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The cooling effect of irrigation on urban microclimate during heatwave conditions

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ABSTRACT

The emergence of integrated urban water management (IUWM), provides a unique opportunity for passive evaporative cooling of urban environments. This study investigates the potential of purposefully managed irrigation for cooling benefits in a suburb of Adelaide, Australia, where IUWM is widely adopted. SURFEX was used to simulate heatwave conditions across a suburban environment. Results from two simulation periods are presented: model validation period and a heatwave case study. Model validation suggests SURFEX can broadly capture the average intra-suburban diurnal air temperature variability, but not the average maxima and minima. A range of idealised irrigation scenarios were tested with different rates and timing of watering implemented. Clear evidence was found that irrigation reduces air temperature in urban environments. The diurnal average air temperature was reduced by up to 2.3 °C. The cooling benefit of increasing irrigation was non-linear, with negligible additional cooling predicted above 20 $L\,m^{-2}\,d^{-1}$. The magnitude of cooling was proportional to the pervious (irrigated) fraction, meaning less cooling occurred in areas with greater urban development. Although irrigation increased humidity, it still improved outdoor human thermal comfort during heatwave conditions. IUWM approaches can provide an additional fit-for-purpose water supply to the urban environment, which should be utilised for cooling benefits.

1. Introduction

The warmer climates observed in cities increase the risk to urban dwellers of heat stress and heat related illness. In Australia, where extreme weather and prolonged drought are common, heat exposure in urban areas can be exacerbated. The combination of increasing urban development, excessive urban heating, and lower water availability, alongside the impacts of future climate change could have damaging implications for the health and well-being of urban dwellers. Water management in cities plays an important role in determining urban climates (Coutts et al., 2012; Gober et al., 2010), but minimal work has directly acknowledged these interconnected issues. Integrated urban water management (IUWM), which aims to manage the entire

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urban water cycle in an integrated and sustainable way, is growing across Australia. IUWM approaches, including stormwater harvesting and water sensitive urban design (WSUD), provide a means for retaining and using more water in the urban environment. IUWM approaches also have proven positive benefits for a range of hydrological problems including flood mitigation and improved downstream ecology (Walsh et al., 2005). This study examines the potential for irrigation to provide cooling benefits and reduce human exposure to heat stress in the outdoor environment during heatwave conditions.

One of the major drivers of warmer urban temperatures is the lower levels of evapotranspiration (ET) in the urban environment (Oke, 1987). Less ET occurs in urban areas due to widespread impervious surfaces and reduced vegetation coverage. Therefore, increasing vegetation in cities is a commonly cited heat mitigation measure. Urban vegetation is an effective way to reduce urban temperatures (see Bowler et al., 2010, and references therein) . However, vegetation requires ample water to survive and transpire effectively (Clark et al., 1990), which highlights the importance of urban water management for effective heat mitigation. This is especially relevant in Australia where the security of potable water supplies has been threatened by drought and population pressures (Mitchell et al., 2008). The urban water cycle and the availability of water in the urban environment can significantly influence urban temperatures. However, the potential for modulating urban warmth through direct modifications of the urban water cycle, such as by irrigation, has not been considered in great detail.

The most important time to achieve cooling is during extreme heat conditions when urban populations are likely to suffer from heat stress. Thus, irrigation could be used as a targeted heat mitigation measure during a heatwave. IUWM technologies such as bio-filtration systems, rain water tanks, and stormwater harvesting systems could be used for capturing, storing, and treating stormwater and greywater; while irrigation (active or passive) is used to distribute the water to areas where cooling is needed. Grossman-Clarke et al. (2010) examined the effects of irrigation during an extreme heat event at the local-to-mesoscale using the Weather Research and Forecasting (WRF) model. The authors found maximum air temperature (T_a) increased by 2–4 °C when irrigated agricultural land was converted to suburban development, and urban irrigation caused a 0.5–1.0 °C cooling of maximum T_a during extreme events. Grossman-Clarke et al. (2010) captured roof-level mesoscale conditions, and not the canopy-layer microscale variability that humans were actually exposed to. A recent study from Daniel et al. (2016), looked at the role of watering practices for future heat-wave risk in Paris. This study utilised atmosphere coupled Town Energy Balance (TEB) model, at 1 km resolution, to look at the aggregated cooling effects of irrigation for hypothetical heatwave conditions. Daniel et al. (2016) found that the best performing night time irrigation scenario could reduce average night time air temperature by 2.6 °C. Daniel et al. (2016) and Grossman-Clarke et al. (2010) both provide mesoscale assessments of urban cooling from irrigation. However, the possibility irrigation can be used as a heat mitigation measure during extreme conditions, and reduce extreme heat stress at the microscale, has rarely been examined.

Despite the potential for irrigation to provide cooling in urban areas (Coutts et al., 2012; Gober et al., 2010; Grimmond and Oke, 1995; Kalanda et al., 1980; Oke and McCaughey, 1983), it has received a comparatively small amount of attention in the urban heat mitigation modelling literature. Gober et al. (2010) used the Local-Scale Urban Meteorological Parameterization Scheme (LUMPS) (Grimmond and Oke, 2002) and a simple boundary layer model (Oke et al., 1989) to investigate variability in T_a and ET in Phoenix, Arizona. The authors found the rate of night time cooling increased with irrigation because of reduced daytime storage heat. However, this relationship is non-linear, indicating the magnitude of night time cooling levels off when ET rates (and irrigation) are high. This implies adding water is a thermally inefficient strategy for reducing temperatures in well-watered neighbourhoods. This finding was supported by Demuzere et al. (2014) who found a non-linear relationship between ET and irrigation for a bio-filtration system in Melbourne, Australia. As the relationship between ET and cooling is non-linear, the possibility that cooling via irrigation can be optimised should be considered, so that cooling benefits can be maximised and water-use minimised. Two other water-use focused studies utilised a surface energy balance (bulk approach), similar to Gober et al. (2010), including a study from Portland, Oregon (House-Peters and Chang, 2011) and a study conducted in Canberra, Australia (Mitchell et al., 2008). Mitchell et al. (2008) suggest that compared to a landscape with no vegetation at all, a full vegetated WSUD treatment increased summer evaporation by 1.44 to 1.76 mm d^{-1} and could reduce peak afternoon temperatures by up to 4.2 °C. Overall, these studies reveal important information about the intertwined issues of irrigation and urban climate. However, the spatial and temporal scale and the modelling techniques used in these studies (Gober et al., 2010; House-Peters and Chang, 2011; Mitchell et al., 2008) did not capture the actual human exposure to heat stress in the outdoor environment. Therefore, these studies were not able to directly evaluate the potential for irrigation to reduce human exposure to heat stress during heatwave conditions.

This study examines the potential for irrigation to reduce human exposure (outdoor microscale climate) to extreme heat in a IUWM suburb in South Australia. We utilise the SURFEX (SURFace EXternalisée in French) (Masson et al., 2013) numerical model and high resolution observational data. A model validation was conducted to test model performance against observed data, and the heatwave case study was used to test the effects of different irrigation scenarios on urban microclimate during extreme conditions. Our focus in the present study is the hypothetical cooling effects of irrigation. As such, the approach and experimental design are intended to capture the maximum possible cooling effects of irrigation across the area of interest. The concept of abundantly using water to cool the urban environment during heatwave conditions is in contrast to current outdoor water-use practices in Australia. Due to water scarcity, residents have become highly diligent with their water-use practices, especially during heatwaves and droughts. Therefore, encouraging people to irrigate on a hot day may be counter-intuitive and against normal practice for many residents and local-governments. However, if alternative water is available (i.e. recycled water or stormwater) then water can be justifiably used to cool the urban environment. The rate and timing of irrigation could be modified and tailored to different seasons/environments to achieve highly efficient cooling outcomes. These characteristics of irrigation suggest watering could be an effective approach for cooling urban environments during heatwaves.