System for Integrated Modeling of Metropolitan Extreme heat Risk (SIMMER)

Final Report to NASA

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Introduction

Extreme heat is a leading cause of weather-related human mortality in the United States and in many countries world-wide. Vulnerability to extreme heat is amplified in large cities due to the urban heat island and socioeconomic diversity. Climate change is projected to increase the severity, frequency, and duration of extreme heat events, which may put more people at risk for heat-related mortality and morbidity. The System for Integrated Modeling of Metropolitan Extreme heat Risk (SIMMER) project focused on understanding extreme heat, human health, and urban vulnerability in present and future climates. The primary goals of SIMMER were to: 1) advance the methodology for assessing current and future urban vulnerability from heat waves through the integration of physical and social science models, research results, and NASA data; and 2) develop models and tools for building local capacity for heat hazard mitigation and climate change adaptation in the public health sector.

SIMMER employed a novel extreme heat vulnerability framework (Wilhelmi and Hayden, 2010) and focused on specific research objectives: 1) Characterize and model present and future extreme heat events at regional and local scales; 2) Improve representation of urban land cover and its accompanying radiative and thermal characteristics at local and regional scales; 3) Determine the combined impact of extreme heat and the characteristics of urban environmental and social systems on human health; and 4) Characterize societal vulnerability and responses to extreme heat (i.e., mitigation and adaptation strategies).

The project included regional- and local-scale analyses. The regional-scale study domain covered the contiguous United States and portions of southern Canada at ~ 15 km^2. A local, intra-urban scale (1 km^2; U.S. Census block group) study was conducted in Houston, Texas, the fourth largest city in the U.S. Our team collaborated with scientists and public health practitioners in Houston, as well as Toronto, Canada to ensure that the concepts, methods and models developed for Houston are applicable to other cities. Key findings are presented below.

Present and future extreme heat events at regional and local scales

Oleson et al. (2013) used an urban canyon model coupled to a land surface model to quantify present-day and projected mid-21st century rural and urban heat stress for boreal summer over the U.S. and southern Canada and examine the effects of three urban density classes on heat stress. Simulations were validated versus the NASA/NOAA North American Land Data Assimilation System (NLDAS). Five indices of heat stress were implemented in the model [the NWS Heat Index (HI), Apparent Temperature (AT), Simplified Wet Bulb Globe Temperature, Humidex, and Discomfort Index]. The present-day urban-rural contrast in heat stress differs according to which index is used. Future urban heat stress is amplified by 0.5–1.0 °C for the AT, HI, and Humidex compared to temperature alone. Both Houston and Toronto showed an increase in the number of heat stress days and nights. Houston exhibits noteworthy mid-century increases in high heat stress nights, with more than half of summer nights qualifying as high heat stress, indicating the need for extreme heat adaptation strategies.

Monaghan et al. (2014) performed high spatial resolution (1 km^2) urban climate simulations for 2003–2012 over Greater Houston with the High-Resolution Land Data

Assimilation System (HRLDAS). Simulated temperature and heat indices quantify the intra-urban distribution of heat and were used as inputs to vulnerability and health models. Simulations were validated versus NASA MODIS land surface temperature (LST) fields.

Satellite thermal remote-sensing data are potential observational sources for urban climate model validation with comparable spatial scales, temporal consistency, broad coverage, and long-term archives. However, sensor view angle, cloud distribution, and cloud-contaminated pixels can confound comparisons between MODIS LST and modeled surface radiometric temperature. Hu and Brunsell (2013) examined the impact of cloud cover on LST and the surface urban heat island (SUHI) and quantified the impact of temporal aggregation on LST and SUHI in Houston, Texas using MODIS LST products from 2000 to 2010. The results show that 1) the SUHI values are more notably enhanced in the daytime than nighttime with an increasing trend with larger composite periods. 2) The influences of aggregation in the spring and summer are larger than autumn and winter for the daytime. 3) Temporal aggregation impacts the spatial pattern of the SUHI implying that the higher SUHI regions are more likely to have a larger gap between two composite scales and this is related to the amount and distribution of clouds. To minimize the confounding factors of clouds Hu et al. (2014) proposed and evaluated several model validation methods using MODIS data and simulations from the HRLDAS.

Role of urban land cover in modeling intra-urban distribution of heat

The project quantified the importance of explicitly characterizing urban properties to improve urban meteorological simulations. The accuracy of simulations of the urban canopy can be degraded by inaccurate or oversimplified representations of the urban-built environment within models. Monaghan et al. (2014) explored the model accuracy gained by progressively increasing the complexity of the urban morphology representation in an urban canopy model. The fidelity of the simulations is primarily assessed by a spatiotemporally consistent comparison of a newly developed HRLDAS radiative temperature variable with MODIS LST. The most accurate urban simulations of radiative temperature are yielded from experiments that (1) explicitly specify the urban fraction in each pixel and (2) include irrigation.

Feddema and Liu (2014) developed a new dataset of building properties and examined how building wall variables influence the MODIS LST in Houston using multiple stepwise regression analyses of LST in relation to impervious surface fraction (ISF), albedo, distance to water bodies, and seven major wall types based on 1 km^2 grid. The results demonstrated that both biophysical and building wall variables significantly influenced the spatiotemporal variations of LST. ISF is the most significant variable to explain the variation of LST. In contrast, high albedo materials and presence of open water bodies could mitigate the heat island effect. Furthermore, the building wall variables all increase the LST at daytime and nighttime, but different wall materials have different effects on LST.

Combined impact of extreme heat, environmental and social characteristics on human health

Heaton et al. (2014) combined excess non-accidental mortality counts, HRLDAS simulations, U.S. Census and parcel data into an assessment of vulnerability to heat in Houston, Texas. Specifically, a hierarchical model with spatially varying coefficients was used to account for differences in vulnerability among census block groups. Daily minimum temperatures and composite heat indices (e.g. discomfort index) provided a better model fit than other heat measurements. Neighborhoods with high percentage of elderly, low income, African American, and socially-isolated populations had strong associations with high relative risk heat-related mortality. Positive interactions between elderly populations and heat exposure were found suggesting these populations are more sensitive to increases in heat.

Heaton et al. (2015) analyzed heat-related 911 calls to 1) build a statistical model that can be used as a public health tool to predict the volume of 911 calls given a time frame and heat exposure and 2) investigate weather conditions that result in a high call volume. We found that spatial regions of high risk for heat-related 911 calls are temporally dynamic with the highest risk occurring in urban areas during the day. We also find that elderly populations are at increased risk for heat-related illnesses at cooler temperatures than younger populations. The age of individuals and hour of the day with the highest intensity of heat-related 911 calls varies by race/ethnicity. The weather variables used in both Heaton papers were informed by NASA data, including NLDAS and MODIS.

Societal vulnerability and the responses (i.e., mitigation and adaptation strategies)

To better understand the demographics and adaptive capacity of populations vulnerable to heat Hayden et al. (2015) conducted a comprehensive, semi-structured telephone survey of 901 households in Houston, Texas. The survey identified non-home owners, African American and Hispanic/Latinos, those with incomes less than $20,000 per year, unemployed and those in poor health to be most vulnerable to heat stress. Additionally, findings indicate that these populations have little or no knowledge of the symptoms of heat stress, nor do they know where the closest cooling center is. Often, financial barriers restricted the use of an air conditioner at home, where they felt the greatest number of participants reported symptoms of heat stress. A stakeholder survey was also conducted, and the results showed consensus that heat stress would become an increasing issue in the future and populations with underlying medical conditions, senior citizens, and minorities were at an increased risk. Both surveys helped to contextualize population vulnerability and identify targeted intervention strategies and adaptation actions.

Strategies for building local capacity for heat hazard mitigation and climate change adaptation were discussed and outlined at the stakeholder workshops in Houston and Toronto (Wilhelmi and Hayden 2015). Stakeholders in Houston identified specific actions focusing on improvement of cooling centers, heat risk communication and awareness, public policy, and inter-agency coordination. Stakeholders in Toronto determined short- and long-term methods of integrating SIMMER into public health preparedness and response tools (Hart et al. 2014).

Decision-support tools with usable, actionable information have been developed for the stakeholders, researchers and the public. Web-based applications ("Beat the Heat in Houston" and "Extreme Heat Climate Inspector") communicate complex, multidisciplinary concepts of urban heat vulnerability and aid in public health interventions, protective decision-making, and climate change adaptations.

Summary

The project quantified the importance of characterizing urban properties in urban meteorological simulations, and the role of adaptive capacity in understanding vulnerability to extreme heat. New methods for accurately estimating urban LST from MODIS have been proposed and tested. Climate model simulations project high heat stress days and nights in the U.S. will increase substantially by the mid-21st century. New statistical methods for modeling risk of heat related mortality and morbidity advance our understanding of heat risk factors, and the spatiotemporal distribution of vulnerability within cities. Results have been discussed in the context of public health policies and interventions through a stakeholder engagement process.

Publications cited in the report

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Other SIMMER publications

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Presentations about SIMMER at Workshops, Seminars and Conferences

Banerjee, D., V. Nepal, M. Hayden, and O. Wilhelmi, 2012: Vulnerability to heat related illness in Houston, Texas: Who reports suffering the most from symptoms? *American Public Health Association 140th Annual Meeting*, San Francisco, CA

Barlage M., Monaghan A., Wilhelmi O., Oleson K., Feddema J., and Brunsell N., 2011: Urban Modeling over Houston in Support of the System for Integrated Modeling of Metropolitan Extreme Heat Risk (SIMMER), *AGU Fall Meeting*, December 5-9, 2011, San Francisco, CA.

Conlon K.C., Monaghan A., Hayden M., and O. Wilhelmi, 2014: Modeling Future Heat-Related Exposure for Houston, Texas, *26th International Society for Environmental Epidemiology*. August 26 2014, Seattle, WA.

Conlon K.C., Monaghan A., Hayden M., and O. Wilhelmi, 2014: Modeling intra-urban extreme heat exposure with fine-scale land use data. *20th International Congress of Biometeorology*. September 29 2014, Cleveland, OH.

Hayden M. 2014: Weather, Climate and Health Research at NCAR, University of Colorado School of Public Health. Denver, CO. May 2014. Invited.

Hayden M. 2014: Weather, Climate and Health Research at the National Center for Atmospheric Research, Ministerio de Salud Publica. Invited. Quito, Ecuador. March 2014.

Hayden M. 2014: Weather, Climate and Health Research at the Science-Policy Interface at NCAR, Instituto Nacional de Meteorolgia e Hidrologia (INAMHI). Invited. Guayaquil, Ecuador. March 2014.

Hayden M. 2014: Weather, Climate and Health Research at the National Center for Atmospheric Research", Universidad Catolica Ecuador (PUCE). Invited. Quito, Ecuador. March 2014.

Hayden M. 2014: Reducing urban vulnerability to extreme heat: an integrated approach, *San Antonio Environmental Challenges: Opportunities in Resilience*. Invited. San Antonio, TX February 2014.

Hayden M. 2013: Weather, Climate and Health Research at the National Center for Atmospheric Research. Kenya Medical Research Institute. Invited. Kisumu, Kenya. June 2013.

Hayden M. 2012: Weather and Climate Related Health Impacts. Emory University. Atlanta, GA. Sept. 2012. Invited.

Hayden M. 2012: Challenges in Addressing Weather and Climate Sensitive Health Impacts. *NCAR TOY workshop - Uncertainty in Climate Change Research: An Integrated Approach.* Boulder, CO. August 2012.

Hayden M, Monaghan A, and Wilhelmi O. 2012: Colorado State University School of Public Health. Fort Collins, CO. April 2012. Invited. “Weather, climate and health research at the National Center for Atmospheric Research”.

Hayden M, Monaghan A, and O. Wilhelmi, 2011: Weather, Climate and Human Health. University of Arizona School of Public Health. Tucson, AZ. October, 13, 2011. Invited.

Hayden M, Monaghan A, and Wilhelmi O. 2011: Weather, Climate and Human Health. Colorado State University. Fort Collins, CO. April 20, 2011. Invited.

Hayden M. 2014: Climate Change, Human Health and the Well-Being of Vulnerable Communities. Joint Center for Political and Economic Studies. Washington, DC. July27, 2010. Invited Keynote Speaker.

Heaton, M. 2013: Examples in Exploiting Space-time Correlation to Enhance Statistical Inference. University of Connecticut Department of Civil and Environmental Engineering Seminar. Storrs, CT. November 2013. Invited.

Heaton, M.J. et al. 2013: Identifying Risk Factors for Heat-Related Mortality," *Joint Statistical Meetings*, Montreal, CA, August 2013.

Heaton, M.J. et al. 2013: Analyzing a Marked Point Pattern of 911 Calls for Heat-Related Illnesses to Assess Heat Stress Vulnerability," *Next Generation Climate Data Products* Workshop, Boulder, CO, July 2013.

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Hu, L., N. A. Brunsell, A. J. Monaghan, M. Barlage, and O. V. Wilhelmi, 2013: How can we use MODIS land surface temperature to validate longterm urban model simulations? *AGU Fall Meeting*. 9-13 December, San Francisco, CA.

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Monaghan, A.J., et al. February 2014: Urban Modeling in Support of Characterizing Extreme Heat Vulnerability. *94th AMS Annual Meeting*, Atlanta, GA.

Monaghan, A.J., et al., October 2013: High resolution simulations of the urban heat island. *SIMMER Workshop: Linking Complex Science to Policy for Heat-Health Decision Making*, Toronto, Canada.

Monaghan, A.J., et al., July 2013: Local Climate Modeling. *Fifth Biannual NCAR Colloquium on Climate and Health*, Boulder, CO.

Monaghan, A.J., M.H. Hayden, and O. Wilhelmi, September 2011: The Weather, Climate and Health Program at the National Center for Atmospheric Research. *ISPRS Symposium on Advances in Geospatial Technologies for Health*, Santa Fe, NM.

Oleson, K.W., 2014: Recent developments and research with the Community Land Model Urban (CLMU), *Land Model Working Group Meeting*, February 24-26, Boulder, CO.

Oleson, K.W., 2014: Representing urban areas in climate models: the Community Land Model Urban (CLMU), *CLM Tutorial*, February 18-21, Boulder, CO.

Oleson, K.W., et al., 2013: Representing urban areas and heat stress in climate models (CESM), *SIMMER Workshop: Linking Complex Science to Policy for Heat-Health Decision-Making*, October 24-25, Health Canada, Toronto, Canada.

Oleson, K.W., 2013: Representing urban areas in global climate models: progress and data needs, *Urban Landscapes and Climate Change: From Measurements to Modeling*, August 27-28, Argonne National Laboratory, Illinois.

Oleson, K.W., 2013: Toward representing urban areas in global climate models (CESM): Model overview and some results from SIMMER, *National Renewable Energy Laboratory*, June 26, Golden, CO.

Oleson, K.W., et al., 2013: Poster Presentation: Interactions between urbanization, heat stress, and climate change, *18th Annual CESM Workshop*, June 17-20, Breckenridge, CO.

Oleson, K.W., 2012: Building energy parameterization in the Community Land Model Urban (CLMU), *Integrated Assessment Modeling Group Annual Meeting*, July 19-20, Boulder, CO.

Oleson, K.W., 2012: The Community Land Model Urban (CLMU): A tool for societal dimensions research, *17th Annual CESM Workshop*, June 18-21, Breckenridge, CO.

Sain, S. et al. 2013: "Climate, health, and vulnerability in urban populations," *AAAS Annual Meeting*, Boston, MA, 2/17/2013 (invited).

Sain, S. 2014: "Solving the Earth's equations: Mathematics and statistics at NCAR," *2014 Front Range Applied Mathematics Student Conference*, Denver, CO, 3/1/2014 (Keynote address)

Sain, S. 2012: "Statistical science at NCAR," Dept of Applied Mathematics and Statistics, Univ of California, Santa Cruz, 12/3/2012 (departmental seminar)

Sain, S. 2012: "Statistical science at NCAR," Dept of Mathematical and Statistical Sciences, Univ of Colorado, Denver, 10/31/2012 (departmental seminar)

Wilhelmi, O. and J. Boehnert, 2014. Building local capacity for heat hazard mitigation and climate change. *Esri International User Conference*, San Diego, July, 2014

Wilhelmi, O., M. Hayden, J. Boehnert, and U. Lauper, 2014: "Extreme Heat and Human Health: Science-Policy Interface", Stanley A. Changnon Symposium, the AMS 94th Annual Meeting, 4 February 2014, Atlanta, GA.

Wilhelmi, O., M. Hayden, J. Boehnert, and U. Lauper, 2013: "Extreme Heat and Human Health: Science-Policy Interface," *SIMMER Workshop: Linking Complex Science to Policy for Heat-Health Decision Making*, October 24-25, Toronto, Canada.

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Wilhelmi, O., M. Hayden, T. Greasby, and J. Pelzman, System for Integrated Modeling of Metropolitan Extreme Heat Risk, 2013: *Annual Meeting of Society for Applied Anthropology*, March 22, 2013, Denver CO (invited)

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Wilhelmi, O., R.E. Morss, M. Hayden, L. Dilling, G. Meehl. 2012: Extreme Weather and Societal Vulnerability in a Changing Climate, *American Meteorological Society Annual Meeting*, January 2012 New Orleans, LA

Wilhelmi, O. 2011: Extreme Heat and Societal Vulnerability in a Changing Climate, *The National Academies, Board on Atmospheric Sciences and Climate, Urban Meteorology: Scoping the Problem, defining the needs, Summer 2011 Community Workshop*, July 27, 2011, Wood Hole, MA (invited)

Wilhelmi, O. 2010: Societal vulnerability and adaptive capacity to extreme heat. *Washington AVOID workshop*, American Geophysical Union, Washington, DC, September 14-16, 2010 (invited)

Workshops:

SIMMER Workshop: Linking Complex Science to Policy for Heat-Health Decision Making, October 24-25, 2013, Toronto, Canada.

Extreme Heat and Health in Houston: Reducing Future Impacts. Stakeholder Workshop, August 29, 2013, Houston, TX

SIMMER Project Team Annual Workshops in 2010, 2011 and 2012 in Boulder, Colorado.

Web-based data visualization and distribution applications:

Extreme Heat Climate Inspector: https://gis.ucar.edu/projects/simmer
Beat the Heat in Houston:
http://ncar.maps.arcgis.com/apps/PublicInformation/index.html?appid=9d69e48135554580a25fed921c1a4d6b