

**A Review of Current Investigations of Urban-Induced Rainfall and Recommendations for
the Future**

J. Marshall Shepherd , NASA/GSFC, Earth Science Directorate, Greenbelt, Maryland

**Corresponding Author: Dr. J. Marshall Shepherd, NASA/GSFC, Code 912.0, Greenbelt,
MD 20771, email: marshall.shepherd@nasa.gov**

Abstract

Precipitation is a key link in the global water cycle and a proxy for changing climate; therefore proper assessment of the urban environment's impact on precipitation (land use, aerosols, thermal properties) will be increasingly important in ongoing climate diagnostics and prediction, Global Water and Energy Cycle (GWEC) analysis and modeling, weather forecasting, freshwater resource management, urban planning-design and land-atmosphere-ocean interface processes. These facts are particularly critical if current projections for global urban growth are accurate.

The goal of this paper is to provide a concise review of recent (1990-present) studies related to how the urban environment affects precipitation. In addition to providing a synopsis of current work, recent findings are placed in context with historical investigations such as METROMEX studies. Both observational and modeling studies of urban-induced rainfall are discussed. Additionally, a discussion of the relative roles of urban dynamic and microphysical (e.g. aerosol) processes is presented. The paper closes with a set of recommendations for what observations and capabilities are needed in the future to advance our understanding of the processes.

Introduction:

Urbanization is one of the extreme cases of land use change. Although currently only 1.2% of the Earth's land is considered urban, the spatial coverage and density of cities are expected to rapidly increase in the near future. A recent paper by Elvidge et al. (2004) indicated that the density of the impervious surface area (ISA) for the conterminous United States is 112, 610 km², roughly the size of the state of Ohio and slightly larger than the area of herbaceous wetlands of the conterminous United States. It is estimated that by the year 2025, 60% of the world's population will live in cities (UNFP, 1999). Animation 1 is an illustration of the rapid growth of Phoenix, Arizona over the last few decades. Though urban areas are local in scale, human activity in urban environments has impacts at local, to global scale by changing atmospheric composition; impacting components of the water cycle; and modifying the carbon cycle and ecosystems. However, our understanding of urbanization on the total Earth-climate system is incomplete. Better understanding of how the Earth's atmosphere-ocean-land-biosphere components interact as a coupled system and the influence of the urban environment on this climate system is critical (figure 1).

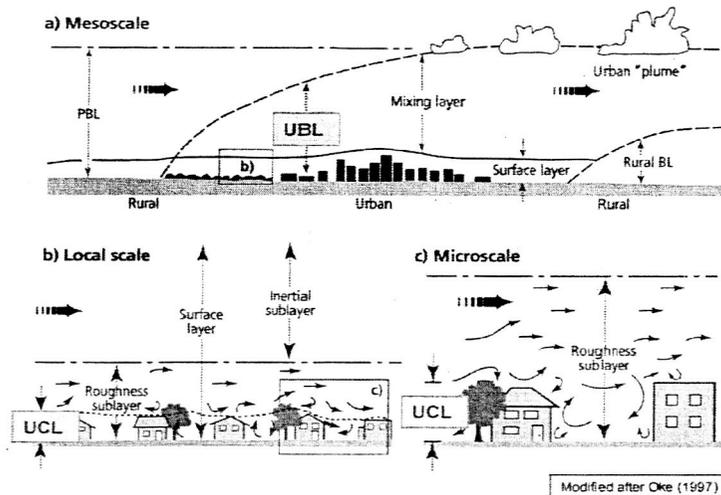


Figure 1-Various scales linking urban environments to the environmental system (modified after Oke (1987)).

As an example of recent concerns about the role of urban environments on the Earth system; several issues or questions raised in the United State's Climate Change Science Program Strategy (2003) echo the aforementioned statement about the urban environment-climate system linkage: A few examples include:

- How are land-use and land-cover are linked to climate and weather?
- How do climate variability and change affect land use and land cover, and what are the potential feedbacks of changes in land use and land cover to climate?
- How do the primary and secondary pollutants from the world's megacities and large-scale, non-urban emissions (e.g., agriculture, ecosystems, etc.) contribute to global atmospheric composition?

- d. How are estimates of atmospheric composition and related processes to be used in assessments of the vulnerability of ecosystems to urban growth and long-range chemical transport?
- e. Research on the climatic effects of temperature on air quality, particularly in urban heat islands and other regional settings, and the potential health consequences.

Urban areas modify boundary layer processes in several ways. One of the primary mechanisms is through the creation of an urban heat island (UHI). In cities, natural land surfaces are replaced by artificial surfaces that have different thermal properties (e.g., heat capacity and thermal inertia). Such surfaces are typically more capable of storing solar energy and converting it to sensible heat. Other contributing factors to the onset of the UHI may be attributed to differences in surface albedo and anthropogenic heat release in the urban area. As sensible heat is transferred to the air, the temperature of the air in urban areas tends to be 2-10 °C higher than surrounding non-urban areas (figure 2). To further understand the origins of the UHI, it is instructive to examine a surface heat budget equation,

$$Q_{SW} + Q_{LW} + Q_{SH} + Q_{LE} + Q_G + Q_A = 0. \quad (1)$$

In equation (1), the terms are: Q_{SW} (net short-wave irradiance), Q_{LW} (net long-wave irradiance), Q_{SH} (surface sensible heat flux), Q_{LE} (latent turbulent heat flux), Q_A (anthropogenic heat input), and Q_G (ground heat conduction).

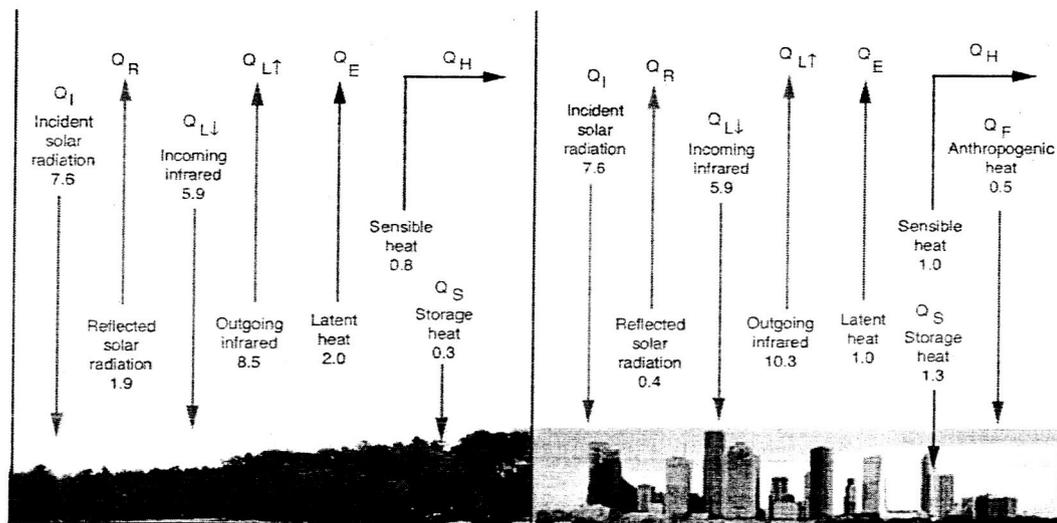


Figure 2-Typical rural and urban surface energy balances.

An equilibrium surface temperature is required for (1) to balance. At the surface, if no heat storage is permitted, differential heating results from horizontal gradients in one or more of the terms in (1). Spatial gradients in this equilibrium temperature in conjunction with the overlying thermodynamic and moisture stratification will dominate the upward or downward flux of heat for thermally-forced systems, which results in horizontal temperature gradients required to drive a mesoscale circulation. In the case of the UHI, the difference in surface properties of urban and rural areas leads to the differences in the thermal fluxes in (1). Vukovich and Dunn (1978) used a three-dimensional primitive equation model to show that heat island intensity and boundary layer stability have dominant roles in the development of heat island circulations. Additionally, Huff and Vogel (1978) found that the urban circulation is primarily enhanced by the increased sensible heat fluxes and surface roughness of the urban area.