URBAN HEAT ISLANDS (UHIs)

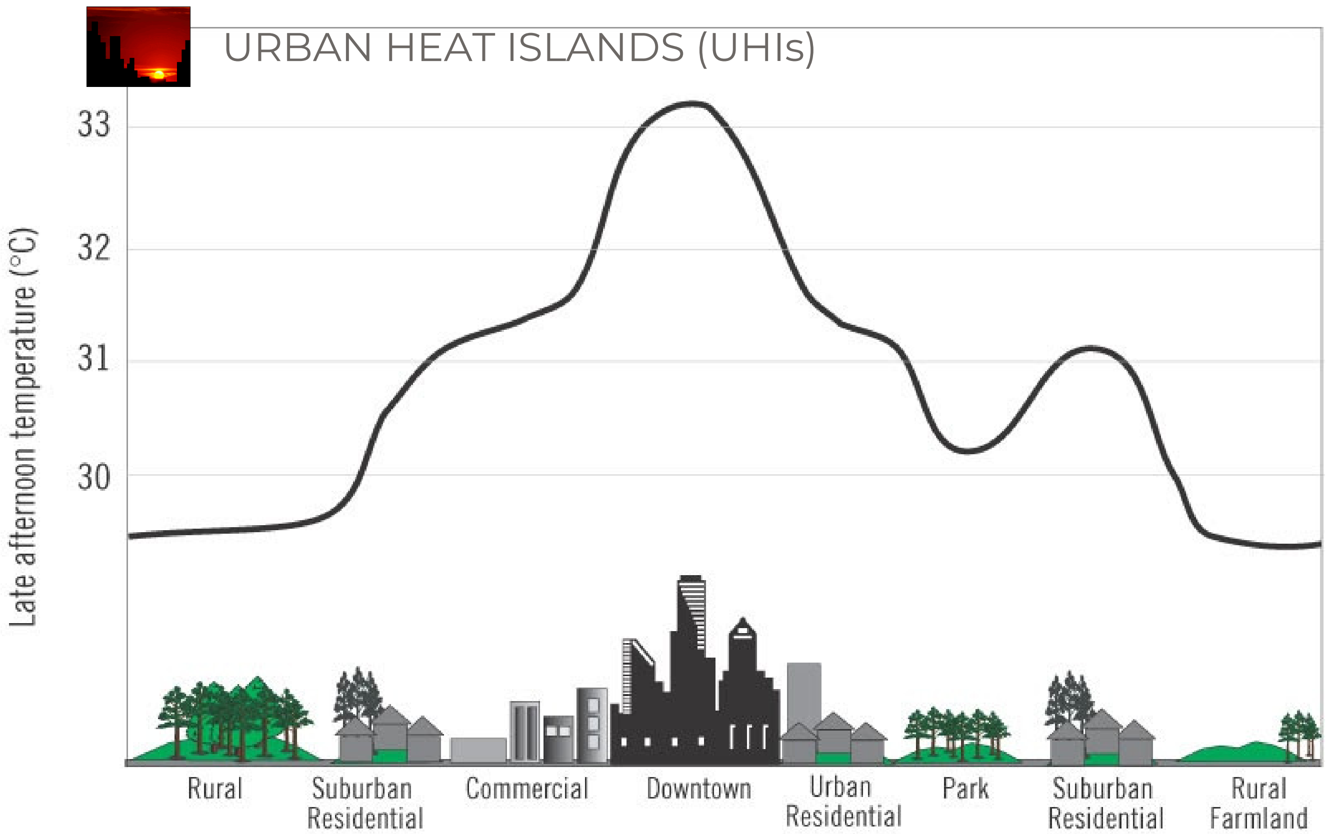
Urban Heat Islands

The Urban Heat Island (UHI) Effect

Definition

Around half of the world's human population lives in urban areas. In the near future it is expected that the global rate of urbanization will increase by 70% of the present world urban population by 2030, as urban agglomerations emerge and population migration from rural to urban/suburban areas continues. Thereby, it is not surprising that the negative impacts related to urbanization is an increasing concern capturing the attention of people worldwide.

Urbanization negatively impacts the environment mainly by the production of pollution, the modification of the physical and chemical properties of the atmosphere, and the covering of the soil surface. Considered to be a cumulative effect of all these impacts is the UHI, defined as the rise in temperature of any man-made area, resulting in a well-defined, distinct "warm island" among the "cool sea" represented by the lower temperature of the area's nearby natural landscape (figure 1). Though heat islands may form on any rural or urban area, and at any spatial scale, cities are favoured, since their surfaces are prone to release large quantities of heat. Nonetheless, the UHI negatively impacts not only residents of urban-related environs, but also humans and their associated ecosystems located far away from cities. In fact, UHIs have been indirectly related to climate change due to their contribution to the greenhouse effect, and therefore, to global warming.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Late afternoon temperature (°C)
33
32
31
30
Rural
Suburban Residential
Commercial
Downtown
Urban Residential
Park
Suburban Residential
Rural Farmland

Figure 1 Source : EPA, 2008

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Causes

It is well-known that the progressive replacement of natural surfaces by builtsurfaces, through urbanization, constitutes the main cause of UHI formation. Natural surfaces are often composed of vegetation and moisture-trapping soils. Therefore, they utilize a relatively large proportion of the absorbed radiation in the evapotranspiration process and release water vapour that contributes to cool the air in their vicinity. In contrast, built surfaces are composed of a high percentage of non-reflective and water-resistant construction materials. As consequence, they tend to absorb a significant proportion of the incident radiation, which is released as heat.

Vegetation intercepts radiation and produces shade that also contributes to reduce urban heat release. The decrease and fragmentation of large vegetated areas such as parks, not only reduces these benefits, but also inhibits atmospheric cooling due to horizontal air circulation generated by the temperature gradient between vegetated and urbanized areas (i.e. advection), which is known as the park cool island effect. On the other hand, the narrow arrangement of buildings along the city's streets form urban canyons that inhibit the escape of the reflected radiation from most of the three-dimensional urban surface to space. This radiation is ultimately absorbed by the building walls (i.e. reduced sky view factor), thus enhancing the urban heat release. Additional factors such as the scattered and emitted radiation from atmospheric pollutants to the urban area, the production of waste heat from air conditioning and refrigeration systems, as well from industrial processes and motorized vehicular traffic (i.e. anthropogenic heat), and the obstruction of rural air flows by the windward face of the built-up surfaces, have been recognized as additional causes of the UHI effect.

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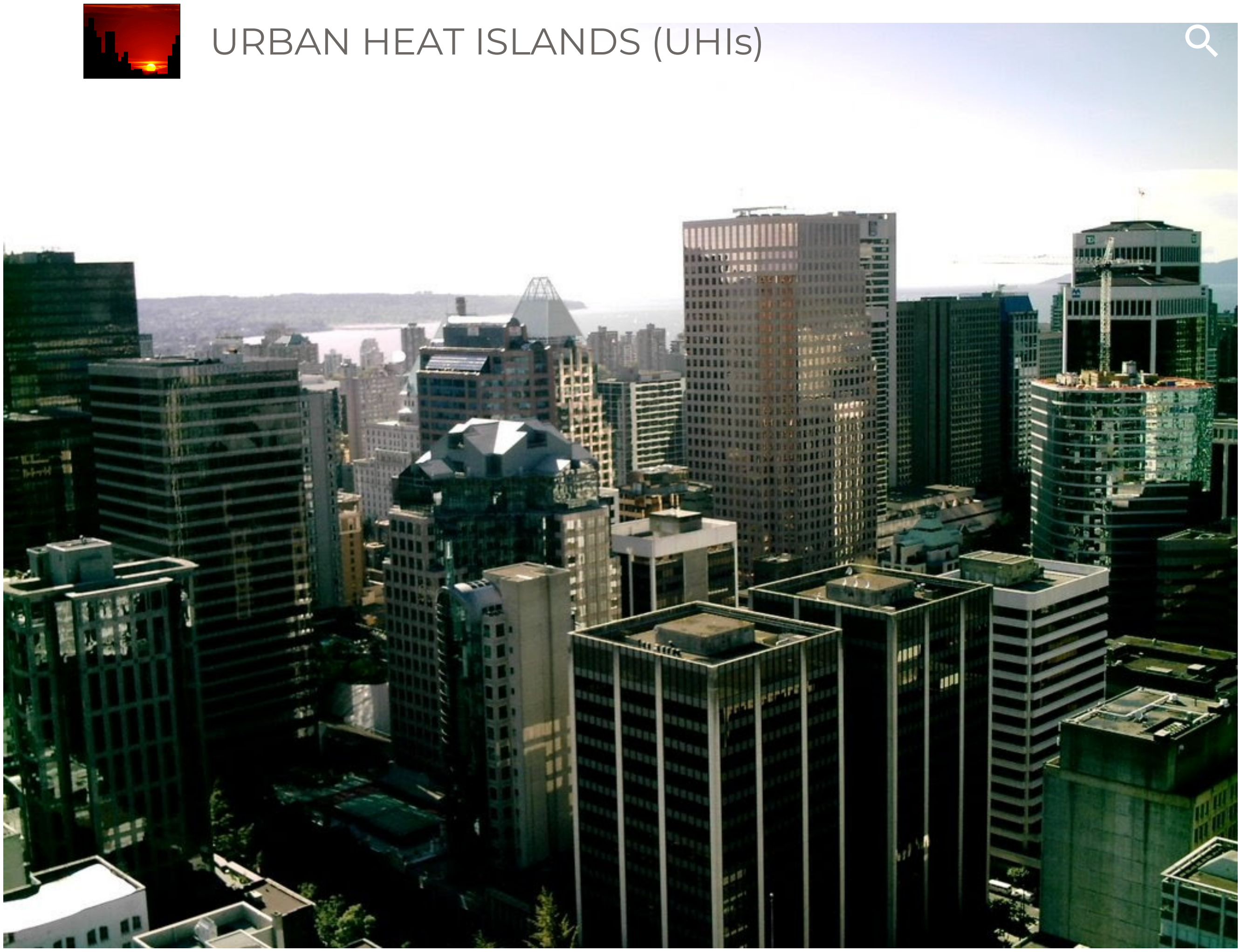
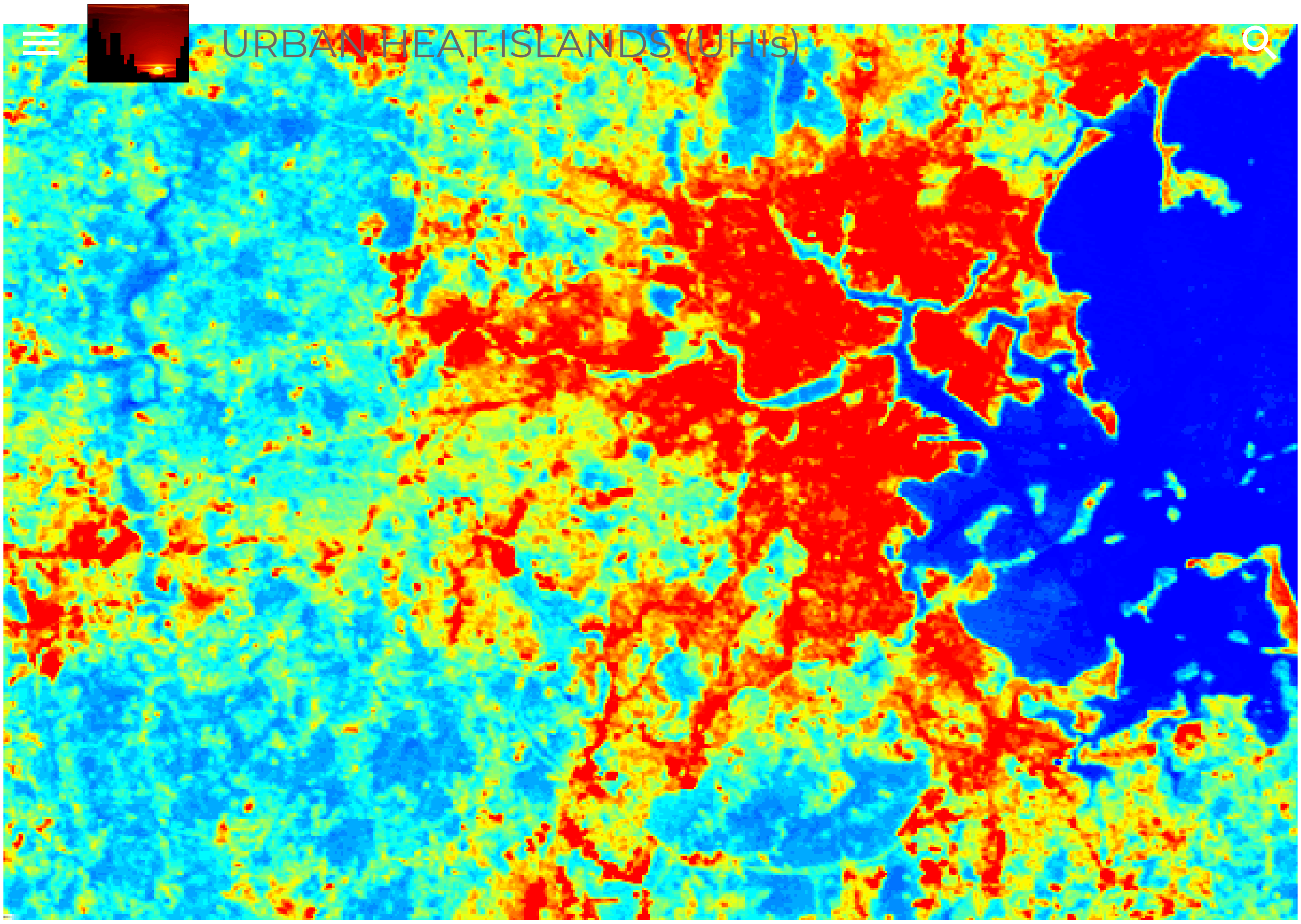


Van s downtown (source : http://www.aboutvancouver.co.uk). Vertical surfaces absorb e energy reflected from most of the three-dimensional built-up surface.

Main spatial and temporal characteristics

In an isothermal map the UHI is represented by closed contours on the urban area, which contrasts with the wider contours of the rural areas. Meanwhile, in a thermal profile the UHI is represented by the isothermic curve rise throughout the urban area, which contrasts with the characteristic low flattened curve of the rural areas. According to the typical thermal profile of the UHI (figure 1), the rural thermal field is interrupted by a steep temperature gradient at the rural/urban boundaries (i.e. cliff), and thereafter a steady but weaker horizontal gradient of increasing temperature (i.e. plateau) is prolonged until reaching the highest temperature point at the urban core or city centre (i.e. peak). The uniformity of this "island" shaped pattern generally indicates a few depressions due to the presence of particularly hot points (i.e. micro urban heat islands) associated with features such as parking lots, malls, industrial facilities, etc, and minor rises due to the presence of particularly cold points (i.e. heat sinks) associated with features such as parks, fields, water bodies, etc. The difference between the warmest urban zone and the base rural temperature defines the intensity or magnitude of the UHI.



Boston, Massachusetts. Surface temperature, 2009. Source : Camilo Pérez Arrau, 2010

The above mentioned highlights the important role that the land use/land cover types have on the thermal pattern of the UHI. In fact, usually a close relationship is expected between the temperature radiated by the land surface (i.e. land surface temperature, LST) and the temperature of the atmosphere situated immediately above it (i.e. near surface air temperature), due to the transfer of energy emitted from the former to the latter. Thereby, over the last decades remotely sensed thermal infrared data have contributed to address the UHI through the estimation of LST, thus originating the study of the surface UHI. Nevertheless, it has been found that atmospheric and surface UHI are coarsely related, and they can exhibit quite different spatial and temporal patterns. Moreover, within the urban atmosphere the heat island may present significant variations between the canopy and boundary layer. The former comprises the space below the general rooftop level, while the latter extends above that level to the point where climatic conditions are modified by the presence of the city.

The next image shows the hottest place in Great Vancouver Area. Surface temperature on this site reached 41,31°C on July 17, 2004 (10:43 am).

Huge parking and industrial area in Vancouver. Source : Google Earth, 2008

This image shows the same place as above seen by a thermal satellite band. The magenta color means the warmest place.

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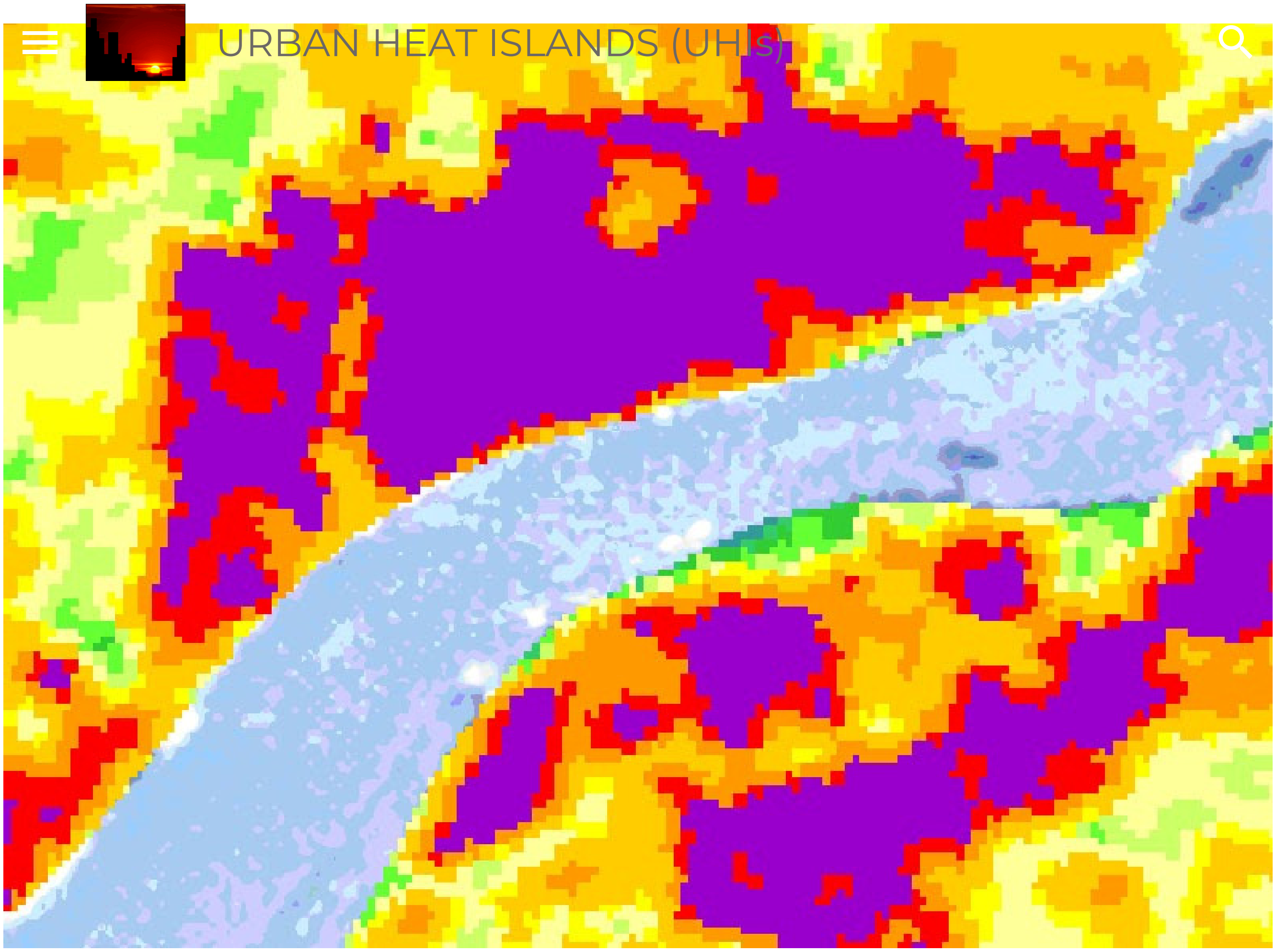

Thermal band of Landsat 5, 2004. Source : Camilo Perez Arrau, 2008

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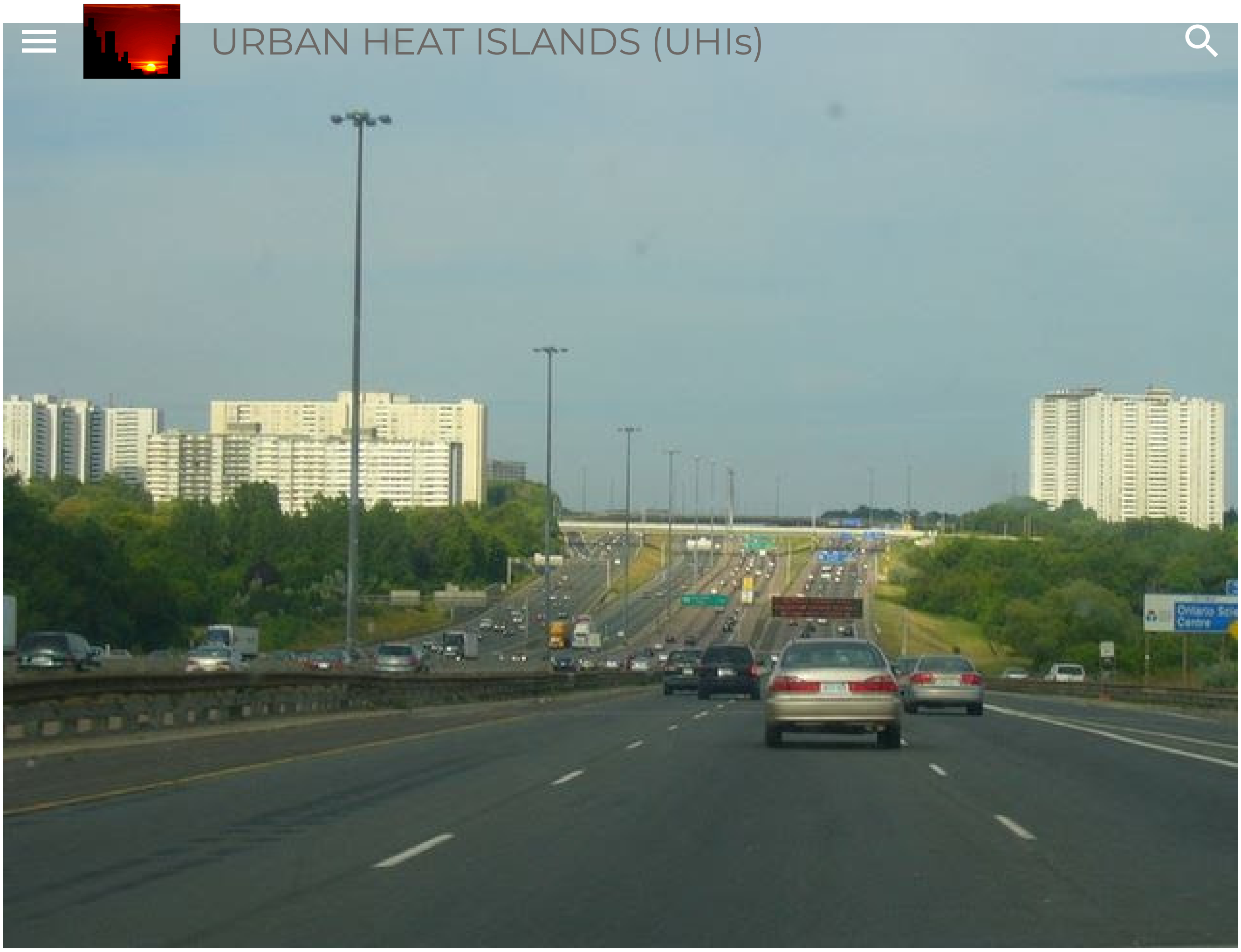
Therefore, characteristics such as development, growth, intensity, and spatial pattern of the UHI will differ depending on where the measurements are made. The atmospheric UHI usually reaches its highest intensity on summer nights, and under calm air and a cloudless sky. This is because construction materials exhibit a high thermal inertia (i.e. a low response to temperature changes), and consequently, they continue releasing heat slowly after sunset and even near dawn, when most of the rural surfaces have cooled down. On the other hand, light winds are not capable of driving turbulent exchanges of heat, while clear skies enhance rural cooling by allowing radiative heat loss to the relatively cold night sky. In spite of this, UHIs have been also reported in wintertime and under variable meteorological conditions. The UHI measured at the canopy layer may exhibit high spatial and temporal variation as a result of the variable thermal properties of the urban construction materials, that in combination with the three-dimensional geometry of built-up surfaces modifies neighboring air temperatures. Instead, the UHI measured at the boundary layer may remain more stable throughout day and night, since the atmosphere is less influenced by the city structure. Lastly, since urban temperature is strongly commanded by the high thermal inertia of the contruction materials, the surface UHI usually reaches its highest intensity during the afternoon, when the urban surface has sufficiently warmed-up, thus maximizing its heat release.



Toronto's suburban highway. Asphalt paved roads have thermal and radiative properties that promote a high heat release. Source : Camilo Pérez Arrau, 2007

Impacts

It has been largely demonstrated that cities with variable landscapes and climates can exhibit temperatures several degrees higher than their rural surroundings (i.e. UHI effect), a phenomenon which if increases in the future, may result in a doubling of the urban to rural thermal ratio in the following decades. Hence, assessment of the UHI and strategies to implement its mitigation are becoming increasingly important for government agencies and researchers of many affected countries.

As it would be expected, the characteristic inclination towards warming of urban surfaces is exacerbated during hot days and heat waves, which reinforces the air temperature increase, particularly in ill-ventilated outdoor spaces or inner spaces of residential and commercial buildings with poor thermal isolation. This increases the overall energy consumption for

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cooling (i.e. refrigeration and air-conditioning), hence increasing the energy production by power plants, which leads to higher emissions of heat-trapping greenhouse gases such as carbon dioxide, as well as other pollutants such as sulfur dioxide, carbon monoxide and particulate matter. Furthermore, the increased energy demand means more costs to citizens and goverments, which in large metropolitan areas may induce significant economic impacts. On the other hand, UHIs promote high air temperatures that contribute to formation of ozone precursors, which combined photochemically produce ground level ozone.

A direct relationship has been found between UHI intensity peaks and heat-related illness and fatalities, due to the incidence of thermal discomfort on the human cardiovascular and respiratory systems. Heatstroke, heat exhaustion, heat syncope,and heat cramps, are some of the main stress events, while a wide number of diseases may become worse, particularly in the elderly and children. In a similar way, respiratory and lung diseases have shown to be related to high ozone levels induced by heat events. Several of the above mentioned impacts have been addressed by the US EPA (for further information see links in the "External link" section of this website).

The anomalous warm of the city creates relatively low air pressures that cause cooler, rural air to converge on the urban center, thus forcing warm air to ascend (i.e. convection), which at higher altitudes condensates and precipitates. Studies carried out in several cities of the United States such as Atlanta, New York, Chicago and Washington, have shown that urban-induced precipitation and thunderstorm events are mainly initiated by the UHI. Other meteorological impacts of the UHI are associated with reductions in snowfall frecuencies and intensities, as well as reductions in the diurnal and seasonal range of freezing temperatures. Lastly, high temperatures may produce physiological and phenological disturbances on ornamental plants and urban forests.

Although in wintertime the UHI can result in energy savings (i.e. winter penalty), there is a great consent among researchers that this benefit is outweighed by the detrimental effects that ocurr in summertime.

Mitigation strategies

In countries like the United States heat is the primary weather-related cause of death, and therefore, promotion of strategies for mitigating the UHI are a big concern for government agencies. There are two main UHI reduction strategies: first, to increase surface reflectivity (i.e. high albedo), in order to reduce radiation absorption of urban surfaces, and second, to increase vegetation cover, mainly in the form of urban forests and parks, in order to maximize the multiple vegetation benefits in controlling the temperature rises.

Refle rfaces simply results from light colored or white paint on the surface of a given

Montreal's downtown. Light-colored rooftops increase the albedo of a given building, thus reducing their energy absorption potential. Source : Camilo Pérez Arrau, 2008

Increasing vegetation cover is mainly focused on planting trees at nearby houses, and residential and commercial buildings. A particular emphasis has been placed on vegetation planting on the roofs of buildings (i.e green roofs), in order to achieve the same aim as lighter-colored roofs. Strategically placing trees in front of windows and on the sunniest sides of a house maximizes energy savings. Trees placed on the east and west sides of a structure are most effective because they block the morning sun as well as the afternoon sun. Larger trees also tend to be more effective, as they provide a greater canopy cover and shade area. In addition, energy demand and costs also can be reduced by placing an air-conditioner in a shaded window, for example shaded by a strategically planted tree.


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U ndscape of Santiago, Chile. White paint and trees are key factors to diminish the urban heat release. Source: Camilo Pérez Arrau, 2008

Several of the references listed in the "Bibliography" link of this website were consulted for the construction of this text.

Even in a cold country like Canada, some big cities like Toronto, Vancouver and Montreal are taking into consideration the heat problem seriously. How do they think going to managing an emergency plan in the event of a heat wave? The replacement of vegetation by asphalt and concrete is a big problem everywhere, and the covering of natural soils with artificial materials like synthetic turf is an emergent issue. At the same time, scientific research are predicting a warmer climate for the future. How do they face all this?

Thanks for your visit!

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