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Short Communication

Urban heat & critical infrastructure networks: A viewpoint

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ABSTRACT

The forthcoming century will see cities exposed to temperature rises from urbanisation as well as greenhouse gas induced radiative forcing. Increasing levels of urban heat will have a direct impact upon the people living in cities in terms of health, but will also have an indirect effect by impacting upon the critical infrastructure networks of the city itself (e.g., ICT, transport and energy). Some infrastructures are more resistant than others, but there is a growing reliance on the energy network to provide the power for all of our future critical infrastructure networks. Unfortunately, the energy network is far from resilient from the effects of urban heat and is set to face a perfect storm of increasing temperatures and loadings as demand increases for air conditioning, refrigeration, an electrified transport network and a high-speed ICT network. The result is that any failure on the energy network could quickly cascade across much of our critical infrastructure. System vulnerabilities will become increasingly apparent as the impacts of climate change begin to manifest and this paper calls for interdisciplinary action outlining the need for high resolution monitoring and modelling of the impact of urban heat on infrastructure.

1. Urban heat

Cites are remarkable concentrations of population and infrastructure. Indeed, the world is becoming rapidly urbanised with over 67% of the world population now projected to live within cities by 2050 (United Nations, 2011). As such, urban areas are becoming larger and more numerous, with

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an ever increasing number of people now dependent on urban infrastructures. Urban dwellers inadvertently modify the local climate by producing waste heat and replacing natural surfaces with concrete and asphalt, effectively transforming cities into large-scale heat stores. The consequence is the Urban Heat Island (UHI) effect which can result in cities being up to 10 °C warmer than their surroundings (Fig. 1: Tomlinson et al., 2012). During extreme events (i.e., heat-waves), the added presence of an UHI has significant implications for city dwellers both in terms of thermal comfort and how effectively the city can function. Indeed, heat-waves provide a unique opportunity to assess the current, and future, vulnerabilities of urban areas (McCarthy et al., 2010; McEvoy et al., 2012). The 2003 European heat-wave was the hottest summer on record in Europe and was responsible for thousands of deaths across the continent (Dousset et al., 2010). The majority of these deaths were in urban areas and were a direct result of the concentration of population with decreased thermal comfort due to the UHI effect. For many regions, climate change will exacerbate the incidence of heat-waves and as in 2003, this will be most noticeable in urban areas. Indeed, the 2003 heat-wave may well be typical by 2050. As such, mitigation and adaptation measures are now increasingly

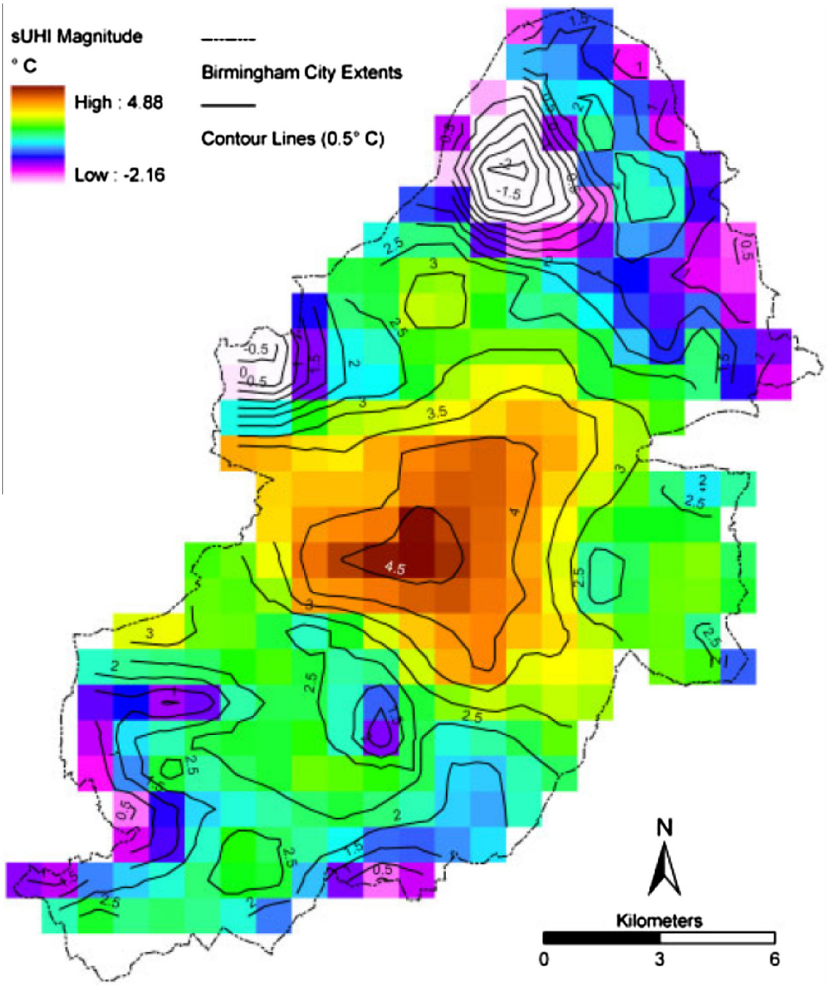

Figure 1. Surface heat island of Birmingham derived from MODIS imagery for a heat-wave event (18th July 2006) Source: Tomlinson et al. (2012).

essential in urban areas to ameliorate the UHI and subsequently reduce the impact of heat-waves which will impact upon human health, society (e.g., law and order) as well as the vital interconnected critical infrastructure of the urban areas themselves.

2. Critical infrastructure networks

Critical infrastructure is a collective term for assets essential to the functioning of society and where prolonged disruption would result in a negative economic impact. Examples of critical infrastructure include: education, healthcare, transport, utilities and communications. Urban heat can have a significant impact on many of these sectors. However, the most acute problems will potentially occur on infrastructure networks due to the increased network density and demand in urban areas; i.e., energy (electricity), transport and information & communication technology (ICT) networks. There exists a spectrum of resistance across the infrastructure networks with some being more resistant to the impacts of urban heat than others. For example, the ICT network (fixed and mobile communications, internet, broadband etc), despite having some potential problems relating to the sub-optimal location of masts (transmission is dependent on temperature), is actually considered to be quite resistant to the impacts of urban heat (DEFRA, 2011).

The transport network is more complicated. Indeed, there has been a gradual expansion of academic discussion away from the mitigation of climate change in the transport sector (e.g., via decarbonisation Perkins, 2011) towards addressing the potential impacts of climate change on transport (e.g., Koetse and Rietveld, 2009; Jaroszweski et al., 2010). With respect to urban heat, there are a number of impacts and opportunities (e.g., railway buckling (Dobney et al., 2010), low adhesion, passenger thermal comfort, road rutting, potholes, winter road maintenance etc). The enhanced effect of climate change on these current impacts is the subject of ongoing research, but there are few studies that specifically make the link between urban heat and the increased severity of impacts (e.g., Bradley et al., 2002; McColl et al., 2012).

Of all the critical infrastructure networks, electricity provision is the most susceptible critical infrastructure network to high temperatures exacerbated by urban heat (McColl et al., 2012). This is due to the potential impact of heat on transformer temperatures where increased temperatures reduce the efficiency of operation and the subsequent life expectancy of the asset. A 6 °C increase in temperature above 98 °C results in halving the operational life of the transformer (IEC, 2005). Using Birmingham in the UK as an example, there are presently two transformers operating above 98 °C, however by 2050 nearly all pass this critical threshold [see: Tomlinson et al., 2013 for full details]. Hence, transformers located in the core areas of the UHI will have a significantly shorter life expectancy the presently predicted. However, this is only half the story as energy efficiency is a function of both ambient temperatures and transformer loading. Many existing transformers were installed when cities had lower population density and electricity demands. Hence, the energy sector is fast heading towards a critical situation as both temperatures and loadings will increase significantly in line with climate change (i.e., significantly greater loadings prompted by higher demand for air conditioning and refrigeration).

However, whilst some networks are more resilient than others, the situation is complicated due to the interconnected nature of infrastructure assets which can cause significant vulnerabilities (Fig. 2). For example, even if the ICT network is resilient to the impact of urban heat, it is very dependent on the electricity network to power it. Conversely, other networks are dependent upon ICT for control systems, e.g., Smart Grids for energy. Similarly, the electrification of transport networks (e.g., rail and electric vehicles) frequently cited as one approach towards meeting climate change mitigation targets in the transport sector (Perkins, 2011), also leads to transport being increasingly reliant on the energy sector. Hence, any significant failure on the electricity network could ultimately cascade onto the transport network with far reaching consequences. Similarly, a widespread failure in the transport sector would prevent key-workers in the energy industry from getting to where they are required for urgent maintenance. Ironically, it is the increased future demands of ICT and transport which may prompt the failure in the first place, by adding additional strain onto a future energy network already struggling under increased temperatures and demand for cooling and reduction in

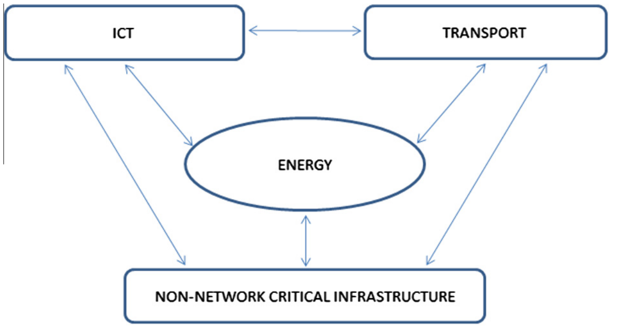

Figure 2. System interdependencies.

availability of fossil fuels. Overall, it is not possible to predict the degree and precision of potential consequences of cascading infrastructure failure (Boin and McConnel, 2007).

3. Discussion

The interdisciplinary nature of the challenge to model infrastructure and provide adaptive capacity to prevent cascade failure means that there is no quick fix to this problem. A solution will need the co-operation of climate scientists, social scientists, engineers and industry (Jaroszweski et al., 2010). Whilst such projects are now becoming accepted as essential in certain disciplines, there are few scientists who have worked across all disciplines sufficiently to make informed judgments' regarding the bigger picture – a new kind of scientist is needed (Schmidt and Moyer, 2008). Socio-economic scenarios provide the basis for emissions scenarios for climate change models, population growth in urban areas and indeed the nature of future infrastructure. In terms of engineering, climate model output needs to be used locally to provide a probabilistic approach that will yield adaptation measures for problem locations on infrastructure networks (Table 1). However, this also brings a new set of infrastructure adaptation challenges as there is then a need to consider and incorporate adaptive capacity

Table 1
Infrastructure adaptation/mitigation measures.

Network	Impact	Adaptation/mitigation
Energy	Asset failure	Air conditioned assets (i.e., indoor or underground)
	Increased demand for cooling (general UHI mitigation)	Passive cooling in building design Santamouris and Assimakopoulos (1996)
		District heating and cooling Chow et al. (2004)
		Increased trees and vegetation for shade Akbari and Rose (2008)
		Green roofs Akbari and Rose (2008)
		Cool roofs/walls/pavements Akbari and Rose (2008)
	Increase demand for other networks	Localised microgeneration
Transport	Buckling of railway lines	Increased shading
		Re-stressing of tracks Dobney et al. (2010)
	Rutting of roads	New road surface specifications DEFRA (2011)
		Cool pavements Akbari and Rose (2008)
	Increased energy demand for power	Off grid charging points powered by microgeneration
		Hydrogen fuelling infrastructure Chapman (2007)
		Promote walking and cycling Chapman (2007)
ICT	Asset failure	Air conditioned assets (i.e., indoor or underground)
		Localised shading of nodes
	Increased energy demand for power	Off grid charging points powered by microgeneration

simultaneously across all sectors. Furthermore, there is a tendency for such projects to focus at the national/continental level and city-scale investigations are rare. Clearly, the first over-arching step here is to simple tackle the root of the problem via significant UHI mitigation.

However, perhaps the biggest challenges face climate scientists. At the moment, the interaction between climate change and the urban modification of climate are inadequately accounted for in climate change projections. Despite this, the advances are clear to see in the performance of UHI models (Grimmond et al., 2010) and the global climate models (GCM) used for projections, more effort is still required in linking the two. The two sets of models can be complimentary and a nested coupling using urban land surface schemes within a GCM appears more than possible (McCarthy et al., 2010). However, whilst this approach will eventually provide projections for urban areas to inform adaptation measures, there is a need to get the basic baseline science right before attempting to project forward. This is hindered by the fact that the basic measurement of temperature across urban areas remains very limited and there is a paucity of urban areas with a sufficient enough spatial resolution to verify the numerical climate models needed to make recommendations regarding future adaptation. Attempts at sensor networks to achieve this have been made (see: Muller et al., in press for a full review) but such networks frequently suffer from long-term funding problems before a useful dataset is fully realised. A further issue is the location of the sensors themselves. There is a tension between locating the sensors in representative urban environments (Stewart et al., 2009) for climate model verification as opposed to locating on infrastructure corridors for real-time monitoring (e.g., what effect does an electricity substation have on the local microclimate?). Sensor networks need to be big enough and flexible enough to cope with both of these demands.

In summary, this article has highlighted the impact of increasing levels of urban heat fuelled by population growth and climate change on critical infrastructure. However, it also calls to focus attention on reducing the increasing reliance on the electricity network – the most vulnerable network to urban heat. This network is already under increasing strain from peak oil forcing a changing supply mix, made worse by increased demand. The increased use of electricity would lead to larger CO_2 and other anthropogenic emissions, because electricity tends to have lower efficiency and higher CO_2 emissions per unit energy consumption than oil or gas (Kahrl and Roland-Holst, 2009), therefore exacerbating climate change (Li et al., 2012) and indeed, the UHI effect (Ichinose et al., 1999). System vulnerabilities will become increasingly apparent as the impacts of climate change begin to manifest and there is a pressing need for high resolution monitoring and modelling of the impact of urban heat on infrastructure. Ultimately, there is a growing need to get the fundamental climate science and engineering correct to ensure the continued functioning of the infrastructure critical to our survival. If the lights can be kept on, then perhaps all will be well.

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