Conflicting Theories of Inadvertent Weather Modification in Urban Areas

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Abstract

Cities have their own peculiar climates because of the influence of local environmental factors. These "new" climatic controls interact in effect to produce the well-known urban heat island. Urban climatological investigations are increasing, both methodologically and geographically. As a result, certain "firmly established" hypotheses have been challenged or modified. Certain of these hypotheses are reviewed in this paper. It is concluded that theoretical conflicts exist both because of the relative immaturity of urban climatology as a science and because of real variations in relevant urban and climatic variables, and interactions, from city to city.

Cities have their own peculiar climates (distinct from surrounding regional climates) due to the influence of local environmental factors. Climatologists have been studying the causes and properties of urban climates for nearly 140 years (18). Numerous analyses have been conducted, mostly of large European and American cities. Five basic characteristics that set a city's climate apart from that of the countryside are now recognized: 1) the urban fabric, the predominantly rocklike materials of the city's buildings and streets, which conduct heat about three times as fast as wet sandy soil; 2) the city structure, a complex web of multiple reflections and energy exchanges; 3) artificial heat production, mainly during the winter; 4) the urban water balance, marked by rapid drainage and reduced humidity; and 5) urban air pollution. These factors act singly and in combination to produce a multitude of unique city climates.

Perhaps the most common urban climatic element is the so-called "urban heat island." The heat island refers to the warm-air dome found over all cities (with the possible exception of tropical cities), caused by the efficient absorption of solar radiation and the release of artificial heat. Heat islands have been described for a diverse range of cities: large and small, flat and hilly, continental and littoral.

By definition, heat islands tend to be atypically warm for their meso-climatic locale, especially at night and during winter months. Various other manifestations of inadvertent weather and climate modification, not so obvious as the added warmth of the city, have been reported for certain heat islands. Landsberg reported that urban climates had been found to be, on the average, wetter, cloudier, warmer, and more prone to storms than the rural environs, but less humid, snowy, and more restricted in illumination and visibility (23, 24, 25).

These ideas remain essentially valid. For example, the amount of solar radiation received has been consistently reported as reduced

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in urban environments. However, increased research in recent years has led to certain unresolved theoretical conflicts. Several of these contradictory hypotheses are considered here, under the broad headings of the effect of city size on the heat island, the spatial extent of the heat island, and theories of inadvertent modifications of precipitation, wind, and temperature parameters.

The Relationship Between City Size and Urban Climate

A number of studies have considered the influence of city size on the magnitude of the heat island effect, with conflicting results. Several authors have stated that the development of the heat island is directly related to the population density of urban areas, generally increasing as the city grows in population and size (4, 22, 23, 24, 25, 30, 31). For example, Landsberg compared temperatures at Los Angeles and San Diego over a 30-year period and discovered that as the difference in population between the cities increased so did the difference between mean temperatures (26).

However, certain complicating factors make the interpretation of the city size—heat island relationship difficult. One such factor is the possibility of regional climatic changes during the period of study. "Several of the processes of heat island genesis depend upon the levels of regional temperatures, cloud amounts, and windspeeds and any changes in these will be paralleled by heat island changes quite independent of city growth (6)."

Even more interesting is the recent discovery that large nocturnal urban-rural temperature contrasts exist in rather small cities. Maximum temperature differences of 4 to 6°F were reported at Palo Alto, California (population 33,000) (11). A definite heat island was noted in Corvallis, Oregon, (population 21,000) on two occasions, with maximum temperature differences of 13°F and 10°F (20). A similar report was made for Ina, Japan (population 12,000) (37). These figures may be compared with the following large-city differentials: St. Louis, 5°F (16); Des Moines, Iowa, 5-17°F (10); and Toronto, up to 34°F (29). A heat island effect resulting even from a small isolated building complex has recently been detected (28).

It appears that a positive, though not linear, correlation does exist between city size and heat island development, but it remains a questionable relationship, and one easily obscured by regional climatic change and local microclimatic conditions.

Spatial Extent of the Heat Island Influence

The region of maximum urban influence is generally accepted to be the approximate center of each heat island, normally coincident with the most densely built-up zone of the city. The greatest difference in temperature between city and countryside occurs at this location.

However, authors do not agree on the influence of urban areas on precipitation variables such as geographical distribution and frequency of occurrence. In 1927, a peak of mean annual precipitation was reported for the eastern (downwind) sector of Munich (36). Other investigators have found precipitation maxima located somewhat downwind of many cities. This "shift" is attributed to the transport of rainfall-augmenting pollutants by prevailing winds. The most notable example of this phenomenon has been documented in Changnon's study of precipitation parameters at La Porte, Indiana, located about 30 miles downwind of the industrial complex of Gary. For the period of 1951-1965, Changnon reported positive anomalies at La Porte of 31% for mean precipitation and 38% for the number of "thunderstorm days" (7).

Some researchers are dubious of this leeward shift of precipitation maxima. Peterson has observed that the presence of Lake Michigan and its associated circulations makes it doubtful that the La Porte data are applicable to other cities (33). Other authors were unable to note such shifts in the Washington, D. C. or St. Louis areas (12, 41).

Recently, a "fresh examination" of the La Porte precipitation record was undertaken, and it was concluded that the La Porte anomaly was observer-perpetuated and fictional (17). Changnon has rebutted that this thesis is ". . . not substantiated . . ." and ". . . provides little new information . . ." (8).

At this point it seems probable that urban precipitation effects are normally greatest somewhat downwind of a city. The magnitude and type of industrial activity within the urban area are likely to play a key role in the development of such a shift. La Porte, leeward of an extensive steel mill complex, may be an extreme or totally anomalous case. The entire matter remains debatable; it is complicated by the difficulties inherent in meterological data collection and analysis.

Mean Annual Precipitation

Several studies indicate that increased convection and numbers of condensation nuclei cause increased precipitation over metropolitan areas (1, 28). Conversely, other workers believe that mean precipitation may be reduced and the frequency of droughts increased over cities where automotive pollution is dominant (35). In such environments, submicroscopic lead particles may combine with traces of iodine in the atmosphere to produce lead iodide, an excellent cloud-seeding agent. So much lead is released into the air that clouds become colloidally more stable and "overseeded." Los Angeles is cited as an example and preliminary research indicates a similar phenomenon at Houston, Texas (J. R. Norwine, unpublished data).

Frequency of Thunderstorms

Urban climatologists have reported increased frequencies of hail and thunderstorms over cities, due to added convection, turbulence and condensation nuclei (2, 36). Schaefer has added that the cause of urban droughts may, in turn, sometimes cause downpours: ". . . a sudden influx of particles may send cloud droplets falling all at once (35)."

Fewer studies indicate that thunderstorm frequency is reduced near cities (17). Some cities may act as "thermal barriers," diverting approaching weather systems and associated precipitation (9).

Frequency of Small Amounts of Rainfall

Some workers have suggested an increase of 5 to 10% in the number of days with small amounts of rain (<0.10 inch) in cities (19). The added convection and nuclei over the city are believed to trigger "drizzles" not experienced in rural surroundings.

Certain cities, such as Tokyo and Los Angeles, have been described as experiencing reduced numbers of "weak rainy days" (38). This is again attributed to lead iodide-induced overseeding of clouds.

Amount and Frequency of Snowfall

Similar arguments persist on the matter of snowfall in urban environments. Several authors (21, 26) suggest that total snowfall is reduced because of the higher temperatures of the heat island. Other studies substantiate this but add that the frequency of "snow days" and even snowstorms is increased by extra updrafts and atmospheric pollution (14, 27). Finally, Changnon has stated that his work on urban climates in the midwestern United States shows little evidence of any effects on snowfall amounts (7).

Theories of Urban Alteration of Wind Speeds

Most work on urban wind fields dates from 1950 (33). Studies which have appeared since then confirm that average wind speeds within cities are lower than over the countryside, due to the increased frictional drag of the rough atmosphere-city interface (14, 15).

However, some recent work has challenged certain assumptions made about urban wind fields. For example, increased wind speeds in downtown London were reported when regional winds were light (5). Light winds were found to increase in speed in central areas, in response to the downward transport of momentum by mechanically-induced eddies. Also, fewer calms and light winds were reported over the city (5). Clearly, much additional research into the urban effect on wind fields is needed.

Theories of Urban Alteration of Mean Temperature

Finally, and perhaps most significant, is the question of the influence of cities upon mean temperature. This problem is of great importance because of the likelihood than man's industrial activities are modifying not only urban microclimates but large climatic regions and even the global climate.

The variables involved in this gigantic interrelationship are extremely complex. Research efforts have tended to focus on the two elements of the terrestrial heat budget chiefly influenced by air pollution: absorptivity and effective emissivity. Some studies have reasoned that 1) atmospheric absorptivity has been reduced by an increase in "earth brightness" or albedo (due to increased dustiness or turbidity) (33), and 2) tropospheric effective emissivity has been lowered by an increase in atmospheric carbon dioxide content (3). Theories have been advanced to the effect that "increased particulate pollution increases the earth's albedo, hence causes cooling," and "increased CO_2 stimulates the 'greenhouse effect' and thereby raises temperatures" (35, 40). These hypotheses may or may not be valid. Recent studies suggest that absorptivity, emissivity, radiation, temperature, air-circulation patterns, atmospheric stability, cloudiness and evaporation may interact in such ways as to give thermal effects quite unlike those originally expected (32). Global cooling has occurred in recent decades (31), possibly due in part to the influence of increased air turbidity. Certain regions which have not experienced this cooling trend, such as northeastern North America and western Europe, are regions marked by the persistent outpouring of CO_2 into the atmosphere. This seems in accord with a recent study, in which a simple numerical model of the energy balance of the earth-atmosphere system was applied, with the mean annual sea level temperature in 10° latitude belts as the dependent variable. It was concluded that man's industrial activity, particularly the increased use of stored energy, should eventually lead to a global climate much warmer than today's (in spite of increased turbidity) (39).

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