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MODELING THE COMPLEX INTERACTIONS AMONG URBAN CLIMATE, AIR QUALITY, AND ADAPTIVE/REACTIVE HUMAN RESPONSE

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1. INTRODUCTION

It is well known that urban activities impact the local climate and air quality. What is not well understood is how human activity adapts and responds to changes in climate, air quality, and policy actions, and how the resulting feedback impacts the urban climate - air quality system. This poster summarizes the scientific goals and methods of a recently funded 4 ½ -year long project aimed at incorporating these feedback mechanisms in a new paradigm for integrated analysis of the urban climate-air quality-human response system. Additional project details can be found at www.fuse.pdx.edu.

2. RESEARCH OBJECTIVES

Our goal is to understand how the components of the urban atmospheric environment interact, with a particular emphasis on understanding and incorporating complex feedback mechanisms into an integrated modeling system that can be used to forecast human response to and impact on heat waves and episodes of poor air quality, and to test policy options for mitigation. In pursuing this goal we will seek answers to the following specific questions:

1. *What is the nature and importance of various feedback mechanisms in the urban climate – air quality – human response system?*
2. *Can improved representation of such mechanisms in a holistic analysis framework improve our understanding of how these interactions impact the urban environment?*
3. *How do heat waves and poor air quality episodes impact urban activity and emissions in the presence or absence of regulatory action or governmental advisories?*
4. *Do feedback mechanisms exist whereby a policy action intended to mitigate one problem exacerbates another?*

3. METHODOLOGY

The conceptual framework for this study is given in **Figure 1**. This framework consists of three layers: surface characteristics & infrastructure; the urban atmosphere; and human dimensions. The linkages among the components of this 3-layer system are labeled with numbered arrows. The research outlined below seeks to quantify each of these linkages.

The communication among the component modules is key to the successful coupling of the various feedback mechanisms in this complex urban climate - air quality - human response system. Although the system is solved in a sequential computational framework the linkage of modules at a small aggregate number of time steps provides necessary feedback at relevant time scales.

4. TEST SITES

While the science of the feedback mechanisms within the urban environment is the focus of this project there is a need to select specific sites for model development and performance evaluation. We will apply our model framework to two very different urban environments to assess the potential variability in the strength of the response functions. The test bed cities for this evaluation were selected based on a combination of factors – availability of validation data and ease of gathering additional information; past modeling experience; and ongoing research offering opportunities for synergistic collaboration.

Portland Oregon, while not widely viewed as a city with significant heat or air quality issues, is particularly vulnerable to environmental changes and increasingly affected by such problems. As suggested by recent health studie s (Davis et al., 2003; McGeehin and Mirabelli, 2001) the heat vulnerability stems from the relatively low penetration of air conditioning into residences and the general lack of acclimatization of the populace. Currently it is estimated that about one third of residential structures in the Portland metropolitan area have some form of air conditioning. Adding to this vulnerability is the increased susceptibility of the population to air quality and heat-related health problems due to a lack of prior exposure and acclimatization. At the same time, peak summer temperatures and incidence of heat waves in Portland have been on the rise in recent years - e.g., the Oregon DEQ called 2, 7, and 16 Clean Air Action Days (CAAD) in 2001, 2002, and 2003, respectively.

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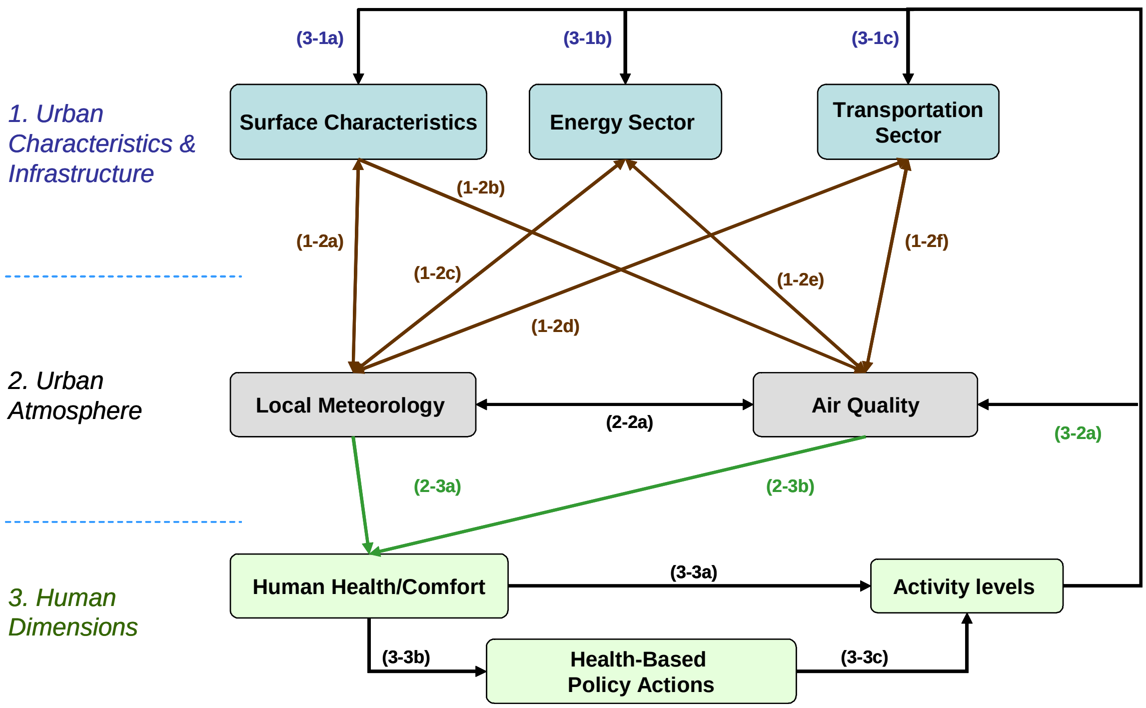

Figure 1. Framework and feedback network for the urban climate - air quality - human response system.

These conditions are likely to worsen in upcoming years due to two factors: (1) the city is growing and becoming more dense, resulting in increased emissions from various sources and a potentially larger urban heat island effect; (2) global climate change is projected to result in greater temperature elevations (both minimum and maximum) in northern latitudes (IPCC, 2001). These factors, combined with the general vulnerability of the urban population to climatic changes make Portland a particularly interesting city for study.

Houston Texas is among the most polluted urban regions in the country –fifth most ozone polluted city according to (ALA, 2002) - with 142 unhealthy ozone days over the period 1998-2000. The Houston-Galveston area is classified as "*severe"* by the EPA. In contrast with other regions, however, Houston has seen a steady decline in heat-related mortality rates with no excess mortality in the last decade (Davis et al., 2003). However, the significant air quality problems facing Houston have resulted in a tremendous amount of research activity in recent years – much of it focused on improving the accuracy of air quality models (e.g., Taha 2003c). The result is a city with exceptional availability of meteorological and air quality data, detailed gridded emissions inventories, as well as detailed urban surface characteristic data. Houston therefore represents an interesting contrast to Portland in terms of pollutant levels and the potential for dramatically different human response characteristics.

5. URBAN CHARACTERISTICS

The surface and infrastructure module will specify all surface characteristics (dynamic or fixed in time) to be used as boundary conditions in the atmospheric modules. This module can be used to test urban heat island mitigation strategies such as increases to urban albedo or vegetative cover. This module will also determine spatially resolved heat and moisture inputs associated with anthropogenic activities which vary with ambient weather and air quality as well as the presence/absence of health advisories.

6. URBAN METEOROLOGY

We are developing a modified version of the Penn State/National Center for Atmospheric Research mesoscale model (MM5 v3.6) for use in the meteorology module. In recent work we have successfully integrated static anthropogenic heating profiles (Sailor, D.J., 2003; Sailor, D.J. et al., 2003) and a representation of the diurnal variability of effective urban albedo (Sailor, D. J. and Fan, 2002) in the MM5. In addition to these modifications we will explore potential improvements in modeled urban meteorology to be obtained through explicit incorporation of an urban canopy parameterization (e.g., (Martilli et al., 2002). Our version of the MM5 currently uses an input file to specify the hourly variation of anthropogenic heating. The data for the input file are generated using detailed analysis of historical energy consumption and traffic patterns in the city of interest, but is based on representative weather patterns for different seasons (currently just summer and winter profiles). This formulation will be replaced by one in which the temperature-dependence and human response impacts on anthropogenic heating will be explicitly included.

We will implement the MM5 model in a nested structure using 5 nest levels. The outermost domain will be sufficiently large to capture synoptic scale forcing suitable for analysis of 3 to 5 day long heat wave/AQ episodes. To capture the details of the atmospheric structure in and above the urban PBL we will employ 35-40 non-uniformly spaced vertical levels, such that the lowest level corresponds to an atmospheric depth of ~10 m. We will explore various model physics options (e.g., Blackadar, MRF, and Gayno-Seaman PBL schemes) in an attempt to optimize model performance. Time steps will be selected to ensure model stability.

7. URBAN AIR QUALITY

We will base the air quality module on a modified version of the CAMx model, a state-of-science tool that has made significant inroads into scientific and regulatory applications and is being widely used by regulatory bodies in the US. Initially we will establish a baseline of model performance by running the photochemical model and meteorological model in a traditional sequential linkage.

The external drivers for photochemical modeling include: 1) the meteorological conditions produced in the meteorological simulation loop and 2) the human-response impacts, e.g., changes in traffic density, cooling (energy) needs and loads, or other actions related to heat and air-quality advisories. The updated emission rates (for power plants, mobile sources, biogenics, etc) and resulting pollutant mixing ratios (e.g., PM, O_3, NO_x, VOC) computed in this step and their related attributes will be passed back to 1) the meteorological model and 2) the human response model. The information passed back to the meteorological model will be used in updating the meteorology based on predicted species concentrations and related physical properties, such as optical depth and albedo/scattering, radiative forcing, PM and condensation nuclei, cloud cover and precipitation. The information passed back to the human impact module will be used to assess possible heat and health implications and potential reactions or actions taken in response.

In addition, it is important to capture the spatial and temporal variations in emissions as a function of changing meteorology and human response. Thus models of anthropogenic and biogenic emissions will be used for updating the grid-resolved emissions at each “time step” of the meteorology module. For the purpose of calculating emission rates of various pollutants, emission models will be modified to adapt for the time-scales and model linkages developed in this study. The system will also be used to update biogenic hydrocarbon emissions (isoprene and monoterpenes) for changes in temperature, solar radiation, atmospheric water vapor and CO_2, and spatially resolve them according to vegetative species distribution in the domains of interest.

At each time step the updated emission scenarios will drive the air-quality simulations, producing the species concentrations fields needed in the next step calculations for the meteorology and human response modules.

8. HUMAN DIMENSIONS

We will investigate how human activity levels respond to oppressive atmospheric conditions (heat and air quality) and health advisories in both test bed cities using a prospective longitudinal cross-sectional survey system to be activated at the conclusion of selected heat waves during the summers of 2005-2008. These surveys will be triggered in some instances by less severe conditions than those needed to trigger an ozone or heat advisory so that we can isolate response with and without the presence of advisories. This trigger will be designed based on analysis of 3-5 years of historical data so that there is a high probability of triggering multiple non-advisory surveys each summer. These panel studies will be supplemented by one-time surveys of major employers in each city. The Oregon DEQ currently contacts ~550 employers when an advisory (Clean Air Action Day) is called (Drake, 2003). A similar set of employers will be identified for Houston. Both sets will be surveyed to assess the actions they take during such advisories and to estimate the resulting impacts on emissions.

In each city we will enroll approximately 500 individuals representing a cross-section of the population. For purposes of avoiding participant fatigue we will subdivide each group into two panels of 250 subjects each. An initial recruitment survey (20-25 minutes in length) will establish baseline information. A version of this baseline survey will be repeated in each subsequent year to assess drift in the baseline.

Follow-on surveys (10-15 minutes each) will be conducted each summer shortly after episodes of poor air quality and/or oppressively hot conditions to assess human response to such conditions. Each sub-group will be surveyed on 2 to 3 occasions during each summer. The timing of the surveys will correspond to periods of excessive temperature and/or poor air quality and encompass both weekday and weekend episodes as well as episodes with and without accompanying health advisories. These surveys will also identify the way in which respondents obtain information regarding adverse health conditions, and their perceptions of the reliability of such information.

Variables for the human response analysis will be constructed using the Rasch rating scale model (Rasch, 1980) and Winsteps (Rasch measurement analyses software). The Rasch model is a probabilistic item response theory model that constructs an objective, latent scale through an iterative maximum likelihood calibration procedure. By employing this methodology, the raw ordinal data from the survey will be converted to interval scaled measures. Through calibration, each item and subject is measured on the latent scale in logits (log-odds units), which range in value from $-\alpha$ to α although typical values fall between -3 and 3. We will convert individual survey results to quantifiable aggregate measures of changes in transportation, energy consumption and emissions by linking these results with ancillary data and models. Specifically we will gather episode-specific daily and hourly data including traffic counts, electric utility loads, weather, and air quality parameters. We will also develop modified energy models (statistical as well as physically-based building energy consumption models) relating activity levels and behavior (e.g. thermostat settings) to energy consumption levels. This information will be compiled into a comprehensive set of modifier functions to be applied to baseline consumption and emissions profiles.

9. MODULE LINKAGES AND INTEGRATION

Initially we will implement the MM5 module in "restart" mode, periodically saving a complete set of model data. The output of the MM5 will be fed into the air quality model (CAMx), which is also to be run in restart mode. These two modules will be integrated forward in time for 30 minutes to 1 hour at which time the meteorological and air quality output will be used as input to the human response and emissions processor modules. The updated heat, moisture and pollutant emissions fields along with the modified atmospheric attenuation characteristics will then be fed back into the meteorological module and the entire system integration will repeat until the episode is complete.

The modules discussed above form the building blocks for the integrated system and will be designed under a common framework so that their integration will be straightforward. The entire system will be coupled in the final two years of the project and applied to specific test cases to evaluate its performance and the robustness with which it can be applied across different urban domains (e.g., the proposed two test cities).

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