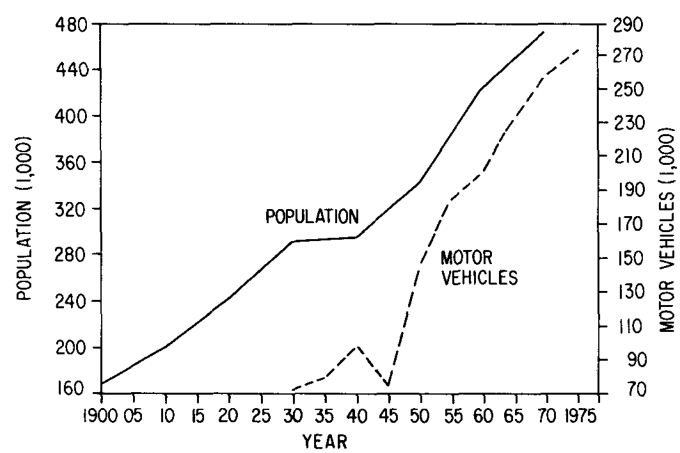

FIG. 2. Population and number of registered motor vehicles in Syracuse (1900–75).

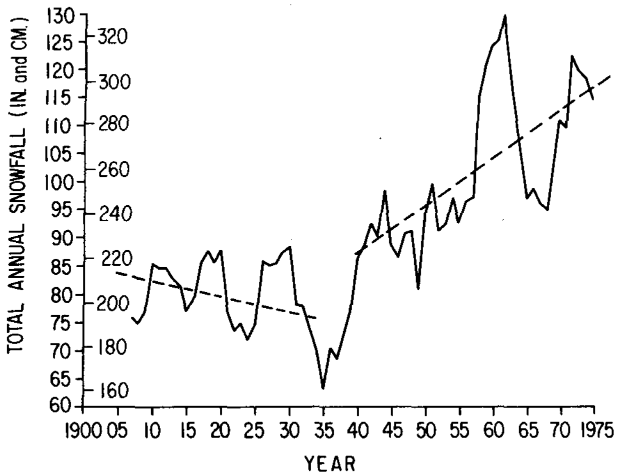

FIG. 3. Annual snowfall for Syracuse (1900–75, 5-year running means).

(directly analogous to standard deviation). Comparisons between trends for the weather variables and urbanization variables were made. For more detail the reader is referred to Jones (1977).

3. Results

a. Weather and urban data

Table 2 shows for each of the four major cities during the two time periods the time variation of the weather variable slope (change in variable per decade), the respective correlation coefficients, scatter and mean value (entire 75-year period). As an example, the temperature trend lines at Albany indicated an increase in temperature (+0.28°C per decade) from 1900–39 and a decrease (−0.17°C per decade) from 1940–75, with respective time series correlation coefficients of +0.71 and −0.57, respectively. The mean temperature over the 75 years at Albany was 8.9°C, and the mean temperature change between period I and period II was significant at the 0.05 level based on the Student two-tailed t-test (last column).

Scanning the table of weather variables and trends, it is evident that the correlation coefficients for the linear regression lines versus time are generally not high. This perhaps is not surprising considering the high degree of variability of weather elements, even with some smoothing provided by the 5-year running mean approach. For each time period, a correlation coefficient of ~0.32 would be considered significant at the 0.05 level (Brooks and Carruthers, 1953). Certain trends are worth noting.

1) During period I, the temperature trends were increasing (positive) at all four cities, consistent with well-known general warming in the Northern Hemisphere at that time. Conversely, during period II (1940–75), N.H. cooling was reflected at all three cities (and all rural control areas) except New York City.

2) In period I all four cities had negative (decreasing) snowfall slopes. In period II New York was the only city with a negative snowfall slope, while snowfall trends were rather dramatically increasing at the other three cities. Also, while Albany, Buffalo and Syracuse had overall increases in annual precipitation totals, New York City had a negative trend.

3) Warm and cold season precipitation and number of days with more than 0.1 inch (0.254 cm) of precipitation (not shown) had inconsistent information

FIG. 4. Annual snowfall for Buffalo (B) and control town Fredonia (F), 5-year running means.

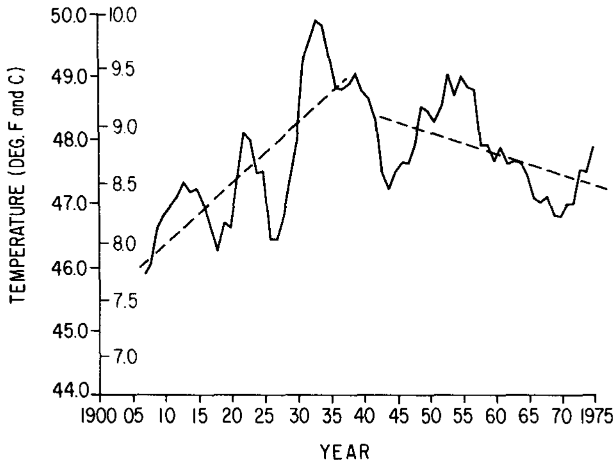

FIG. 5. Annual temperature for Syracuse (1900–75, 5-year running means).

for the two time periods, and no general pattern was evident. Warm season precipitation did evidence an increase (large positive slope) during the period II at Buffalo and Syracuse.

4) The last category, the number of days with more than 1 inch (2.54 cm) of precipitation, may also be thought of as a measure of convective activity. It is seen that, with the exception of Albany, all cities showed negative slopes of period I and positive slopes in period II. Albany, the least urbanized area, showed opposite trends.

b. *Correlations of weather variables and urbanization parameters*

Figs. 1 and 2 depict the non-weather or urbanization trends from 1900–75 for Syracuse. The other three urban areas considered were very similar (Jones, 1977). During period II (1940–75) the steady increase in population and number of motor vehicles, with a corresponding decrease in farm acreage, is quite evident and of no surprise to followers of demographic trends.

Each of the four main weather parameters discussed was linearly regressed against the four urbanization parameters for period II. The regression line slopes and correlation coefficients of the weather variables versus area population and total manufacturing wage earners are typical and are shown in Table 3. Snowfall, our variable of most concern, and temperature yield the stronger trends. For example, snowfall at Albany can be thought of as showing an increase of 14.2 cm for every 1000 manufacturing workers added with a correlation of 0.90. Similarly, Buffalo and Syracuse indicate comparable trends (New York City does not).

The yearly snowfall trend for Syracuse is illustrated in Fig. 3, showing the rather dramatic increase since 1935–40, the inception of steep industrialization growth. Note the relatively high correlation of snowfall with population and with manufacturing workers in Table 3 particularly for Syracuse and Albany.

Thus, one might ask whether snowfall is being increased anomalously in such urban areas, as suggested, or is this a "nonsense" correlation? We conclude the latter based on examination of all the data and the *decisive* fact that rural control stations (such as Gloversville and Fredonia) showed very similar trends. From Fig. 4 the annual snowfall at Buffalo and its control station, rural Fredonia, follow very similar patterns, and in particular a general increase in snowfall amount since 1940. A very com-

FIG. 6. Annual temperature for Buffalo (B) and control town Fredonia (F), 5-year running means.

TABLE 3. Correlation of weather parameters with urban area population and manufacturing wage earners, 1940–75 (city, left columns; rural control, right columns).

Weather	Population		Factory workers		Population		Factory workers	
	Slope*	CC**	Slope*	CC**	Slope*	CC**	Slope*	CC**
	New York City				*Mohonk*			
TEMP	0 C	0.10	0.0002 C	0.10	−0.0002 C	−0.53	−0.001 C	−0.53
SNOW	−0.005 cm	−0.20	−0.033 cm	−0.20	0.033 cm	0.76	0.196 cm	0.76
PREC	0.005 cm	0.21	0.023 cm	0.21	−0.003 cm	−0.11	−0.013 cm	−0.11
DAYS-1	0.0004	0.11	0.002	0.11	−0.0004	−0.18	−0.002	−0.18
	Buffalo				*Fredonia*			
TEMP	−0.001 C	−0.22	−0.008 C	−0.22	−0.001 C	−0.38	−0.016 C	−0.38
SNOW	0.117 cm	0.41	1.33 cm	0.40	0.069 cm	0.32	0.795 cm	−0.32
PREC	0.013 cm	0.26	0.155 cm	0.26	−0.015 cm	−0.35	−0.160 cm	−0.35
DAYS-1	0.001	0.28	0.016	0.28	−0.001	−0.10	−0.009	−0.10
	Syracuse				*Baldwinsville*			
TEMP	−0.003 C	−0.54	−0.028 C	−0.54	—	—	—	—
SNOW	0.353 cm	0.68	3.23 cm	0.68	—	—	—	—
PREC	0.030 cm	0.19	0.279 cm	0.19	0.010 cm	0.08	0.089 cm	0.08
DAYS-1	0.005	0.21	0.045	0.21	—	—	—	—
	Albany				*Gloversville*			
TEMP	−0.004 C	−0.57	−0.115 C	−0.57	−0.006 C	−0.68	−0.163	−0.68
SNOW	0.467 cm	0.90	14.2 cm	0.90	0.457 cm	0.81	13.8 cm	0.81
PREC	0.010 cm	0.06	0.328 cm	0.06	−0.041 cm	−0.19	−1.19 cm	−0.19
DAYS-1	−0.002	−0.08	−0.073	−0.08	−0.020	−0.47	−0.594	−0.47

* Regression line slope represents change in weather variable per 1000 people.
** CC indicates correlation coefficient.
No entries indicated an inadequate data record.

parable dual trend for Albany and its Gloversville control was observed.

A more reasonable hypothesis to explain at least part of the snowfall trend is suggested by the corresponding temperature patterns. Decreasing temperature trends at three of the four cities are associated with increasing snowfall amounts since 1940 (e.g., Syracuse, Fig. 5; Buffalo and Fredonia, Fig. 6). Conversely, New York City evidenced no such temperature decline and correspondingly no enhancement of snowfall. During the earlier turn of the century (period I) the opposite was true at all four cities: increasing temperature trends and decreasing winter snowfall amounts (Table 2).

Total cold season precipitation does not show any strong consistent pattern between the two periods and for the various regions studied. Thus, a lowering of temperature appears to influence mainly the phase of the precipitation, i.e., more of the precipitation falls as snow. This inverse temperature-snowfall relation was particularly pronounced at Albany, with the two variables during period II yielding a correlation coefficient of approximately −0.60 (significant at the 0.01 level).

Total annual precipitation shown in Table 3 indicates an increase (positive slope) at three of the cities with decreases (negative slopes) at the control towns. The fourth pair—Syracuse and Baldwinsville—suggest a much weaker increase at the control town although at a low significance level. This observation taken in conjunction with the previously noted (Sections 3a, 3c and 3d) indications of enhanced convective activity may be suggesting some selective inadvertent increase of urban precipitation during the summer season. More data and additional study approaches would be required to verify the reality of such a trend.

One might speculate as to why New York City temperature and snowfall patterns have run counter to the other city trends since 1940. The heat island effect for urbanized areas is well documented (e.g., Kopec, 1970; Bornstein, 1968; Peterson, 1969); that such heating could completely nullify the general Northern Hemisphere cooling over this period would be impressive. The City's coastal location and maritime influence may also play a moderating role, although nearby Setaucket, Long Island (55 km east-northeast of New York City) evidenced cooling during the same period. As mentioned, snowfall at New York City has not increased in the recent period and, in fact, has shown a decline (at a low significance level). The noted link with temperature is suggested.

4. Concluding remarks

Four urban areas in New York State were examined for the possibility of man-made modification of the climate since 1900. Albany, Syracuse, Buffalo and New York City were each studied for changes in snowfall, temperature and seasonal precipitation. Without considering control stations, one might have been deluded into associating observed pronounced increases in snowfall at the first three cities since 1940 with enhanced urbanization.

Some of the main conclusions of this study are as follows:

1) Increased snowfall trends in Buffalo, Syracuse and Albany were due to natural causes, presumably in part to decreased temperatures at these stations.

2) Only New York City experienced increased local temperatures (counter to the Northern Hemisphere trend) and decreased snowfall amounts since 1940. Anthropogenic causes are suggested.

3) Total cold season precipitation showed no significant changes with degree of urbanization. Warm season convective precipitation, as reflected by the number of heavy rainfall days during the latter half of the study generally appeared to show such a change; the exception was Albany, the least urbanized city of the four.

4) Thus a distinct possibility exists that a *few* of the local climate changes noted in the four urban areas studied have been induced by man's activities. With the possible exception of New York City, however, natural rather than anthropogenic causes generally are indicated.

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