

HEAT – First Planning Workshop
Urban Effects on Convective Processes in a Coastal Environment
Working Group Report

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1. Introduction

The Scientific Overview Document (SOD) for the Houston Environmental Aerosol Thunderstorm Project (HEAT) outlines a field program designed to determine what processes contribute to lightning enhancement in the Houston area. The scope of the field program necessarily includes issues related to cloud microphysics, convective initiation and development, and natural or anthropogenic atmospheric inhomogeneities. This working group was charged with considering and refining the hypotheses and observational requirements that relate to modification of the atmosphere by the underlying surface.

The discussion in the SOD is organized around specific processes. The processes of interest to this working group fall under two categories: urban effects and sea breeze effects.

The processes and experimental goals related to urban effects are as follows:

U1: Urban Heat Island Thermodynamics

Goal: Document the spatial (and temporal) variability of planetary boundary layer (PBL) temperature and moisture in and around the Houston metropolitan area, associated with the urban heat island effect and other land surface inhomogeneities.

U2: Urban Wind Modification

Goal: Measure the horizontal wind and convergence pattern in and around Houston, associated with enhanced urban drag and other land surface inhomogeneities.

U3: Urban Updraft Enhancement

Goal: Measure convective updraft strength over Houston compared to surrounding areas.

U4: Urban Effects on Storm Splitting, Merger, and Initiation

Goal: Identify and track convective cells and their kinematic, microphysical, and lightning characteristics.

(Note: The title of U4 is broadened here from what appears in the SOD based on discussions of scientific interests in the March 2004 workshop.)

C1: Sea Breeze Modification

Goal: Document the temporal and spatial evolution of the sea breeze and associated convergence, as produced by the complex coastline.

C2: Sea Breeze Interaction with the Houston Heat Island

Goal: Determine how the sea breeze is modified through interaction with the Houston urban heat island and related urban effects.

C3: Intensity of Sea Breeze Convection

Goal: Characterize sea breeze convection as it develops and propagates across the Houston area.

While there was little dispute with the above-listed goals, the working group found that the observational requirements for addressing the urban objectives (U1-U4) and coastal objectives (C1-C3) overlap considerably, such that it was not useful to retain this framework for its discussions. Therefore, the group reorganized the scientific objectives in a manner that enables clear identification and prioritization of observational needs and platforms.

2. Revised Scientific Objectives and Observational Needs

Because of the overlap between the observations needed to determine the separate effects of urban and coastal processes, those processes are combined here under the heading Urban Effects on Convective Processes in a Coastal Environment: Observations, Modeling for Field Studies, and Analysis. Within this overall heading are three major areas of observational emphasis. These three areas and associated observables are described below.

2.1 Urban Modification of the Surface and Lower Atmosphere

Understanding the effect of the city on the lower atmosphere will require observations both of the effects themselves as well as the causes: the land surface inhomogeneities and the heat, moisture, and momentum fluxes associated with those inhomogeneities. Merely documenting the effects would be adequate for the core objectives of HEAT, but comprehensive observations are impossible and numerical modeling will form a fundamental part of scientists' attempts to determine the urban effects. As such, it is necessary to document the air-land interaction within and around Houston in order to provide observational grounding for the processes that drive atmospheric inhomogeneities in numerical models as well as the atmosphere.

To determine the specific urban effects themselves will require a combination of surface and PBL data. The existing surface network, consisting of a combination of ASOS/AWOS stations and air quality monitoring stations, provides good spatial coverage and excellent temporal coverage for documenting the evolution and spatial variation of wind and temperature. Most air quality sites lack humidity measurements, so surface observations of moisture variables will not be so plentiful.

Within the PBL, atmospheric variations of wind, temperature, and moisture need to be documented on a variety of scales. First, variations on the urban scale must be measured in order to determine the gross effects of the urban area on the PBL. Second, variations on the convective and turbulent scale will be needed in order to look specifically at the causes of variation of convective initiation between urban and rural areas. In addition to these measurements within the well-mixed daytime PBL, measurements of the PBL height itself and how it varies spatially and temporally are needed to understand how the thermodynamic inhomogeneities modify the thermodynamic profiles in urban and rural areas. PBL height measurements may be a combination of urban and rural wind profilers (for temporal evolution) and aircraft observations (for spatial distribution).

Documenting the fluxes that lead to these expected PBL inhomogeneities requires characterization of surface properties across the Houston area. Such characterization may best be done through remote sensing techniques. It requires measurements of radiative fluxes and the urban aerosols that might contribute to radiative forcing variations. Finally, it requires measurements of the surface energy fluxes themselves. Because of the need to measure these fluxes across a range of land surface types in the Houston area, as many as twelve flux sites may be appropriate.

2.2 Urban-Coastal Interactions

Determination of the effect of the urban area on the sea breeze and other such interactions requires merely a broadening of the scope of observations described under section 2.1. The most fundamental type of measurements would be those that determine the variations of thermodynamics and wind along a coastline-normal axis. This could be accomplished through a combination of surface measurements and measurements within the PBL. Aircraft would be required to measure the vertical structure of the sea breeze front and its associated vertical motion at several locations, taking into account the coastline shape and the proximity of the urban area.

The location and progression of the sea breeze front itself would be an important observed element. Neither surface nor aircraft observations would be ideally suited to this task. Optimal would be the deployment of one or more radars, presumably the SMART radars, near the coastline and the urban area, so that the location and progression of the sea breeze front can be tracked.

The surface flux measurements required to support investigations of urban-coastal interactions would be available from the surface flux network described under 2.1.

Neither 2.1 nor 2.2 require the presence of thunderstorms or thunderstorm initiation. It is expected that the important, fundamental processes involving the urban heat island and the sea breeze will be present day after day, and may in fact be easier to isolate and identify on days which are clear and sunny. Therefore, the bulk, though not all, of the objectives incorporated in 2.1 and 2.2 can be achieved with measurements taken on days in which convective initiation and lightning are not expected to occur.

2.3 Urban-Coastal Impacts on Convective Processes

To directly relate the PBL variations to variations in developing convection, observations of wind and thermodynamic variations within the PBL beneath developing updrafts will be important. Determining whether variations in turbulence strength, convergence, or thermodynamic properties are primarily responsible for variations in convective development will be an important goal.

The variations in behavior of the convection itself must be thoroughly documented through analysis of radar data. Among the parameters to be tracked should be cell initiation, cell motion, cell size, cell merger, cell splitting, and cell decay. In addition to the characteristics of the cells themselves, the intensity of the convection and adjacent lightning as a function of time should be documented.

Once precipitating convection develops, downdrafts and outflow boundaries will rapidly modify the urban and rural PBLs. Lightning-producing convection may primarily be initiated by these outflow boundaries and their interaction with the urban environment and the sea breeze. Some thermodynamic sampling by aircraft will be useful, but the primary observational tool will be single and multiple-Doppler radar observations at low levels within and around Houston.

3. Observational Platforms

3.1 Essential Platforms

Radar wind profilers would serve multiple purposes within HEAT. First, a network of profilers would provide continuous measurements of the wind profiles throughout and above the PBL in and around the Houston area. Second, the profilers would provide

continuous measurements of the PBL height, indirectly measuring thermodynamic variations across Houston. Both measurements would provide valuable temporal continuity and a context for the much more limited aircraft measurements. One wind profiler is operated by TCEQ in the Houston area; others may be deployed as part of the Second Texas Air Quality Study (TexAQS-II).

Sodars would complement the profilers by measuring the wind variations in the lowest few hundred meters of the atmosphere. Such measurements would provide information on the wind structure in the urban area at low levels as well as high-resolution documentation of the wind structure associated with the sea breeze.

Flux sites are needed for directly measuring the variations in urban and rural atmospheric forcing. Such sites should include flux towers for measuring momentum heat and moisture fluxes, radiation measurements (both broad spectrum and wavelength-resolved), measurements of soil moisture and temperature, and measurements of evaporation and transpiration.

Aircraft observations are needed within the PBL to document the spatial structure of thermodynamic variations within and around the Houston area, to measure the thermodynamic and momentum properties of air entering convective updrafts, and to measure the structure and thermodynamic characteristics of the sea breeze and its interaction with the PBL over land and over the urban area.

Radar is needed to track the evolution of convection. More specific to understanding urban effects on convection in a coastal environment, radar (perhaps in combination with scanning lidar) is needed to map the three-dimensional wind pattern within the PBL, in order to measure urban effects on wind patterns, sea breeze evolution and intrusion, the interaction between the sea breeze and the urban environment, and the evolution of outflow boundaries within the PBL.

3.2 Highly Useful Platforms

Ground-based lidars would lack the wind information provided by profilers, but would be just as valuable for documenting the evolution of PBL height and would also provide information on aerosol content and its variation with height.

An airborne lidar would provide the same observations as a ground-based lidar, but for the purpose of three-dimensional mapping of the PBL and aerosols during particular time windows.

Soundings would document the convective instability characteristics and their evolution over time. Furthermore, soundings would provide direct measurements of PBL thermodynamic structure and serve as an independent measure of PBL height separate from profilers. Ideally, the sounding network for HEAT would consist of two stationary sites and two mobile sites. One or more stationary sounding sites may be taking

observations as part of TexAQS-II. Aircraft soundings may help fill gaps in the sounding network.

Tethersondes would provide low-level measurements of wind and temperature that would be particularly valuable in the urban environment where representative surface sites are difficult if not impossible to identify.

Measurements of the aerosol optical depth would allow assessment of the possibility of an aerosol-radiative feedback on the urban-rural environment.

Sea surface temperature measurements will be needed. These can be obtained through a combination of existing buoy, platform, and satellite observations.

4. Concluding Remarks

The suite of objectives, and the meteorological measurements needed to accomplish them, make HEAT a worthy successor to the METROMEX field program. The lightning, Doppler radar, and other measurements will allow the surface and PBL measurements described here to be directly connected to the effects of the urban (and coastal) environment on convective initiation, convective intensity, and lightning. The multiple purpose of radar measurements (cloud microphysics, cloud kinematics, and PBL kinematics) allows the study of the urban meteorology to take advantage of platforms that would otherwise be impractical for a pure heat island study.