Urban Influence on Rainfall

During urbanization natural land covers are removed and replaced by buildings, roads, parking lots, sidewalks, and other impervious surfaces. One effect of this conversion is the modification of the land-atmosphere interaction. Impacts to the land-atmosphere dynamics are manifested in modified temperature and moisture profiles (e.g., Oke 1987), augmented precipitation patterns (e.g., Changnon 1968; Ibrahim et al. 1981; Changnon 1992; Shepherd et al. 2002), and wind perturbations and enhanced turbulence (e.g., Fernado et al. 2001).

The urban influence on rainfall is caused by one or a combination of four factors:
1. Enhanced thermal mixing due to Urban Heat Island (UHI)
2. Increased turbulence and mechanical mixing due to increased aerodynamic roughness created by tall buildings
3. Modified low-level atmospheric moisture, potentially caused by augmented water and energy budgets or water vapor releases from stacks and cooling towers
4. Increased concentrations of cloud condensation nuclei (CCN) from automobiles and industry

Downscaling Analysis

The downscaling analysis concept involves identifying and quantifying urban rainfall anomalies at progressively smaller space and time scales. Their process can be broken into three steps:

1. Define the Upwind Region (UR), Urban Area, and Urban Impacted Region (UIR) based on the mean 700 hPa steering flow from TRMM PR data (see figure). This first step is critical because the UIR is defined based on the mean 850-700 hPa flow from the NCAR-NCEP reanalysis dataset.
3. Downscale in space and time by using ground-based radar and rain gage data to analyze at a finer resolution the urban impact on spatial and temporal rainfall patterns.

The Urban Houston Center is located near Galveston Bay, about 30 km inland from the Gulf of Mexico. The warm prevailing near-surface flow is predominately southeasterly (i.e., sea breeze driven). However, for steering flow and upwind-downwind delineation, the 700 hPa (mb) surface is most critical. We have analyzed the robust climatological record of the NCAR-NCDF rainfall dataset and found that the mean 850-700 hPa flow is roughly from 230° (South-Southwest). Therefore, we align our reference coordinate system along the 230° vector (see coordinate system figure).

The eastern boundary of the UIR is 150 km from the orange ellipse. The Warmest boundary of the UIR is 100 km from the orange ellipse.

Research Hypothesis

The central Houston Urban District and regions to the northeast through east exhibit enhanced rainfall amounts relative to segments of southwest of the city.

Possible mechanisms include:
• Enhanced convergence zone created by Houston UHI-Sea Breeze-Galveston Bay Interaction in subtropical environment
• Enhanced convergence due to increased surface roughness and destabilization due to UHI-driven modification of the boundary layer. UHI-induced convection is translated downstream by prevailing flow or mesoscale circulations on the rainfall-urban interface create an enhanced convergence zone with the prevailing south-southwest flow in the downwind sector
• Enhanced aerosols in Houston urban environment provide robust supply of cloud condensation nuclei (CCN)
• Numerical modeling of the sea breeze-Galveston Bay interaction to clarify the causative factors of the urban rainfall anomaly

Summary

A collaborative research effort has produced interesting results. A robust analysis of TRMM PR data found embedded mean rainfall amounts within and northeast of Houston, consistent with the research hypothesis. Further analysis of GATE radiosonde data corroborated these findings and further elucidated the urban influence on warm season convective rainfall and the diurnal rainfall pattern. On-going work related to this project includes:
• Analysis of the impacts of urbanization on rainfall by investigating temporal trends in the rainfall records
• Numerical modeling of the sea breeze-UHI interaction to clarify the causative factors of the urban rainfall anomaly

Acknowledgments

This work was partially supported by a Ming Ying Wo (NASA) Undergraduate Research Program (URP) and NASA/ASEE Summer Faculty Fellowship.

For further information contact Marshall Shepherd (shepherd@eng.uark.edu) or Steven Burian (sburian@eng.uark.edu)