THE ATLANTA THUNDERSTORM EFFECT

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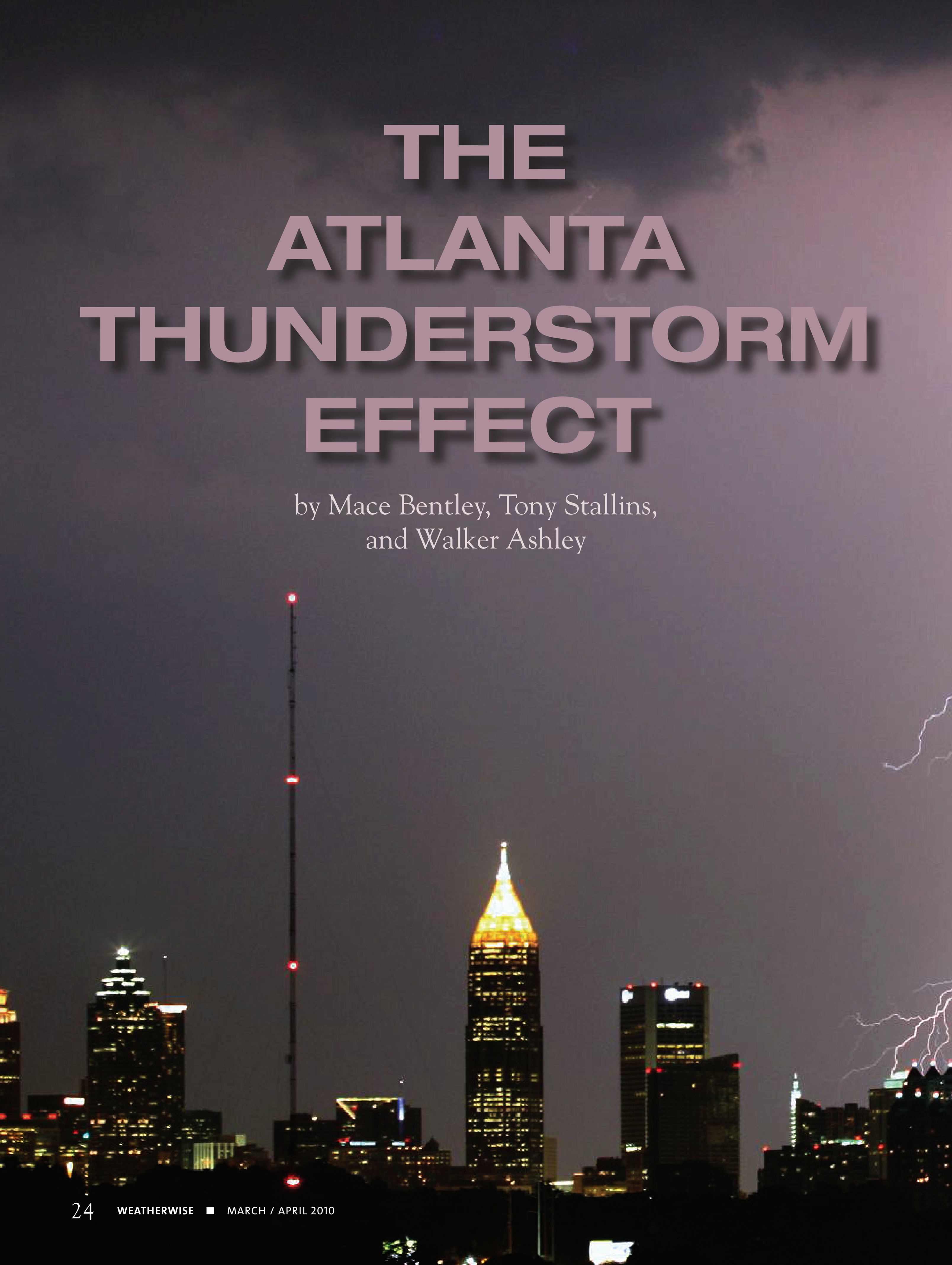

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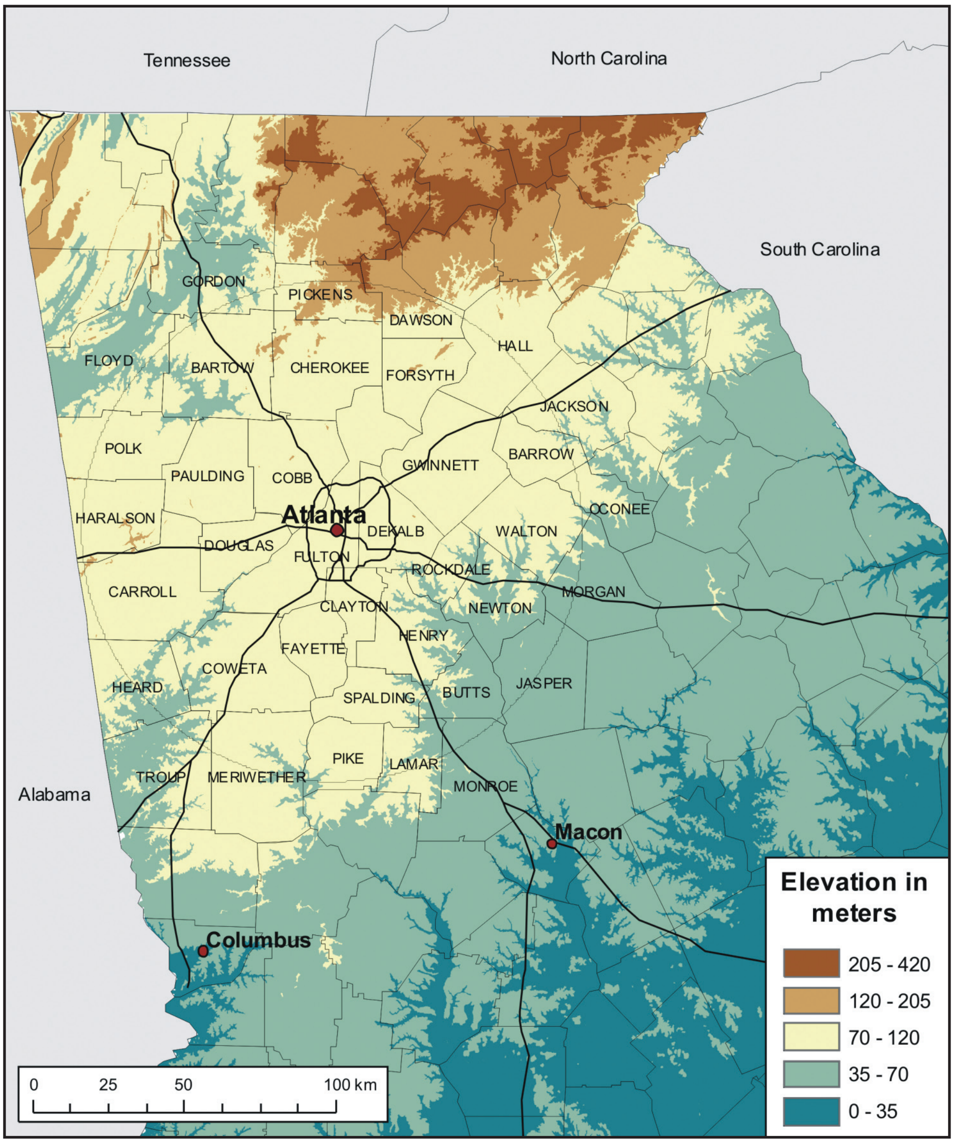
"lightning accounts for more deaths than hurricanes and tornadoes combined"

Although nearly everyone is fascinated by lightning, some of us are terrified, while others are drawn to its elusive beauty. Lightning is one of the most photogenic of all atmospheric phenomena, but also one of the least understood. For all of its beauty, lightning is a major cause of weather-related deaths in the United States and accounts for more deaths than hurricanes and tornadoes combined. Nearly 40 percent of all lightning deaths occur when a person is involved in some form of outdoor recreation.

Now, new evidence suggests that lightning and its parent thunderstorms might actually be enhanced by cities. Urban areas are literally hotbeds for producing heat and lift, two important ingredients for thunderstorm formation. At the same time, throughout the world people are continuing to migrate to cities for employment opportunities and the search for a better life. Eighty percent of the U.S. population now lives in cities. City growth has increased the amount of urbanized land cover in the United States to nearly the size of Ohio! In the United States, many of our cities in the south are growing rapidly due to their location in a more temperate climate. However, a temperate climate also means cities are more prone to thunderstorms. Could all of these factors together combine to increase risk of lightning and other thunderstorm hazards to urban communities around the world?



Map of Atlanta, Georgia, region illustrating land cover, major interstates, and counties.

The Atlanta metro area serves as a perfect case study for researchers working to answer these questions. During one three-and-a-half-hour period on a recent late summer day, 97 lightning strikes pummeled Gwinnett County, Georgia, a suburb of Atlanta. The aftermath left 19 homes and two apartment buildings damaged, two people injured, and many others shaken as they cleaned up the damage. Georgia ranks ninth in the United States for the most lightning casualties, and lightning ranks as the top cause of weather-related deaths for the state. Estimated annual losses due to lightning in Georgia range as high as $27 million, most occurring in the highly populated and thunderstorm-frequented Atlanta Metro area.

Results from a 10-year investigation of lightning and thunderstorm activity surrounding Atlanta identified increases in thunderstorm intensity, rainfall, and lightning over and downwind of the city center during the summer months of June, July, and August. But why was there more lightning and thunderstorm activity over the metro area? Given the magnitude of damage and dangers of lightning to people outdoors, researchers sought to determine whether an urban area such as Atlanta might, in fact, create or intensify thunderstorm activity.

The Urban Heat Island

The first step in unraveling the question is to understand the interaction between the land and atmosphere. It is currently thought that several processes in this complex interaction are likely at work in altering thunderstorm distributions around cities.

The first is the urban heat island effect, perhaps the most well-known atmospheric phenomenon produced by a city. An urban heat island occurs when the city registers higher temperatures than the surrounding rural areas. Cities heat up because of all the "activity" in them. Cars, air conditioning units, idling engines, and miles of asphalt and concrete all either produce or retain heat. The most notable feature of an urban heat island is the lack of cooling during late afternoon and evening after temperatures normally reach their highest. When compared to the rural countryside, urban corridors have much less area exposed to open air and instead have many warm buildings facing each other. Less heat is lost, and higher nighttime temperatures result. After sunset, city-to-countryside temperature differences grow quickly and can reach, in some cases, more than 10°F. The greatest city-to-countryside temperature differences occur during the long, hot days of summer when daylight is maximized.

"Canyon" Winds

Wind also plays a vital role in the intensification of urban heat. Similar to a sea breeze, the warmer air over the city reduces atmospheric pressure and promotes lift. The same process occurs over the hot sands along a beach, causing the overlying air to warm and rise. This lift draws air from off the sea onto the coast, creating the pleasant, comfortable sea breeze. The lower air pressure found over cities also causes cooler air to flow from the countryside toward the city.

As these winds encounter the urban canyons and the roughness of tall buildings, the winds tend to slow, converge, and rise over the city. The urban heat island and converging winds cause air to ascend over the city center and sink along its periphery. The lifting of warm, humid air over the city center often creates clouds that can develop into thunderstorms if the air remains unstable and continues to rise. These thunderstorms then drift, pushed by the prevailing winds, over the downwind suburbs.

> “The lifting of warm, humid air over the city center often creates clouds that can develop into thunderstorms”

Thunderstorms that are already formed and moving over a city can also be enhanced by the urban area. As storms approach a city, the thunderstorm winds interacting with the urban heat island circulations described above can cause the storms to split and move around the downtown. Because the urban heat island leads to both thunderstorm development over the city center and the splitting of storms along its periphery, the downtown as well as suburbs surrounding the city can see increases in thunderstorms and lightning.

Pollution, Thunderstorms, and Cloud Electrification

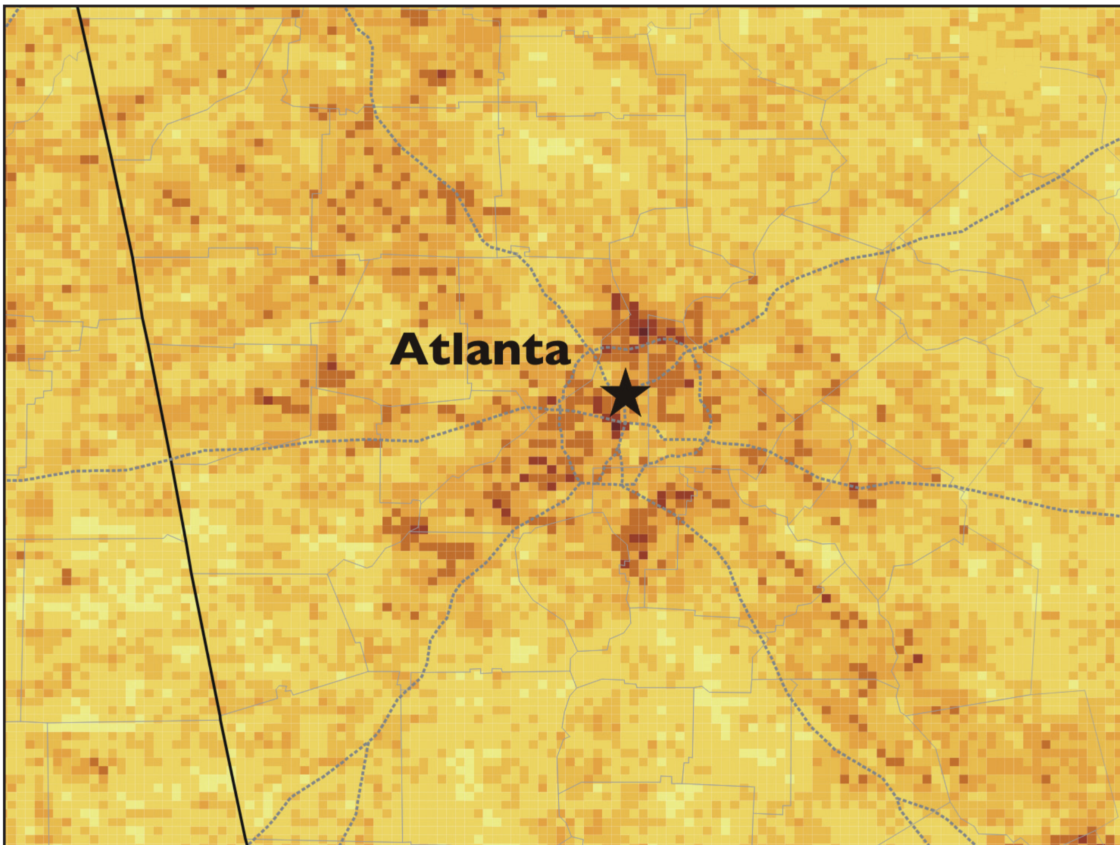
Finally, what about all the pollution found in large cities? Pollution from car and bus exhaust, cooling systems, generators, and other engine activity injects billions of small particles into the atmosphere. These particulates or aerosols can be caught in the updrafts produced by the urban heat island and lifted into developing thunderstorms. Pollution keeps droplets smaller and allows more water to be transported higher where temperatures are lower. The importance of these aerosols in thunderstorm development and lightning modification is currently not well known; however, evidence suggests that their presence can alter how a thunderstorm forms. Pollution aerosols are some of the best cloud embryos, as water readily condenses onto them, forming cloud droplets. The haze that you see on hot, humid summer days is often a result of water vapor condensing onto pollution and dust particles. The more of these aerosols that are present in the atmosphere, the denser and more prevalent cloud development is. However, more clouds may not necessarily lead to increased rainfall or more intense thunderstorms. Because of higher concentrations of droplets within clouds forming in polluted environments, there is greater competition for the remaining water vapor to condense onto these droplets and allow them to grow large and heavy enough to fall as rain. Therefore, pollution may actually act to initially suppress rainfall but increase cloudiness and humidity, in effect priming the atmosphere for more vigorous thunderstorms later in the day.

> “Pollution can alter how a thunderstorm forms”

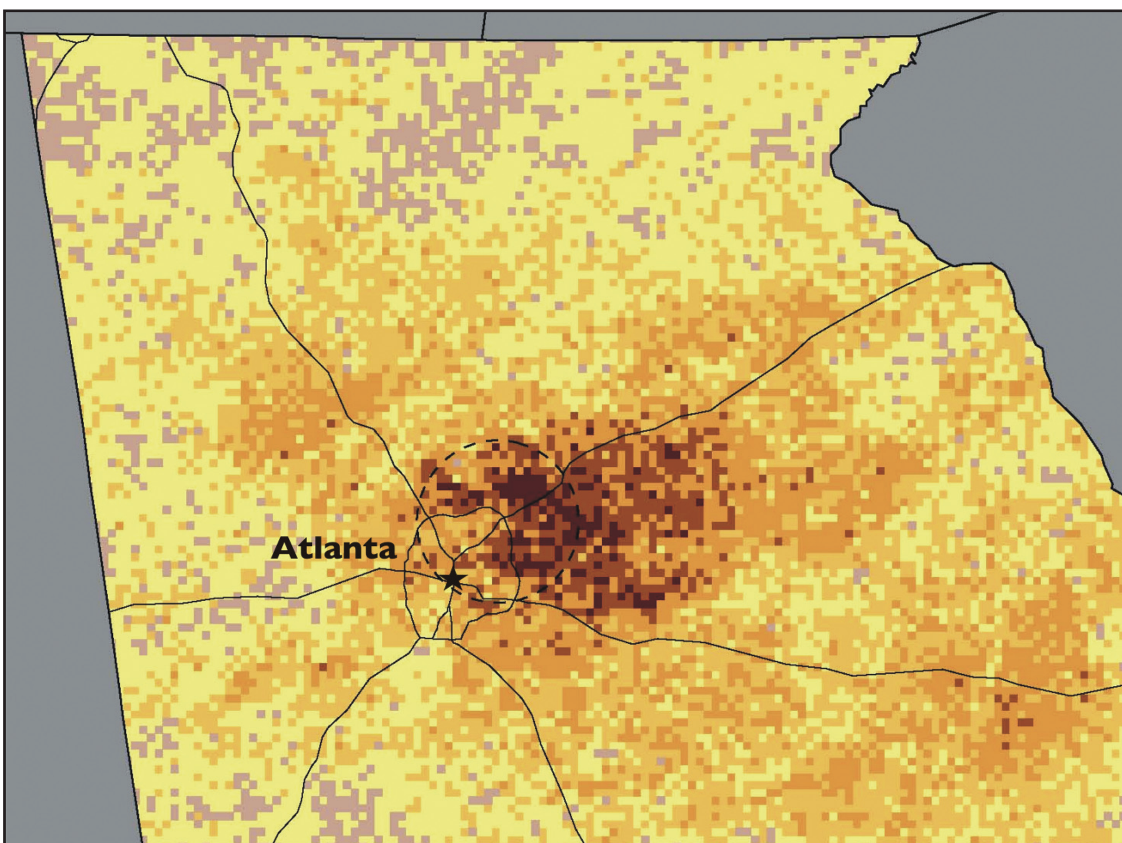
Lightning might also be enhanced by pollution as the cloud droplets in the cloud take on different electrical charges. Because pollution can lead to higher concentrations of cloud droplets, a “polluted cloud” can lead to greater cloud electrification. This is amplified when a portion of a growing cumulonimbus cloud passes through the freezing level on its upward climb. As water droplets collide and freeze onto hail and other ice particles, negative charges are removed from the updraft and added to the downdraft of the thunderstorm. This causes positive and negative charges to reside within different regions of the same cloud and, like they say, “opposites attract,” leading to the development of lightning that temporarily releases the buildup of opposing charges.

The Atlanta Case

The 10-year study of lightning, rainfall, and thunderstorm activity in Atlanta in the summer months showed that enhanced thunderstorm activity was found to shift due to prevailing winds. For example, westerly winds produced a distinct increase in lightning activity east of downtown Atlanta. Evidence suggests that thunderstorms developing over the city center, as well as storms along the periphery, were being directed by the westerly winds to the east side of the city and suburbs. The Atlanta enhancement, particularly



Radar climatology illustrating the clustering of strong thunderstorm days directly over and immediately surrounding Atlanta, Georgia.



Plot of lightning events during periods of westerly flow illustrating downwind enhancement east of Atlanta, Georgia.

> “As water droplets collide and freeze onto hail and other ice particles, negative charges are removed from the updraft and added to the downdraft of the thunderstorm”

for lightning, was well developed for westerly and northwesterly winds that carried thunderstorms east and southeast of downtown. Thunderstorm enhancement can occur in all directions around downtown Atlanta, directed primarily by the prevailing wind direction.

The rainfall and lightning characteristics of thunderstorms developing in and around Atlanta were also detected when examining radar reflectivity. Over the 10-year study, high radar reflectivity "hotspots" were persistently found along and north of downtown Atlanta and immediately east of the central business district. Towering cumulonimbus clouds containing high concentrations of water droplets and ice crystals reflect significant amounts of microwave radiation back to the radar antenna. On weather radar displays, highly reflective areas are thunderstorms, which are typically color-coded in hot colors (i.e., reds, oranges) to make it easy to identify their size and location. Radar-identified thunderstorms were found to be greatest over the downtown with a general decrease moving outward from the city center. A similar pattern was found over other southern U.S. cities. It appears that the Atlanta urban heat island and associated buildings may combine to produce the downtown thunderstorm radar "hotspot," while the urban heat island-produced circulations on the fringes of the city lead to increases in suburban thunderstorms, lightning, and rainfall.

> “Radar-identified thunderstorms were found to be the greatest over the downtown”

Although less important, the terrain might also be linked to the lightning and rainfall patterns surrounding Atlanta. Winds from the northeast off the Appalachians and the focus of rainfall and lightning activity on the upwind side of Atlanta suggest that elevation changes across the metro area may interact with the urban heat island circulation and focus lightning and rainfall on the north side of the city. One explanation is that air flowing downhill from the Appalachians will be forced to rise once it encounters the buildings on the northern edge of Atlanta. This is distinct from other prevailing wind directions, where lightning activity was found to intensify over and downwind of the city center.

Complex Controls

The interactions among differing land cover, pollution, and terrain suggest that untangling the significance of each of these variables remains the greatest challenge in our understanding of how cities influence their weather. In particular, given that pollution levels, land cover, and terrain can rapidly change across larger cities, there is no reason to assume that an urban area would exhibit consistent increases in lightning and rainfall production throughout the entire city. Complex interactions between the urban heat island, pollution, terrain, and land cover are all likely responsible for increasing thunderstorms and their associated threats across cities. Understanding the effects of cities on thunderstorms is becoming very important, as urban areas become increasingly densely populated regions that contain an infrastructure highly susceptible to disruption and damage from lightning and flash flooding. While global climate change affects the frequency, seasonality, and intensity of weather-related hazards, thunderstorm enhancement through urban growth is equally capable of impacting large populations in a much shorter time span. W

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