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The effects of increasing surface reflectivity on heat-related mortality in Greater Montreal Area, Canada

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ABSTRACT

Heat-related mortality is increasing as the result of climate change, extreme heat events and higher ambient temperature because of urban heat island (UHI) phenomenon. We coupled the Weather Research and Forecasting model (WRFV3.6.1) with a multi-layer of the Urban Canopy Model (ML-UCM) to investigate the effects of UHI intensity during the 2005 and 2011 heat wave periods in Greater Montreal Area (GMA), Canada. Each day of simulation is categorized into an air mass type using the Spatial Synoptic Classification. Using the non-accidental mortality data during summer period, the number of deaths above the expected mean anomalous daily mortality is calculated for each air mass classification. Results indicate that moist tropical plus and dry tropical weather have the highest rank in heat-related death. We assessed the effects of increasing surface reflectivity (ISR) on four meteorological parameters: 2-m air temperature, 10-m wind speed, 2-m relative humidity, dew point temperature, and four heat stress indices: National Weather Service – Heat Index, Apparent Temperature, Canadian Humid Index, and Discomfort Index (DI). ISR decreased air temperature by 0.6 °C, increased relative humidity by 2%, increased dew point temperature by 0.4 °C. The DI improved by 3% and heat-related mortality decreased by nearly 3.2% during heat wave periods in GMA.

1. Introduction

Heat-related mortality can be magnified in urban areas because of the urban heat island effects. The climate change can also exacerbate the extreme heat events and the intensity, frequency and duration of UHI (IPCC, 2014). UHI intensity and duration cause an increase in morbidity and mortality (Nitschke et al., 2011; Wang et al., 2012; Jenkins et al., 2014; Horton et al., 2014; Hajat et al., 2010; Harlan et al., 2006; Harlan and Ruddell, 2011). Health impacts range from heat exhaustion to heat stress, kidney failure and heart attacks (WHO, 2010; Matzarakis and Nastos, 2011). Heat-related mortality occurs mostly for vulnerable sections of the society as elderly, homeless, and socially disadvantaged people (Vandentorren et al., 2006; Vaneckova et al., 2010; Peng et al., 2011; Cusack et al., 2011; Yardley et al., 2011; Oliver et al., 2015). Much of the excess mortality is related to cardiovascular, cerebrovascular and respiratory causes and is concentrated in the elderly (Åström et al., 2011; Bunker et al., 2016).

Epidemiological and statistical studies indicated a positive correlation between extreme ambient temperature and mortality during summer time within elderly particularly among women (Mcgeehin and Mirabelli, 2001; Diaz et al., 2002; O'Neill et al., 2003, 2005; O'Neill and Ebi, 2009). People living in urban environments are at greater risk than those in rural areas (Diaz et al., 2002), whereby inner urban environments, with high thermal mass and low ventilation, absorb and retain heat and can amplify the rise in

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temperature. Anderson and Bell (2009) estimated an increment in death by 4.5% per degree Celsius in heat wave intensity and 0.4% per day in heat wave duration. Zanobetti and Schwartz (2008) and Zanobetti et al. (2014) used mortality data across the United States and found out that mortality increases by 3.6% per °C increase in temperature. Basu (2009) and Basu and Samet (2002) evaluated the relationship between the mortality rate and temperature and found that mortality rate increased 4.6% per °C rise in apparent temperature. Mcmichael et al. (2006) presented the results of an investigation on the relation between temperature and mortality in eleven cities of eastern United States. They defined a U-Shaped relation between number of daily deaths and daily temperature and illustrated that mortality rates rise as temperatures reach beyond the upper and lower thresholds of human comfort.

Air temperature in urban area is typically higher than that of the surroundings. In addition, because of climate change, the extreme heat waves are becoming more frequent, prolonged and severe. The combination of these two phenomena leads to higher day-time temperatures, causing heat stress for urban dwellers. The extreme heat events analyses indicated that UHI plays an important role in premature urban mortality (Conti et al., 2005); hence signifying the importance of the UHI characterization on air temperature, humidity, wind speed, radiation, and air pollution (Fischer et al., 2012). The indirect effect of UHI is to increase cooling energy demand in summer time and increase photochemical reaction rates, thus worsen air quality. The adverse impacts of air pollution on human health should also be considered, which is beyond the scope of this study.

The effects of UHI and extreme heat events can be evaluated by numerical simulations. Several numerical modeling studies investigated the effects of only temperature during heat wave period (Diffenbaugh and Ashfaq, 2010), but few considered the combination effects of temperature and humidity (Sherwood and Huber, 2010; Smoyer et al., 2000). Increasing surface reflectivity is a verifiable, measurable, and repeatable mitigation strategy to fight the impacts of UHI in regional, urban and global scales (Akbari et al., 2001, 2009; Arnfield, 2003; Ban-Weiss et al., 2014; Taha, 2008, 2009; Taha, 1997). Akbari and Touchaei (2014) and Akbari and Kolokotsa (2016) indicated that the albedo of most surfaces in urban areas, whether as roofs or pavements, range from 0.1 to 0.2, but it can be even higher due to the use of different materials in cities` structure. Taha (1997) considered the impacts of surface albedo, evapotranspiration, anthropogenic heating, and presented that increasing the albedo by up to 0.15 can reduce summertime temperatures in the urban area of Los Angeles by up to 1.5 °C. Jandaghian et al. (2017) showed that by increasing surface albedo during a rainy episode in summer 2009, air temperature decreases by 0.2 °C, wind speed slightly increases, relative humidity and precipitation respectively decrease by 2.8% and 0.2 mm over GMA.Jandaghian and Akbari (2018) also showed that increasing surface albedo in Sacramento, Houston and Chicago result in a decrease in air temperature by 2.3 °C in urban areas and 0.7 °C in suburban areas; a slight increase in wind speed; an increase in relative humidity (3%) and dew point temperature (0.3 °C); a decrease of $PM_{2.5}$ and O_3 concentrations by 2.7 μg/m^3 and 6.3 ppb in urban areas and 1.4 μg/m^3 and 2.5 ppb in suburban areas, respectively. Akbari et al. (2009) and Oleson et al. (2010 and 2011) simulated the energy saving aspect of highly reflective surfaces on a global scale. Jacobson and Ten Hoeve (2012) used a global model to analyze the effect of urban surfaces and white roofs on global and regional climate. Increasing solar reflectance of pavements are currently employed in several cities across globe (Chip seals in San Jose, California; Grass-Crete in Singapore and Osaka, Japan) (Akbari and Kolokotsa, 2016). The cool pavement strategy reduces the urban temperature and thus cooling energy demands in buildings by 2% in Greater Montreal Area (Touchaei and Akbari, 2015). Successful implementation of cool pavements depends on many factors (such as its materials and life-cycle cost performance) that need to be considered (Akbari and Kolokotsa, 2016).

Here, the first intention is to simulate the impacts of extreme heat events on meteorological parameters and heat-related death over the Greater Montreal Area during two heat wave periods in 2005 and 2011. We applied the fully coupled online Weather Research and Forecasting model (WRFV3.6.1) with a multi-layer of the Urban Canopy Model (ML-UCM). We evaluated the model performance by comparing the meteorological parameters: 2-m air temperature, 10-m wind speed, 2-m relative humidity, dew point temperature with measurements obtained from four weather stations over the domain. The second objective is to assess the effects of increasing surface reflectivity (ISR) on aforementioned meteorological parameters and four indices of heat stress: National Weather Service – Heat Index (NWS-HI), Apparent Temperature (AP), Canadian Humid Index (CHI), and Discomfort Index (DI). Another focus is to analyze the effects of ISR on air mass type modifications and heat-related death. Each day of simulation is classified into an air mass type category. Then, the number of deaths above the expected mean anomalous daily mortality is calculated within each classification.

We limited our analysis *only* to the effects of surface albedo enhancement on aforementioned parameters and heat-related mortality and did not consider the pedestrian thermal comfort. The evaluation of day-time pedestrian thermal comfort level depends on using sky-view factor (SVF) as an indicator of the complexity of urban geometry, street orientation and winds pattern (Kruger et al., 2010). Hong and Lin (2014) used simulation platform for outdoor thermal environment and concluded that building layout pattern and trees arrangement have significant effects on the wind pattern and thus pedestrian thermal comfort. Another factor in such estimation is solar radiation loads.Although, understanding these factors is essential in terms of heat-related morbidity, but it is beyond the scope of present study.

2. Methodology

2.1. Air mass classification and heat related mortality

A wide range of weather metrics are used to investigate the heat-health relationship such as temperature, relative humidity, solar radiation, barometric pressure, and wind speed (Barnett et al., 2010; Zhang et al., 2014a & b). The Spatial Synoptic Classification (SSC; Sheridan, 2002) was developed based on a set of meteorological conditions (i.e., air temperature, dew point temperature, air pressure, wind speed, cloud cover) to place each day into a specific air mass type for the particular location and time of year. The SSC