Possible Urban Effects on Maximum Daily Rainfall at Paris, St. Louis and Chicago

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ABSTRACT

The seasonal maximum daily rainfall values for the 1871–1970 period at these three large cities in different climates were studied to discern trends. Upward trends of 19–38% were found in the warm season values at all cities, but no significant up or down trends were found in the cold season values. The upward trends in the warm season appear to reflect both natural climatic changes and inadvertent urban effects on local convective precipitation.

1. Introduction

In the last decade many studies have revealed evidence of the urban effects on the climate of cities (Landsberg, 1970). Considerable attention has been focused on potential urban-related changes in cloud and precipitation process (Changnon *et al.*, 1971). Urban-altered climate is an important problem because the climatic anomaly is city-size or larger, and up through the year 2000, urbanization is expected to increase. Some experts think that within 25 years, more than 80% of the people of industrialized countries will live in cities.

For some meteorological parameters, excellent definitive results and realistic predictive models of urban effects now exist. For instance, the urban heat island is well known. Its causes are well understood and there is good agreement between results from a large number of cities of varying sizes.

A less well established relationship concerns the urban effect on precipitation. Results differ between cities, and apparent urban-related changes are not always convincing because of the complex coupling between surface conditions and the cloud levels and rain processes. Certainly, studies of city influence on rainfall processes face further difficulties because of possible spatial differences in rain due to catchment differences between raingages and their sites, and the considerable natural variability of rainfall. As yet, we do not know specifically how various urban-related processes modify the rainfall regime in and near cities. The suspected effects have included the effect of the heat island, atmospheric pollutants, roughness, turbulence, etc. Results from METROMEX (Semonin and Changnon, 1974) suggest that all these effects are active in influencing convective processes at St. Louis.

2. Precipitation data for Paris, St. Louis and Chicago

An analysis of a time series of precipitation values for three cities with apparently good 100-year (1871–1973) measurements has furnished interesting new results about possible shifts in heavy daily rainfalls in urban areas. A brief summary of the three stations and cities investigated follows.

1) PARIS. In 1871 the Montsouris Observatory station was in the south of Paris, which had a population of 2.0 million, and the site was quite near the open country. By 1970, the Montsouris Observatory was near the center of greater Paris (city and suburbs) with more than 8.0 million people.

2) ST. LOUIS. The official weather station was in the downtown business area from 1871, when the urban population was 310 000, through 1954 when it was moved 19 km to the northwest edge of the city suburbs. In 1954 the metropolitan population was 1.3 million and it grew to 1.5 million in 1970.

3) CHICAGO. The official weather station was in the downtown business district from 1871, when the population was 300 000, through 1925 when the station was moved 9 km south to the University of Chicago, which was still well within the central urban area. In 1942, it was moved 13 km west to the Midway Airport which was in the mixed industrial and residential zone of the city. The 1970 metropolitan population was 7.4 million.

3. Results of the time-series analyses

The characteristics of the time-series results for the maximum daily rainfall amounts during warm and cold seasons of each year are summarized in Table 1. The maximum daily rainfall value each season was chosen for investigation because it is a readily available value in historical records and it is a value often used in hydrologic designs. The warm season was May–October in Paris and April–September in Chicago and St. Louis, and the cold season was November–April in Paris and October–March in Chicago and St. Louis. Analyses were performed for the various periods defined by the raingage relocations at both Chicago and St. Louis.

TABLE 1. Goodness of fit probabilities for the normal distribution and the trends in the maximum daily rainfall and their significance.

	gfp for normal	Trend b (mm)	Standard error of b	Two-tail probability that trend results from chance
		Warm season		
Paris (1874–1973)	0.01	0.100	0.043	0.020
St. Louis (1871–1954)	>0.20	0.262	0.141	0.063
St. Louis (1871–1970)	0.19	0.059	0.106	0.575
Chicago (1871–1973)	>0.20	0.100	0.075	0.182
		Cold season		
Paris (1874–1973)	0.12	0.011	0.021	0.582
St. Louis (1872–1954)	0.20	0.036	0.087	0.660
St. Louis (1872–1970)	0.20	−0.003	0.063	0.960
Chicago (1872–1973)	0.09	0.053	0.054	0.327

The normal distribution was fitted to the time-series data for the three cities. The Kolmogorov-Smirnov "goodness of fit" test was applied to the data and the resulting goodness of fit probabilities (gfp's) are listed in Table 1. The gfp represents the probability that the observed differences between the data sample and the normal distribution could have occurred by random chance.

The gfp's indicate that all of the time series except the warm season series at Paris (1874–1973) can be described by the normal distribution. Each series was regressed on the time series scale, and the regression coefficients (i.e., trends) for each sample are listed in Table 1 as the b values. The trends were tested for significance by the usual methods of multiple correlation and regression (Snedecor and Cochran, 1967). Since the warm season data for Paris (1874–1973) could not be fitted by the normal distribution, the Mann-Kendall rank statistic (a non-parametric test) was employed to test for the trend statistic Υ (Mitchell, 1966). The two-tail probability that Υ found for Paris could have occurred by random chance was 0.041, indicating that the trend is significant at the oft-cited 0.05 level of significance.

The two relocations at Chicago were not found to produce detectable shifts in the long-term trend of the Chicago seasonal values. However, the 1954 St. Louis station shift from the city center to the northwestern edge of the urban area brought a distinct downward shift in the magnitude of values and greatly altered the trend that existed before that time. Hence, two sets of values are presented for St. Louis: that for 1871–1954 (no station shift), and that for 1871–1970 (with shift).

Increasing maximum daily rainfall values during the warm season (Table 1) are most pronounced at St. Louis (1871–1954) and Paris with probabilities that they are not due to chance of 93.7% and 98.0%, respectively. The warm season shift at Chicago is upward, but there is a 18.2% probability it is due to chance. The trends of the maximum daily values of the cold season (Table 1) and those for the total annual rainfall values (see Table 2) are very weak.

The upward trends in the warm season values may result from a general climatic shift or from gradual improvements in rainfall measurement techniques. However, since the shift is largely in the warm season values, it may reflect urban-related alterations of convective processes leading to an increase in storm rainfall intensities during summer. METROMEX studies at St. Louis of the 1971–73 summers have shown an average midday heat island that is 1–3°C greater than rural values (Jones, 1974), and this heat island often extends upward from 500 to 1500 m (cloud-base height) above the city (Braham, 1974; Semonin and Changnon, 1974; Changnon and Semonin, 1975). We think that the heat islands result in larger and more intense shower clouds, as found in St. Louis studies (Huff and Schickedanz, 1974), and perhaps in liaison with the greater instability, the cities help transport large condensation nuclei and ice-forming nuclei to cloud base (Braham, 1974; Ackerman, 1974). It is also probable that the sizable increase in urban pollutant aerosols create ice-forming nuclei sufficient to measurably alter the precipitation process. Case studies of nine rain days in the St. Louis area have shown that the city, through mechanical effects and heating, sets up convergence zones over or near the city (Changnon and Semonin, 1975). In turn, these zones are where cloud and then storm activity often first began, and these zones were frequently instrumental in dictating the daily rainfall distribution in and near the city.

Importantly, the results for cities from two different continents and in two different climates show similar results, particularly with upward trends of 19, 37 and 38% in warm season heavy daily rainfalls (Table 2). This suggests either (i) that urban-related effects of very large cities have enhanced convective precipitation, particularly of the more intense nature, or (ii) that there has been a natural hemispheric-type climatic shift over the past 100 years leading to more intensive convection. However, the latter possibility is not supported by a hemispheric-scale study of thunderstorms which shows downward trends since the 1930's in thunderstorm frequency in the mid-latitudes that include Paris, St. Louis and Chicago (Changnon, 1973).

Table 2. Trend summary (difference between first and last year values, expressed as percent of first year value).

	Daily maximum warm season	Daily maximum cold season	Annual rainfall
Paris (100 years)	+38%	+ 6%	+15%
St. Louis (84 years)	+37%	+ 6%	− 3%
Chicago (100 years)	+19%	+15%	+17%

Although the causes for the increases in heavy daily rainfalls cannot be clearly identified, changes of 19–38% are relevant shifts in values used in the design of hydrologic structures, urban water and sewage treatment plants, and in assessments of urban water quality. Results from METROMEX also show an increase in heavy rain days and in the intensity of rainfall rates (Huff, 1975).

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