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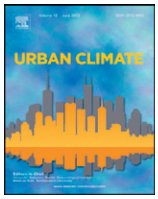

Predicting surface temperature variation in urban settings using real-time weather forecasts

Maryam Karimi [a,b], Brian Vant-Hull [c], Rouzbeh Nazari [d,*], Megan Mittenzwei [d], Reza Khanbilvardi [c]

[a] *Columbia University Mailman School of Public Health, 722 W 168th Street, New York 10032, United States*
[b] *The Graduate Center, the City University of New York, 365 5th Avenue, New York 10016, United States*
[c] *NOAA Crest, City College of New York, 160 Convent Avenue, New York 10031, United States*
[d] *Department of Civil and Environmental Engineering, Rowan University, 211 Mullica Hill Rd, Glassboro, NJ 08028, United States*

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ABSTRACT

Densely populated cities experience adverse effects of Urban Heat Island (UHI) including higher numbers of emergency hospital admissions and heat related illnesses. Studying UHI effects and temperature variations has become even more important as global temperatures continue to rise. To better understand UHIs within New York City, an exploratory study was done using a field campaign to measure high resolution spatial and temporal temperature variations within Manhattan's urban setting. These time correlated temperature measurements along with weather model data of temperature and relative humidity were used to predict temperature variability using weather forecasts. The amplitude of spatial variations was most dependent on temperature ($r = 0.400$) and low level lapse rate ($r = -0.258$) while temporal variations were most dependent on temperature ($r = 0.398$), low level lapse rates ($r = -0.361$), and mid-level lapse rate ($r = -0.320$). Regression of weather variables can be used to predict the amplitude of spatial and temporal variation in temperature within a city for each day. This study directs attention towards high resolution near-surface air temperature analysis and offers a new look at surface thermal properties. The application of the resulting data and modeling is most suitable for forecasting microscale variability in urban settings.

* Corresponding author.
E-mail address: nazari@rowan.edu (R. Nazari)

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1. Introduction

UHI effects or local hotspots are common phenomenon experienced in urban settings. These concentrated areas of elevated temperature “represent one of the most significant human–induced changes to Earth's surface climate” (Zhao et al., 2014). UHI is caused by lack of evapotranspiration, waste heat produced by air conditioning, industries and vehicles, air pollution and radiative trapping due to land surface modification in cities (Oke, 1982). The above factors lead to increase in air and surface temperature in urban centers and convection of heat from surface temperatures into the lower atmosphere. Local climate can impact UHI and alter convection patterns, and so statistical models of local climate/weather may help create forecast models for predicating temperature variations at surface level (Zhao et al., 2014). A number of heat transfer mechanisms that vary throughout a city can cause variations in air temperature. For instance, absorption of sunlight will vary by albedo and shading due to building materials and geometry. Infrared radiation is absorbed and re-radiated by surrounding structures, so that variations in exposure to the sky (sky view fraction) will cause variations in radiation cooling. These factors affect surface temperature, which is transferred to the air depending on wind flow. More exposed areas will have both more radiation cooling as well as faster wind flow, so that the heat transfer per volume of air is less, leading to cooler air temperatures. Note that weather variables may have dual effects: higher wind may result in greater air temperature contrasts between exposed and sheltered areas while mixing air between areas. Full cloud cover will produce less variation due to solar heating, and also less variation due to infrared cooling. In studying UHI effects understanding inner city temperature variations are important because health impacts are a sensitive function of temperature (Kinney et al., 2013), so temperature variability within a densely populated area can have large effects.

The U.S. EPA Climate Change Indicators report released its extreme heat section statement of May 2014 specifying that “the number of increased heat-related deaths in the future is going to be greater than the number of reduced cold-related deaths” (2014). “Heat is the number one weather-related killer in the U.S. alone” (U.S. Environmental Protection Agency, 2014). Profound impacts of UHI are seen on the lives of those who reside in cities (Zhao et al., 2014). Hotter days are associated with serious health impacts, heart attacks and respiratory and cardiovascular diseases (Kenward et al., 2014). Extreme climate events are predicted to increase in number, duration, and frequency with on-going climate change (Astrom et al., 2011). In recent decades, several devastating heat waves have caused large health consequences across the globe. For example, the 1987 heat wave caused around 2000 deaths in Athens; the 1995 Chicago heat wave caused around 700 deaths; and the 2003 heat wave in Europe was estimated to have caused 70,000 deaths (Katsouyanni et al., 1988; Semenza et al., 1996).

Densely populated cities like Manhattan can be affected by the impact of UHI much more than less populated cities. Urbanization increases “the diurnal minima and the daily means in all seasons” (Karl et al., 1988). Manhattan lacks evaporative cooling from vegetation and moist soil, and retains heat with its buildings and pavements which causes radiative trapping in canyons. The typical physical features of Manhattan's land surface and its mixture of land cover reacts differently with UHI, causing smaller islands of urban heat throughout the city (Grimmond, 2007). As the impact of UHI increases so does the health risks of heat wave. Even though many studies have been focused on the impact of UHI and temperature changes between urban and rural air temperature, not many look at the temperature variations within a city. These studies mostly use remote sensing data such as MODIS, Landsat and Aster or typical measurements collected by local meteorological station networks. High resolution satellites suitable for urban studies are polar orbiting and tend to be sun synchronous, so do not capture diurnal variations; while the highest resolution instruments such as Landsat have narrow swaths and repeat times on the order of weeks. Cloud free conditions are required. Moreover, satellites measure surface temperatures including rooftops and treetops rather than air temperature. For these reasons a set of surface instruments is preferable for capturing weather effects on urban temperature variability.

In local meteorological study, mobile traverses measured temperature variations within in a town in Hungary 4 h after the sunset to find the impact of UHI. In regression of its measured temperature against building fraction, water fraction, and sky view fraction correlations of 0.8 to 0.9 were calculated based on the season. Ho et al. (2014) used 60 weather stations in the Vancouver area to develop a model for air temperature given sky view fraction, vegetation, elevation and solar radiation. Comrie (2000) mapped the heat island of Tucson Arizona using mobile instruments, and attributed most inner city temperature variability to cool air drainage from the mountains. Eliasson (1996) was able to predict the differences in temperature between two urban locations (open and urban canyon) based on regression of weather variables. A study using a