The Mid-Michigan Heat Model: 
A Modeling Framework for Informing Decision Maker Response to Extreme Heat Events in Michigan Under Climate Change

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Project Summary

Extreme heat events are responsible for more annual deaths in the United States than other natural disasters combined, and global and regional climate models have indicated that more severe and longer lasting heat events are likely to occur in the upper Midwest over the next several decades. Epidemiological studies have contributed to the identification of populations vulnerable to extreme heat. However, local decision-makers still lack tools that would help them evaluate policy and management options to reduce heat risk for these vulnerable populations, and to prevent deaths and illness once a heat event arrives. We developed a system dynamics modeling tool, called the Mid-Michigan Heat Model (MMHM), to depict the dynamics of hospitalizations and deaths over the course of a heat event in Detroit. Modelers incorporated input from decision-makers at each stage of the model-building process, and the project culminated with a workshop in which potential model-users offered feedback on MMHM. The process of building a model in a participatory manner was useful for facilitating conversations and data-exchange around an important topic, and for developing a tool with the greatest potential utility. MMHM could be made more powerful and useful by adapting its framework to local circumstances for decision-making at the municipality scale, and by combining its dynamics with spatial modeling.

Problem Addressed in this Project

Global and regional climate change models have projected an increase in the frequency, duration and severity of extreme heat events in the upper Midwest. The frequency of hot days and the length of the heat-wave season will be more than twice as great under a higher emissions scenario compared to a lower one (United States Global Change Research Program, 2009). This means that heat waves equivalent to the one that killed over 700 people in Chicago in 1995 (Klinenberg, 2002) are projected to occur about once every three years in the Midwest under the lower emissions scenario, and nearly three times a year under the higher emissions scenario (Hayhoe, et al., 2010).

It has been known for some time that extreme heat events can cause increased incidence of human illness, hospitalizations, and death. The old, the young, and those with chronic health conditions are less able to perceive the stress on their bodies and are physiologically less able to withstand this stress (Khosla & Guntupalli, 1999; O'Neil, et al., 2009). Residents of urban areas are subject to the ‘heat island’ effect where pavement and structures retain heat, resulting in even higher and more persistent temperatures (Tan, et al., 2010). In addition, social factors such as poverty and isolation may limit the ability of some population subgroups to take actions to reduce their heat stress by for example, moving to an air conditioned building or shelter (McGeehin & Mirabelli, 2001). The health effects of extreme heat events therefore present an environmental justice problem.

Studies indicate that the relationship of extreme heat to adverse health effects is complex. It is not only the maximum temperature and humidity on a given day that can cause physiologic distress (Haines, et al., 2006). The duration of heat over a number of days, and in particular the elevation of minimum nighttime temperatures without a recuperative period can push the vulnerable into a health crisis (McGeehin & Mirabelli, 2001). Adverse health effects include heat stroke, heat illness, and exacerbation of chronic conditions such as asthma and cardiovascular disease (Kovats & Hajat, 2008; Lin, et al., 2009). Other research has suggested that the behavior and attitudes of vulnerable populations during a heat event are critically important determinants of how their health is affected. For example, individuals’ perceptions of their risk may spur them to take action during a heat event, or conversely, may preclude them from taking action (Wolf, et al., 2010). Local and state public health officials in Michigan have expressed concern that residents of cities such as Detroit and Ann Arbor are not using cooling centers during heat events; however, the reasons for this are not well understood. Any model that develops realistic options for intervention in the human health impacts of extreme heat events will have to depict the behavioral dynamics of the populations at whom the intervention is targeted.

In summary, the impacts of extreme heat on human health in the Midwest are complex, dynamic, and likely to become more severe under climate change. Responses to these impacts will necessarily involve communication and coordination among decision-makers at the state and local levels. To address both of these aspects of extreme heat, we chose to develop a prototype tool to shed light on the dynamics of human health during extreme heat events, presented in a format that is useful for local decision-makers.

Methods

We chose to build the model using a system dynamics framework in order to depict the dynamics of vulnerable populations (Appendix B). System dynamics can effectively integrate multiple types of information that describe the demographic, climatic, behavioral, and socio-economic aspects of heat events (Hirsch, et al., 2007; Schmitt Olabisi, et al., 2010). We used Stella™, a system dynamics software package with an interface that allows users to manipulate variables and observe the resulting change in model output. Two groups of stakeholders were involved in building the model, which was named the Mid-Michigan Heat Model.
(MMHM). During the first data collection stage, we interviewed eight key stakeholders in central and southeastern Michigan who are knowledgeable about the dynamics of heat events and their impacts on human health. These interviewees were selected by the full project team, and included people from the Michigan Department of Community Health, the Department of Environmental Quality, academic institutions, and local public health departments. Some members of the project team were also interviewed, in order to mine their knowledge on heat events in a structured setting. The interviews were transcribed and analyzed for key variables and relations to be included in the model (Vennix, 1996). The literature on heat events was also consulted to build the model structure.

After the initial model structure was constructed from the interviews, the project team met to review the model and suggest revisions and clarifications. The modelers obtained data to parameterize the model from the literature, and from surveys conducted by Washtenaw and Ingham counties. These surveys provided data on behavior during heat events.

The modelers collected heat event records from the National Weather Service for weather stations in the Detroit area, and hospitalization data from Ingham, Washtenaw, and Wayne counties, as well as hospitals in metropolitan Detroit. However, deriving a relation between heat and hospitalizations during heat events in Detroit was not feasible, because the number of excess hospitalizations that could be attributed to heat were low enough to be within the model's margin of error. Instead, the modelers parameterized the relation between heat and hospitalizations/deaths in the model using data from the 1995 Chicago heat wave (McGeehin & Mirabelli, 2001; Semenza, et al., 1999; Semenza, et al., 1996). After developing appropriate relations among the variables in the model, the modelers ran the model through several heat wave scenarios to check for internally consistent model behavior.

The second group of stakeholders involved in the model-building process were invited to a workshop in May, 2012, to evaluate the prototype model. The workshop participants were recruited from stakeholder groups with ties to the project team, and were chosen for their potential interest in the MMHM as a decision support tool (for a list of the organizations represented in the workshop, see Appendix D). At the workshop, two different models were introduced and explored, with the help of a facilitator: the MMHM, and the I-HEAT tool. I-HEAT is a spatial mapping tool developed in collaboration between the researchers at the University of Michigan School of Public Health and Biomedware.

Each tool was described briefly by its respective model-building team, after which workshop participants had the opportunity to interact with both MMHM and I-HEAT and offer individual written feedback. The workshop ended with a group discussion of the utility of each model and how the participants might use them to support their decision-making processes.

After the workshop, the modelers made revisions and additions to the model based on the feedback from workshop participants. Significant revisions to the MMHM model included a re-organization of the interface (See Appendix A), corrections to some of the model logic describing when a heat ‘watch’ or ‘warning’ is designated; and a more sophisticated structure describing vulnerable populations’ willingness to take action during a heat event.

**Decision-Maker Engagement**

Because our main project goal was to develop a tool that is useful for local decision-makers responding to extreme heat events, we made efforts to engage decision-makers at each stage of the model building process. Our project team was comprised of academics and decision-makers at state agencies, and the research objectives were developed through this collaboration. As described above, we consulted local experts to decide which variables should be included in the model, and how these variables should relate to one another. The tool was debuted at a workshop designed to elicit feedback from decision-makers in Detroit and other municipalities who might work with the model. The project activities were consistent with the dual objectives of a participatory modeling approach to problem solving: to represent the ways in which the components of a human-natural system interact, and to foster dialogue among scientists, decision-makers, and affected populations. The interviews and the workshop were intended both to uncover important information about heat events, and to provide opportunities for decision-makers and academic scientists to interact around this information.

**Findings**

**Model Findings**

The model was designed to run numerous scenarios based on changes in such factors as temperature, percent of population with air conditioners and transportation, and number of cooling centers. In a scenario designed to mimic the Chicago heat wave of 1995, model output depicted a total of 60 deaths and 64 hospitalizations over the course of the heat wave (Figure 1). This number seems realistic, but at this point cannot be validated, because records of morbidity and mortality in Detroit during recent heat
events have not yet been compiled and analyzed. This type of data analysis was beyond the scope of the project, but future studies should make this work a priority.

Assuming a consistent vulnerable population of approximately 820,000 people, deaths and hospitalizations in the model were highly sensitive to a brownout situation (in which vulnerable Detroit residents did not have access to air conditioning), to increased access to air conditioning, and to the presence of a media campaign, which would inform Detroit residents about the dangers of extreme heat and actions they could take to avoid harm (Table 1). The model was highly insensitive to the number of cooling centers open, whether these cooling centers could accommodate pets, and access to public transportation. This is because, in the absence of a media campaign informing vulnerable residents where they should go during an extreme heat event, opening cooling centers and providing transportation would not guarantee that people would go to the centers.

**Workshop Findings**

During the workshop, participants were observed to be engaged with the model, assisted by the modelers at each table. Modelers reported that the participants asked frequent questions about how the model was constructed, and what assumptions and data relations went into building it. One of the most commonly cited ‘weaknesses’ of the model was that these assumptions and relations were not always transparent; several participants suggested that a model guide be distributed along with the model (the full text of workshop participants’ model evaluation is contained in Appendix C).

The modeling team repeatedly emphasized MMHM’s purpose as a prototype model for exploring the relative impacts of various proposed policies on deaths and hospitalizations during heat events, rather than as a

<table>
<thead>
<tr>
<th>Variable Description</th>
<th>Baseline Setting</th>
<th>Alternate Setting</th>
<th>Effect on Deaths (compared to baseline scenario)</th>
<th>Effect on Hospitalizations (compared to baseline scenario)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Brownout?</td>
<td>No</td>
<td>Yes</td>
<td>+ 92%</td>
<td>+ 58%</td>
</tr>
<tr>
<td>Percentage of homes with air conditioning</td>
<td>30% have A/C</td>
<td>All have A/C</td>
<td>- 98%</td>
<td>- 100%</td>
</tr>
<tr>
<td>How many cooling centers?</td>
<td>2</td>
<td>20</td>
<td>+/- 0%</td>
<td>+/- 0%</td>
</tr>
<tr>
<td>Accommodation of pets at cooling centers?</td>
<td>None</td>
<td>100%</td>
<td>+/- 0%</td>
<td>+/- 0%</td>
</tr>
<tr>
<td>Proportion of people who encounter media message about heat</td>
<td>0</td>
<td>100%</td>
<td>-95%</td>
<td>- 83%</td>
</tr>
<tr>
<td>Urban heat island effect</td>
<td>4.3 degrees</td>
<td>0 degrees</td>
<td>- 70%</td>
<td>- 39%</td>
</tr>
<tr>
<td>Access to public transportation</td>
<td>38% of vulnerable population</td>
<td>100% of vulnerable population</td>
<td>+/- 0%</td>
<td>+/- 0%</td>
</tr>
</tbody>
</table>

*Table 1. Sensitivity analysis for Mid-Michigan Heat Model. Baseline conditions represent a 1995 Chicago-style heat wave in Detroit with the settings in the second column (No brownout, 30% of homes with A/C, etc., which results in 60 deaths and 64 hospitalizations.*
predictive tool. Nearly all workshop participants understood and seemed comfortable with these qualifications. Overall, they liked the ability to explore scenarios and think about the implications of various actions for alleviating the human health impacts of heat events. Several participants liked the ability to change parameters and watch the model ‘react’, thereby learning about the modeled system.

Workshop participants also appreciated the I-HEAT tool for its spatial detail and its utility in planning city-wide responses to extreme heat events. Several participants commented that they would like to see a tool that combines the strengths of I-HEAT and MMHM.

Key lessons on conducting climate assessment work in the region

1. Participatory modeling is a valuable tool for applying climate data to decision-making needs in the Midwest. In our case, the stakeholders involved in defining the research problem and the model structure were not the same as those who evaluated the model. In the future, modeling workshops could be held at the community level to develop coordination and communication among decision-makers around a problem related to climate change. For example, planners, county health officials, emergency responders, and mayors could co-design a model of an extreme heat event in their city together with scientists, using our model prototype as an example or template. This exercise and the resulting model could help them plan for future heat events.

2. Decision-makers need spatial, dynamic information about the impacts of heat on human health in their regions. Working with the University of Michigan and Biomedware teams, we have submitted an application to the National Institutes of Health to integrate the system dynamics approach of the MMHM with the spatially explicit information provided by the I-HEAT model. We intend to follow up on developing a dynamic, spatially explicit tool, given available funding.

3. Much more research needs to be conducted on the effects of climate change on human health in the Midwest region. Extreme heat, air pollution, water pollution, and vector-borne diseases are all expected to increase under climate change, with potentially serious consequences for human health. Moreover, all of these drivers will interact in complex and dynamic ways, which could be addressed through a comprehensive modeling framework.

References


Appendix A: Model Interface with Baseline Model Settings

Appendix B: Model Structure

B.1. Overall model structure.
B.2. Main model structure.
B.3. Ability to leave home module.

B.4. Media module.
Appendix C: Workshop Feedback on MMHM Model

Strengths

- easy, intuitive use.
- being able to manipulate multiple factors to see additive effects
- useful for making policy decisions: i.e., cooling center vs. vegetative cover
- opportunity for implementation (permutations?)
- allows you to understand the interaction among variables
- reduction of urban heat island effect variable
- mechanistic approach to understanding how people respond to heat events
- the mechanisms are well thought out and backed up by data. the relationships seem realistic and are calibrated(?)
- edit weather (heat index) to run different scenarios. can be used as guidance in an operational setting
- the outcome of the various variables and the interdependency of them
- powerful tool, relatively easy to use interface
- complexity and comprehensiveness of the model. realism
- the first model (that I’m aware of) that incorporates human behavior into what happens during a heat event -- though this is critically important
- we can adjust the settings for whatever type of scenario we have because extreme heat events vary greatly by region and this model allows us to localize information to our specific situation
- ability to manipulate key variables and see how other items/outputs are impacted
- adjustability of the different variables. allows counties #s of scenarios, because every scenario is different
- ability to experiment with alternate management strategies
- get decisionmakers talking about all the variables (individual level and community level)
- allows you to experiment with multiple actions and see potential effects

Limitations

- the clarity of what's behind the variables. e.g., Brownout? How long does this event occur and at what time of day?
- no definitions for variables or explanation of data sources
- complexity of the model may lead to uncertainty in understanding the interaction of components
- knowing what realistic/actual numbers to plug into the model as a starting point
- assumptions are hard to understand without background materials. most people wouldn’t understand how to change any particular variable
- data is somewhat coarse: finer grain may be helpful
- human behavior is difficult to estimate (what variables should influence use of cooling centers, for example)
- more information explaining the different variables
- some of the variables on the interface aren’t actually realistically changeable. I think the interface needs to be more user-friendly and more aesthetically pleasing
- having all users with knowledge base to know how to use the other variables
- explanation of parameters. refinement of interface
- complexity = harder to communicate. yes, ying-yang [Note: this "limitation" was connected to a "strength" comment relating to the value of complexity
- not thoroughly validated / sensitivity analysis conducted
- how likely this model is going to predict a situation
- not robust in terms of variables -- many variables lacked in detail, unclear as to relevance (e.g., use Ingham or Wash. survey data for Detroit)
- cannot run for small areas like zip code or neighborhood scale. a local health department will want to know specifically where to direct resources
- parameters such as ‘reduction in urban heat island effect’ did not translate directly to mgt. choices
- assumptions - although I don’t see this as too problematic so long as they are clearly defined (I like the pop up boxes that do this)
- doesn’t show uncertainties (just a single # of deaths + hospital admissions). also: the pdf documenting data source/assumptions should be a handbook, multipage - not just 1-2 pages
Appendix D: List of Organizations Represented at Stakeholder Workshop Held in Detroit May 2, 2012

- Great Lakes Integrated Sciences & Assessments Center
- University of Michigan School of Public Health
- Michigan State University
- Michigan Department of Community Health
- Oakland County Health Division
- Michigan Environmental Council
- Washtenaw County Public Health Department
- Detroit Office of Homeland Security and Emergency Management
- National Weather Service Forecast Office, Detroit/Pontiac
- Data Driven Detroit
- Biomedware
- Detroit Office of Homeland Security
- Detroit Department of Health and Wellness Promotion, Office of Public Health Emergency Preparedness
- City of Grand Rapids Planning Department
- Michigan Department of Environmental Quality