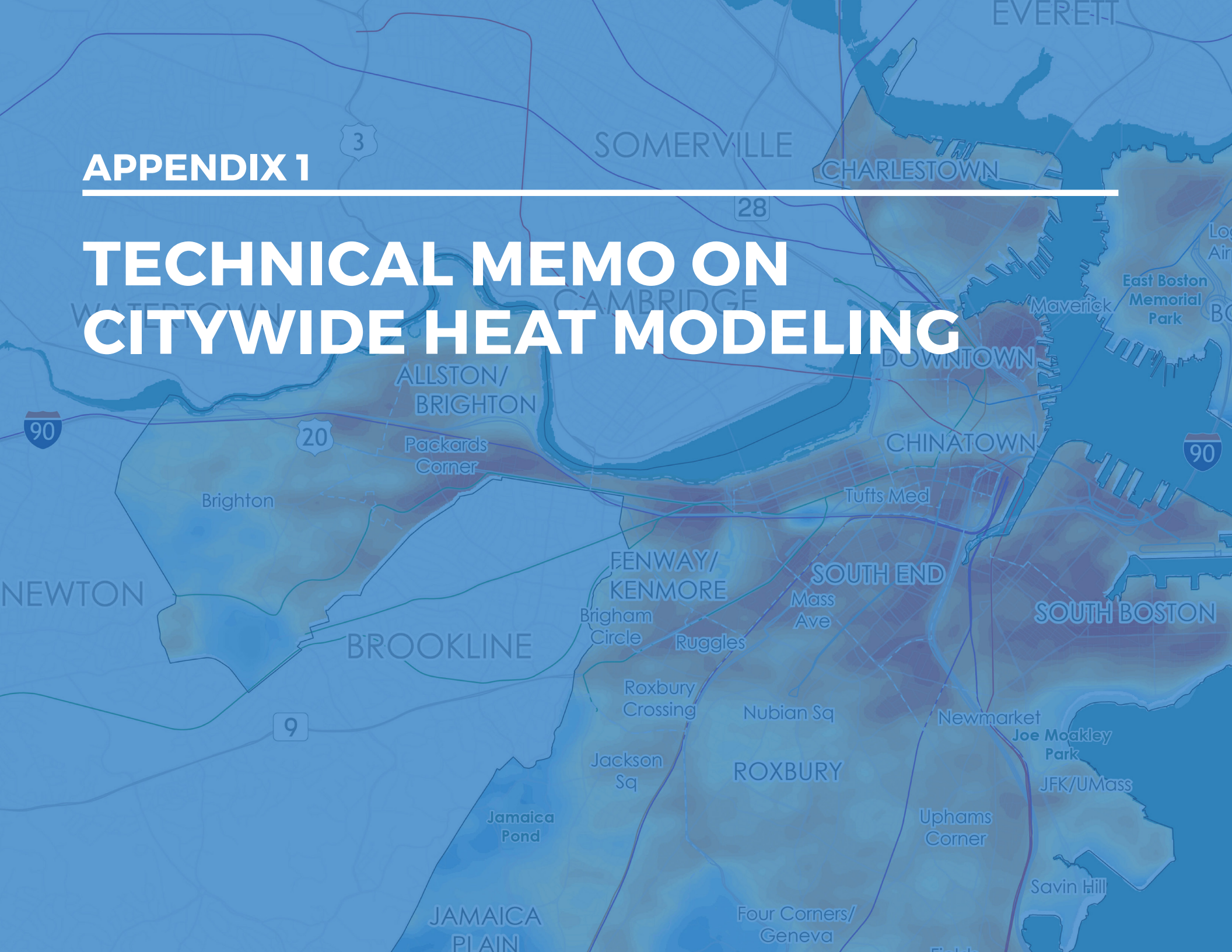


APPENDIX 1

TECHNICAL MEMO ON CITYWIDE HEAT MODELING



Boston Heat Resilience Study

Technical overview of the urban heat island modelling methodology.

May 12, 2021

For

The City of Boston and Sasaki Associates

By

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Summary of Datasets Issued from the Citywide Heat Modeling

The datasets issued and used in the Heat Resilience Strategies for City of Boston is based on a weeklong hourly analysis period for the week of July 18-24, 2019. This period was chosen in collaboration with the City of Boston to model a period that coincided with a reported strong heat wave event in the recent past.

- **Air Temperature (Ta):** This dataset shows the spatial distribution of the near surface modelled air temperature (°F) during the afternoon (3pm) or night (3am) of the warmest day of the analysis week. This dataset helps to identify the relatively warmer (or cooler) areas during a hot day, and areas that retain (or shed) heat during the night.
- **Heat Event Duration (HED):** The heat event duration is the duration (hours) that modelled heat conditions may exceed a heat alert level for the analysis week. The Boston heat advisory protocol determines whether to issue a heat advisory, alert, or emergency based on forecasted weather conditions exceeding certain heat index thresholds. The HED dataset issued shows the modelled number of hours during the analysis week that the heat index, as defined by the National Weather Service, may exceed a threshold temperature of 95°F for days when the daytime low temperature does not drop below 75°F (heat alert level). The HED dataset is useful to highlight which neighbourhood areas may stay above a heat alert level for the longest period during a hot week.
- **Urban Heat Island Intensity (UHII):** The UHII is a measure of the daily intensity and duration of the urban heat condition relative to the regional (rural) condition. The UHII dataset uses the entire weeklong hourly analysis dataset and sums the hourly difference between the local and rural air temperature before averaging this by day i.e.,

$$UHII = \frac{24}{N} \sum_1^N (T_{local} - T_{rural})$$

The issued UHII index divides the UHII by 24 hours to show the UHII as an average daily temperature difference (°F) above the rural temperature. The UHII dataset helps to highlight areas that remain hot and for longer and is therefore reflective of both the intensity and the duration of localised heat within the city during a hot week.

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1. Introduction

This report is part of the work covered in the Boston Heat Resilience study initiated by the City of Boston and led by Sasaki Associates. The report aims to provide a high-level overview of the technical methodology used by Klimaat Consulting & Innovation Inc. (“Klimaat”) to model the urban heat island characteristics across the Boston Municipality (“Boston”). The modelling work is performed to help the design team and the city stakeholders visualise and evaluate the spatial and temporal distribution of urban heat across the city. This report does not intend to be a complete scientific description of the urban Land Use and Land Cover (LULC) influences on urban climatic characteristics and focusses mainly on the overview of the heat modelling and mapping methodology as applied to the heat resilience study.

The specific purpose of the work performed here was to generate georeferenced data (map) layers that allow for a spatial and temporal evaluation of the distribution of urban heat island characteristics within and around Boston. It aims to compliment and support the work performed earlier by others as part of the Climate Ready Boston initiatives.

2. Urban Heat Islands

Urban heat island effects are typically evaluated or defined as the difference between localised urban climatic conditions and the conditions further away from the urban centres such as within its suburbs and the rural outskirts. Many textbooks are available that describe these urban climatic processes in detail, such as Oke et al (Oke, 2017). In general, a combination of urban land use and land cover (LULC) characteristic may modify the surface and near surface energy exchanges with the urban atmosphere that causes climatic differences between rural and urban landscapes. These influences include, but are not limited to,

- increased hardscape and or limited or different urban vegetation cover that alters the amount of solar radiation intercepted by the urban fabric and modifies the latent heat contribution to the near surface energy exchange,
- increased urban massing that changes the ventilating wind flow characteristics within urban streets and neighbourhoods and affects the sensible heat contributions within the urban setting,
- increased urban massing and its form alters the shading and sky view factors especially within denser city contexts which affects the shortwave and longwave radiation exchange within the city,
- differences in urban land cover thermal specifications, such as reflectance, emissivity, heat capacity, material density and moisture content, that changes the local heat transfer and thermal storage characteristics within the urban fabric, and

- anthropogenic heat sources i.e., the additional energy (heat) released into the urban setting due to human activities such as from heating or cooling of buildings, and from operating transport vehicles, to name a few sources.

When studying urban heat island effects, it is important to distinguish between, at least, surface and canopy heat island characteristics:

- surface urban heat island (SUHI) effects are urban-rural differences of *surface temperatures*, and
- canopy urban heat island (UHI) effects are urban-rural differences of *air temperature* in the near surface urban canopy layer i.e., roughly the layer between the surface and the urban massing height.

This distinction is important. High surface temperatures are often recorded during daytime within urban settings, such as solar exposed areas with low reflectance (albedo). These areas may include dark roof tops, asphalt covered parking lots, or even exposed natural or artificial grass surfaces or bare soil and are often also associated with higher local air temperatures. However, these enhanced daytime surface and air temperature characteristics may exhibit different characteristics at night, as the same exposure can also help it to cool more rapidly and generate cooler air temperatures. Thus, a high daytime surface and air temperature difference (high SUHI & UHI) may often diminish at night. Similarly, areas with dense urban massing may have comparably cooler daytime surface and near-surface air temperatures due to reduced grade level interception of solar radiation and enhanced thermal energy storage in the urban fabric. However, at night the denser urban form may be more effective in trapping the stored thermal energy by limiting re-radiation and sensible heat transfer and thereby heating the near surface atmosphere creating warmer air temperatures at night compared to rural surroundings.

As such there is benefit to evaluate urban heat island characteristics in terms of surface temperature (SUHI) and canopy air temperature (UHI) to identify areas that are hot during daytime, hot during nighttime, or potentially worse for summer heat wave conditions, hot during day and nighttime i.e., prolonged diurnal heat wave conditions. This forms the main purpose of the work; to contribute to the study of the urban heat characteristics in Boston to provide spatial and temporal SUHI and UHI data. In the following section a high-level overview is provided of the urban heat modelling and analysis methodology applied in this work.

2.1 Surface urban heat island (SUHI) analysis

Surface heat island effects are often studied by means of remotely sensed data to generate Land Surface Temperatures (LST) maps from multispectral satellite data such as Landsat 8 (<https://landsat.gsfc.nasa.gov/landsat-8/landsat-8-overview>). The purpose here was not to generate new LST maps for Boston from Landsat multispectral satellite data, as this effort is thoroughly covered in work performed by other groups. Instead, it aims to compliment the existing Boston heat map datasets, as currently used by the city for understanding its spatial heat distribution

characteristics, with additional urban canopy heat island (UHI) information. However, Landsat 8 derived LST datasets were produced in this work but were mainly used to test the performance of the urban canopy urban heat island modelling process (K-UCMv1), described below, as hourly surface temperature data is also one of the resolved and exported variables. This makes it useful for independent comparison between the LST information obtained from Landsat and that derived from the urban canopy modelling.

In the current work a LST map was generated based on a Landsat 8 image data taken on July 13, 2016. The land surface data is derived based on the 30m resolution multispectral bands and the 100m resolution thermal bands. The processing is based on a well-established radiative transfer model approach, as described by Peng et al. (Peng, 2020), to derive the LST. The methodology essentially converts the satellite measured at sensor, top-of-atmosphere radiance (thermal band data) to surface radiance and a land surface temperature. The method employs the local normal difference vegetation index (NDVI), derived from 30m the multi-spectral Landsat 8 bands, to approximate the local surface emissivity, and employs an atmospheric correction for the atmospheric condition at the time that the satellite image was taken (Barsi, 2005) (<https://atmcorr.gsfc.nasa.gov/>) to close the surface radiation energy balance equation and derive the ground level surface black body radiation. This in turn provides the surface temperature according to the Planck formula. More complete details are available in Peng et al. (Peng, 2020). A sample of the resultant LST obtained from the Landsat 8 data is shown in the case study results section below. Alternatively, processed LST data can also be directly obtained from the NOAA Landsat program (<https://www.usgs.gov/core-science-systems/nli/landsat/landsat-surface-temperature>).

Surface heat island effects are also studied using Moderate Resolution Imaging Spectroradiometer (MODIS, <https://modis.gsfc.nasa.gov/about/>) satellite data that can provide daytime and nighttime surface temperature analysis with band resolutions from 250m to 1000m. This was beyond the scope of the current work.

2.2 Canopy urban heat island (UHI) modelling methodology

The main purpose of this work is to derive spatial maps of the near-surface air temperature across the Boston region through modelling of the canopy urban heat island effects. An Urban Canopy Model (UCM) generally refers to a modelling approach that aims to perform spatio-temporal modelling of the climate within the urban canopy layer, the layer between the surface and roughly the height of the urban features. This is usually done by solving a surface and near surface energy balance that describes and parameterises the governing physics within the urban canopy layer, based on urban land use and land cover characteristics and specifications and deliver an approximation of time dependent urban climatic condition.

In the current work, the UCM model developed by Klimaat is used (Klimaat Urban Canopy Model, version 1, "K-UCMv1"). A high-level and simplified overview of the K-UCMv1 modelling approach is given below.

2.3.1 Surface Energy Balance

The UCM model used here solves a local surface energy balance (SEB) based on LULC input and regional meteorological forcing. The modelling approach, its solution process and underlying governing physics generally follows that of other single-layer UCM models (Kusaka, 2001) (Lee, 2008) (Ryu, 2011). The SEB is solved per individual tile (pixel) in the analysis domain with every tile representing a position in a 100m resolution grid array generated from the LULC input. The tile input and its UCM solution therefore approximates an average condition of the urban condition, its form and material specification at a resolution of 100m.

The starting point for the UCM is to determine surface temperatures (ground, walls, roofs) by solving an energy balance at the different surface facets of an approximated urban setting at every grid tile. The surface energy balance includes different energy flux contributions to the overall surface energy balance, i.e.

$$Q^* = Q_H + Q_L + Q_G \quad (1)$$

where Q^* , Q_H , Q_L and Q_G represents the net energy contributions from net all-wave radiation (downwelling and upwelling long and shortwave radiation), sensible, latent and ground heat fluxes, respectively, as shown in Figure 1 below.

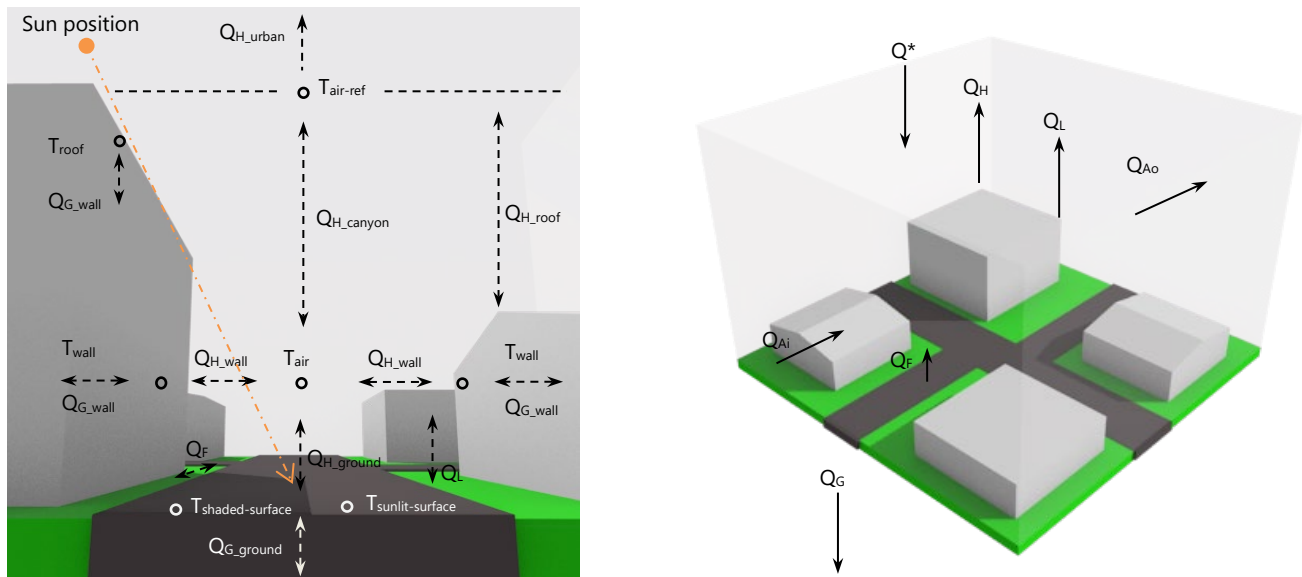


Figure 1: Surface and near surface energy balance components for a single-layer urban canopy model (left) and urban canopy control volume energy balance (right).

An additional energy balance is solved in the air volume that approximates the urban canopy (canyon) that balances the surface fluxes, convective fluxes and local heat sources within the urban canyon to derive the time dependent air properties.

The net all-wave radiation flux, Q^* is the balance of shortwave and long wave radiation components. The shortwave contribution to the surface energy flux is determined by the balance of incoming

shortwave radiation contributions from direct and diffuse solar radiation, as per the meteorological forcing, and the reflected shortwave radiation, influenced largely by the solar reflectance of the surface (albedo), the surface orientation intercepting the incoming flux, the exposure of the surface to direct radiation (hourly shading) and the exposure of the surface to diffuse radiation via the local visibility of the sky hemisphere (sky view factor). The longwave contribution is the balance between the incoming longwave radiation (meteorology forcing) and the upwelling longwave radiation exchange between the urban canyon surfaces and the atmosphere.

The sensible heat flux, Q_H , is the heat flux due to the temperature differences between the urban canopy air and its adjacent surfaces and driven by the turbulent exchange between the surfaces of the urban canopy and the air within and above the urban canopy. For one, the turbulent heat exchange between ground or roof surfaces are parameterised according to Monin-Obuhkov similarity theory to derive the near surface heat transfer coefficient, similar to (Ryu, 2011) (Kusaka, 2001) and approximates the near surface canyon wind speed as a function of reference wind speed, the urban aerodynamic roughness and the urban building form (height to width ratio).

The latent heat flux at the surface is the net energy contribution (or sink) due to the evaporation of water at the surface, controlled in the current model through the evapotranspiration moisture source provided by vegetation. The evapotranspiration is determined according to the Penman-Monteith equation (wikipedia, n.d.) modified to employ hourly meteorology data and scaled according to the fraction of vegetation present at the local surface tile.

The ground or surface heat flux contribution, Q_G , is the transport of heat into or from the surface layers through heat conduction, controlled by the properties of the surface facet layer such as its thermal conductivity, thermal heat capacity and density. The surface heat flux contribution requires coupling of the surface energy balance solver with an additional conduction heat transfer model and solver that can approximate the time-dependent temperature profile within the ground or surface facet. This is important so that the thermal energy storage effect of different surface facets (ground, walls, roofs) is properly accounted for when determining the surface temperatures that exchanges its heat and moisture with the urban canopy atmosphere near it.

The surface energy balance therefore constitutes a set of coupled governing equations that control each of these flux contributions, linked with an additional energy balance within an urban canopy layer control volume that describes the exchange of heat (and moisture) between the surfaces and the atmosphere above it. The latter also includes an additional control volume energy balance contribution from anthropogenic heat or moisture sources. The anthropogenic heat flux is the energy contribution due to man-made fluxes such as heat sources (or sinks) from building heat or cooling or operation of vehicles.

The urban canopy control volume energy balance model solves the time dependent evolution of the temperature and humidity of the near surface air layer within an approximation urban canyon form and specification as determined by the tile averaged LULC and the urban massing input. In the current model, the control volume energy balance solution and subsequent derivation of its

average air temperature is mainly influenced by turbulent exchanges of heat or moisture between the air volume within the canyon, the surfaces (ground, walls, roofs) adjacent to it and the atmosphere above it. Precipitation or soil moisture effects are not currently included in the model.

The energy balance at the surface and within the urban canopy volume, and the coupled ground heat conduction model is driven (forced) by an hourly meteorological forcing dataset and solved at 1 minute time intervals for the duration of a weekly analysis period. Urban canopy climate characteristics are exported hourly.

2.3.2 Meteorological forcing

An hourly or sub-hourly meteorological dataset is required to drive or force the urban canopy model solution process, i.e., it drives the time-dependent solution of the surface and urban canopy control volume energy balances. The forcing data should be representative of the regional meteorological conditions. In the current work the historical hourly forcing data is obtained from the ERA5 gridded re-analysis product of the European Centre for Medium-range Weather Forecasts (ERA5, 2017). Klimaat uses in-house data handling and analysis processes to download and extract the historical hourly near surface meteorological dataset into suitable and standard formatting for use with the K-UCMv1. The meteorology dataset contains hourly data of the near surface air temperature, humidity, wind speed, wind direction, downwelling shortwave and long wave solar radiation components, among other variables. For the current work, two ERA5 datasets were compiled for the year 2016 and 2019, as described below for the case study work. The meteorological datasets are also provided as supplementary materials as part of the overall project deliverable.

It is important to note that the present UCM modelling process is one-way coupled to the meteorological forcing data, meaning the forcing data drives the UCM solution, but without feedback to change the regional meteorological condition, as is often done with high-resolution weather forecasting modelling approaches. The current method should therefore be considered more as an urban climate downscaling method, rather than a complete urban weather model with full two-way coupling with a mesoscale atmospheric model.

2.3.3 Land-use and Land-cover (LULC) specification

A number of important LULC characteristics are required as inputs for the UCM as these represent the tile averaged condition of the urban canopy layer. These include, but are not limited to, spatial maps of land cover characteristic including surface vegetation, water bodies, surface reflectance, terrain elevation and urban massing (building heights). The majority of the land cover specifications are derived from the Sentinel-2 (Sentinel-2, n.d.) multispectral satellite imagery which delivers its multispectral data at 10m resolution. Terrain elevation data is obtained from NASA SRTM (SRTM, n.d.) at 30m resolution. All the processed LULC spatial data is resampled and averaged into 100m resolution grids (tiles) as required for the UCM.

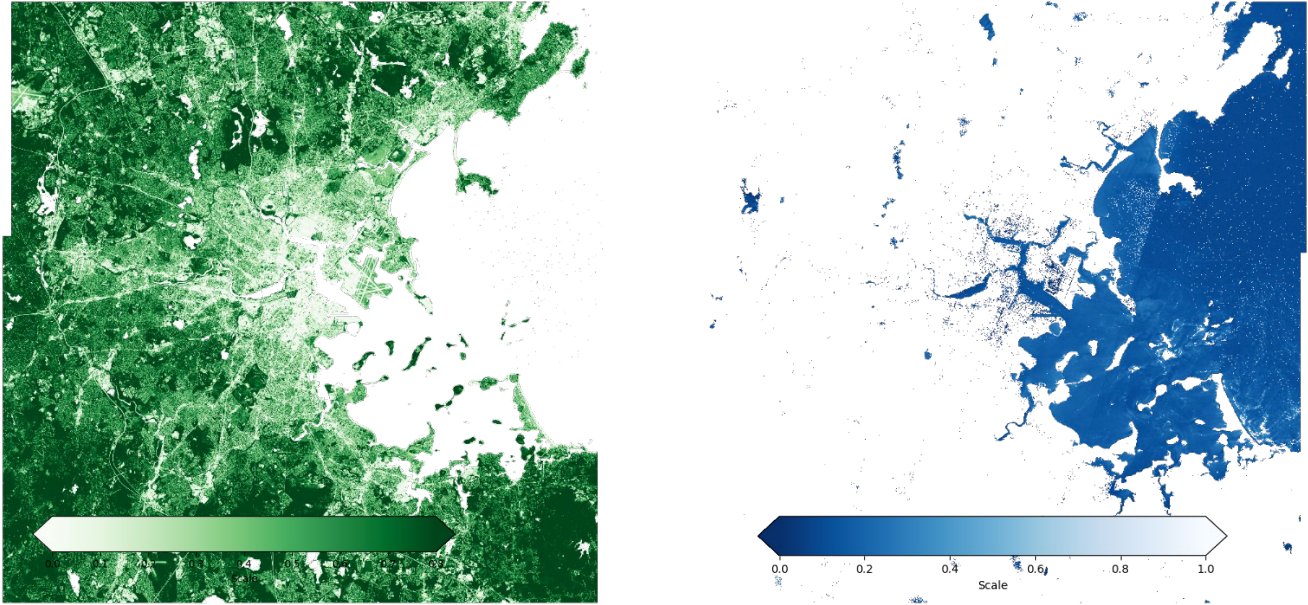


Figure 2: Sample of Sentinel-2 processed data for Normalised Difference Vegetation Index, NDVI (left) and Normalised Difference Water Index, NDWI (right).

The satellite data is processed into different land cover indices used by the UCM through processing of different multispectral band combinations to provide LULC conditions such as Normalised Difference Vegetation Index (NDVI) for vegetation coverage and Normalised Difference Water Index (NDWI) for water bodies i.e.,

$$NDVI = \frac{NIR - RED}{NIR + RED} \quad (2)$$

$$NDWI = \frac{GREEN - NIR}{GREEN + NIR} \quad (3)$$

where NIR, RED and GREEN represent the near infrared, red and green multispectral band data from Sentinel-2. An example of the processed NDVI and NDWI indices for Boston is shown in Figure 2.

For urban massing (building heights) building footprint and elevation data provided by city of Boston (for the Boston Municipality) was combined with older datasets for outlying areas to derive a regional building height map that covers the extents of the model. The building height data is also averaged into a 100m resolution raster tile which is used in the model to mathematically determine the surface sky view factor and hourly shade fractions, among other things that influences the localised surface energy balance solution. Hourly shade fractions at each tile are calculated based on the local hourly solar position, similar to the methodology of (Kusaka, 2001).



Figure 3: Image sample of building footprint and height data for the City of Boston

2.3.4 Additional model thermal specification inputs

Additional modelling inputs and assumptions are required by the model where the information is not provided by the satellite derived LULC tile set, with a selection shown in Table 1.

Table 1: Additional K-UCMv1 land surface specifications

Ground (soil): Specific thermal heat capacity (kJ/m ³ /K), thermal conductivity (W/m/K), emissivity	1900, 0.8, 0.9
Walls: Specific thermal heat capacity (kJ/m ³ /K), thermal conductivity (W/m/K), albedo	1340, 0.8, 0.94, 0.25
Roofs: Specific thermal heat capacity (kJ/m ³ /K), thermal conductivity (W/m/K)	1400, 0.8, 0.94

2.3.5 UCM Modelling Output - Heat indices

The UCM model produces a data array that represents the spatio-temporal climatic variables covered within the model region and for the analysis period. The data array represents the modelled, average hourly urban meteorological condition at 100m spatial resolution. This datasets is further processed into urban heat indices and delivered as georeferenced image layers (geotiff rasters) to the design team (Sasaki) for further processing and integration into the overall study program deliverables. The data layers are resampled to 10m resolution using a bilinear

interpolation. This is done purely for visualisation purposes when overlaying the model data with other datasets. The key data layers that were processed and integrated into the main report include:

- **Air Temperature (Ta):** The near surface air temperature. Four map layers were produced to show the spatial distribution of air temperature across Boston at different time periods on the warmest day of the analysis week. These were air temperatures during the night (3am), morning (10am), afternoon (3pm) and evening (9pm).
- **Urban Heat Island Intensity (UHII):** To better study the temporal effects of the urban heat condition an Urban Heat Island Intensity metric was defined, similar to that described in Taha et al. (Taha, H. and Freed, T., 2015). The UHII uses the entire weeklong hourly dataset and sums the hourly difference between the local and rural air temperature before averaging this by day i.e.,

$$UHII = \frac{24}{N} \sum_1^N (T_{local} - T_{rural}) \quad (3)$$

The index therefore provides a daily degree hours ($^{\circ}\text{F}\cdot\text{hr}\cdot\text{day}^{-1}$) index as a measure of the overall difference between a local condition and the regional temperature. In effect, the degree hour map helps to highlight areas that remain hot and for longer and is therefore reflective of both the intensity and the duration of localised heat within the city. The design team (Sasaki) have subsequently modified the exported data layer further to show the UHII as an average daily temperature difference above the rural temperature.

- **Land Surface Temperature (LST):** The surface temperature of the ground at 10am of the warmest day during the analysis week. This provides an additional measure of the ground surface temperature condition within the urban context at a similar time stamp when Landsat 8 satellite data is gathered.
- **Heat Event Duration (HED):** The heat event duration is the modelled duration (hours) during which heat conditions exceed heat advisory levels during the analysis week. The Boston heat advisory index determines whether to issue a heat advisory, alert, or emergency based on forecasted weather conditions and uses the heat index, as defined by the National Weather Service (NOAA, n.d.), to determine the heat event level. In this work the HED is calculated as the number of hours during the analysis week that the heat index exceeded a threshold temperature of 95°F (heat alert level) for the days when the daytime low temperatures did not drop below 75°F. This index useful to determine which neighbourhood areas would stay the hottest for the longest during weeks with heat wave events.

3. Urban Heat Modelling Runs

An analysis domain was selected with an extent of approximately 31km by 31km centred over the Boston Municipality. For this domain, two different weeklong historical analysis periods were analysed:

- The first period selected was for a week of July 10-17, 2016. This sample period coincides with a day (July 13, 2016) during which a near cloudless Landsat 8 image was available from which a LST surface map could be generated that is independent of the K-UCMv1 derived land surface temperatures. The purpose here was to compare the Landsat 8 LST map and the K-UCMv1 LST approximation as a measure of the performance of the modelling approach to predict surface temperatures.
- The second period selected was for a week of July 18-24, 2019. This period was chosen in collaboration with the City of Boston to model a period that coincided with a reported strong heat wave event in the recent past. The analysis results and data layers obtained from this modelling period was the main focus and deliverable of the current work. The resultant output data layers were integrated and overlaid with additional datasets by the design team (Sasaki) as shown and discussed in the main report.

A few key output data layers for the analysis periods are provided as samples below. The raw data layers were processed and integrated by the design team (Sasaki) into the main Task 2 report that forms part of the overall Heat Resilience dataset.

3.2 Case Study: July 10-17, 2016

For the current work surface temperature predictions were used to test its performance against Landsat 8 processed data. The modelled land surface temperature obtained from the K-UCMv1 is shown here for comparison to the Landsat 8 derived LST in Figure 4. The K-UCMv1 model land surface temperature map is produced for the same hour during which the Landsat 8 satellite image was taken, between 10am and 11am on the morning of July 13, 2016. As shown in Figure 4, the spatial distribution of the warm and cooler surfaces predicted by K-UCMv1 generally seems to agree with the surface temperature distribution and range found from the Landsat 8 analysis.

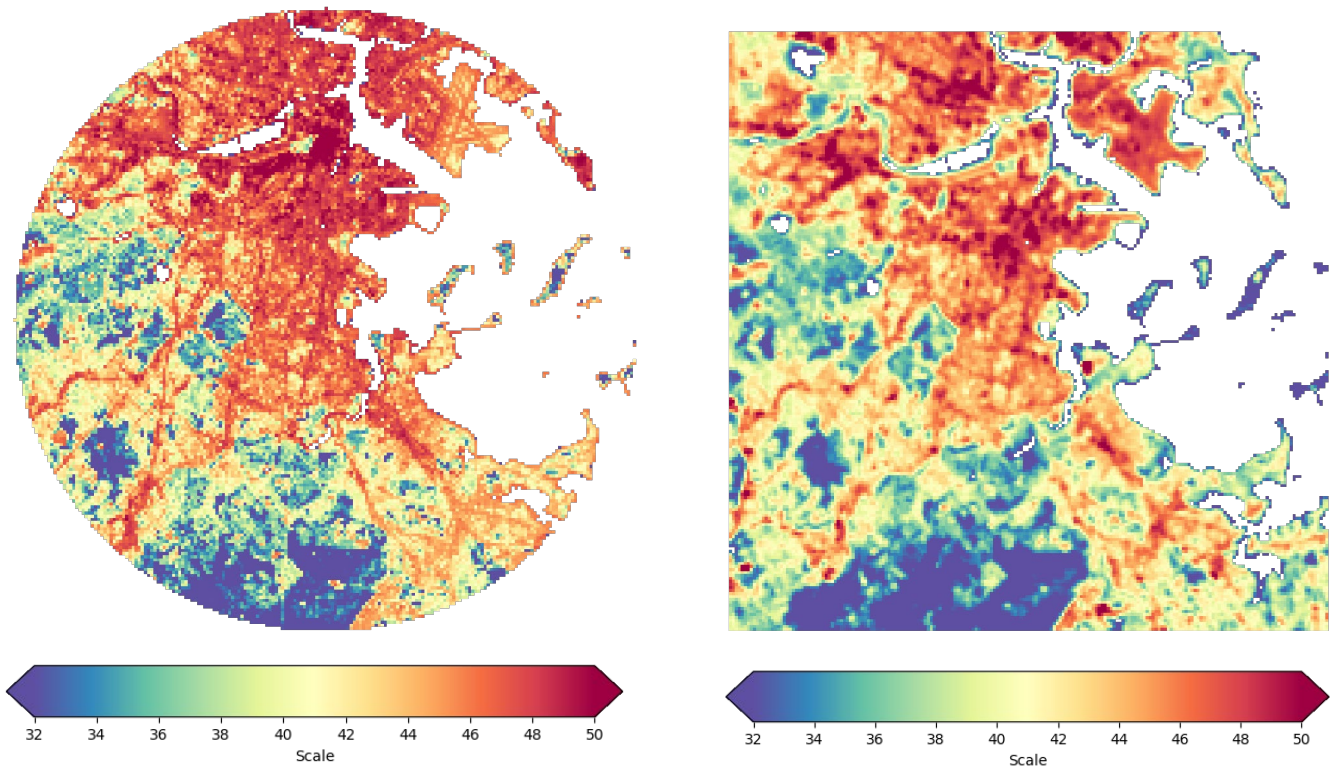


Figure 4: Spatial comparison of the LST as modelled by K-UCMv1 (left) and processed from Landsat 8 data (right) for July 13, 2016, at approximately 10am. Temperature scale is in °C.

Figure 5 shows a pixel-by-pixel comparison between the K-UCMv1 model and the Landsat 8 processed land surface temperature data. This suggests that the K-UCMv1 model is capable of producing similar trends across the analysis region. The correlation between the Normalised Difference Vegetation Index (NDVI) and the surface temperature is also compared in Figure 5. This shows that the K-UCMv1 model generally matches the trend of the Landsat 8 surface temperature variation with NDVI although the Landsat 8 data has more variation across NDVI levels.

The current work and this methodology report do not intend to be a complete validation of the K-UCMv1 method as this is an on-going effort with continuous modelling approach updates and improvements. In particular, the K-UCMv1 model is part of an international comparative study to assess the performance of urban canopy models to predict surface energy fluxes.

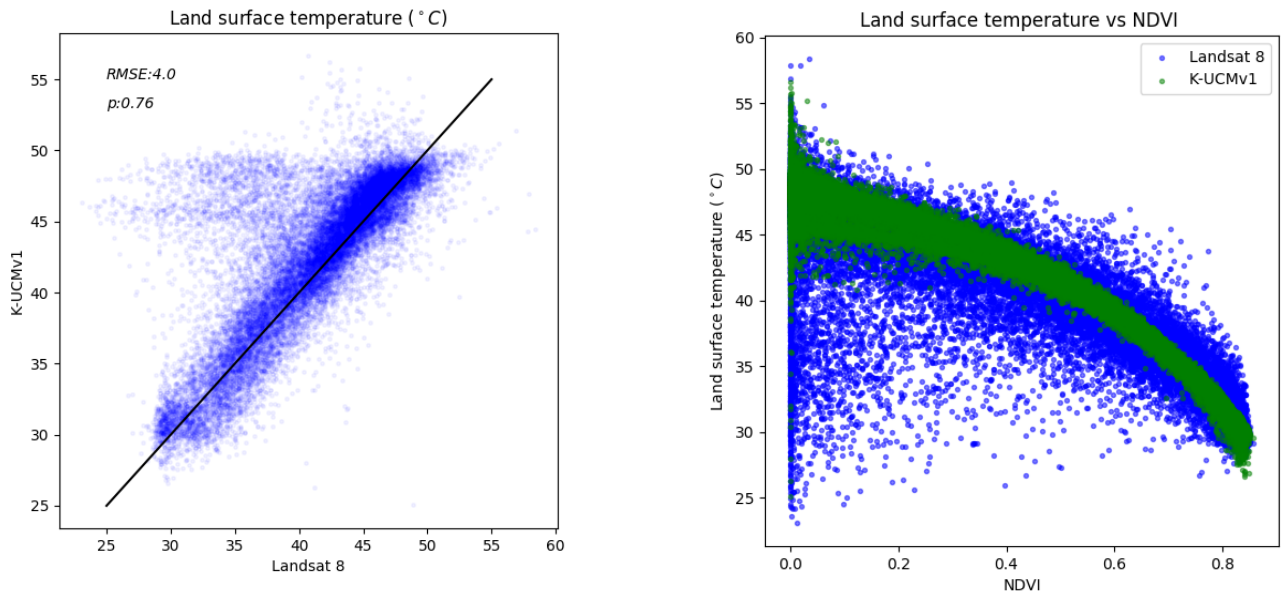


Figure 5: (Left) Correlation between the land surface temperature (°C) modelled by K-UCMv1 and from processed Landsat 8 data for July 13, 2016 10am. (Right) Correlation between the Normalised Difference Vegetation Index (NDVI) and the predicted land surface temperature from K-UCMv1 and Landsat 8.

3.3 Case Study: July 18-25, 2019

Based on discussions with the City of Boston, a weeklong period of July 18 to 24, 2019 was selected to produce the heat characteristics maps for the Boston Heat Resilience Study. This week coincided with a very intense heat wave with peak temperatures of approximately 36°C on July 21 and July 22 measured at the airport. The main output data layer results are discussed in the main report of the Heat Resilience Study as integrated into the design team deliverable by Sasaki. A sample of the set of the data layers provided to the design team is shown below only to highlight the different output data layers with a brief description of the spatial and temporal heat characteristics across the city. The main design report uses the exported data layers to zoom into specific focus areas (neighbourhoods) to examine the urban context that may cause elevated high urban heat island conditions and help identify potential mitigation measures to improve it.

Figure 6 shows a map of the modelled Urban Heat Island Intensity (UHII) index and the Heat Event Duration (HED) index for the week of July 18 to 24, 2019. The UHII index highlights areas that have the hottest and longest departure (difference) from the rural temperature condition. This is also shown in the Heat Event Duration index, which shows that solar exposed neighbourhoods, with extensive hardscape, massing and limited vegetation, stays within heat wave conditions the longest (33 to 36 hours) compared to rural outskirts and forested areas that stay within heat wave conditions the shortest (25 hours) during the analysis week of July 18 to 25, 2019.

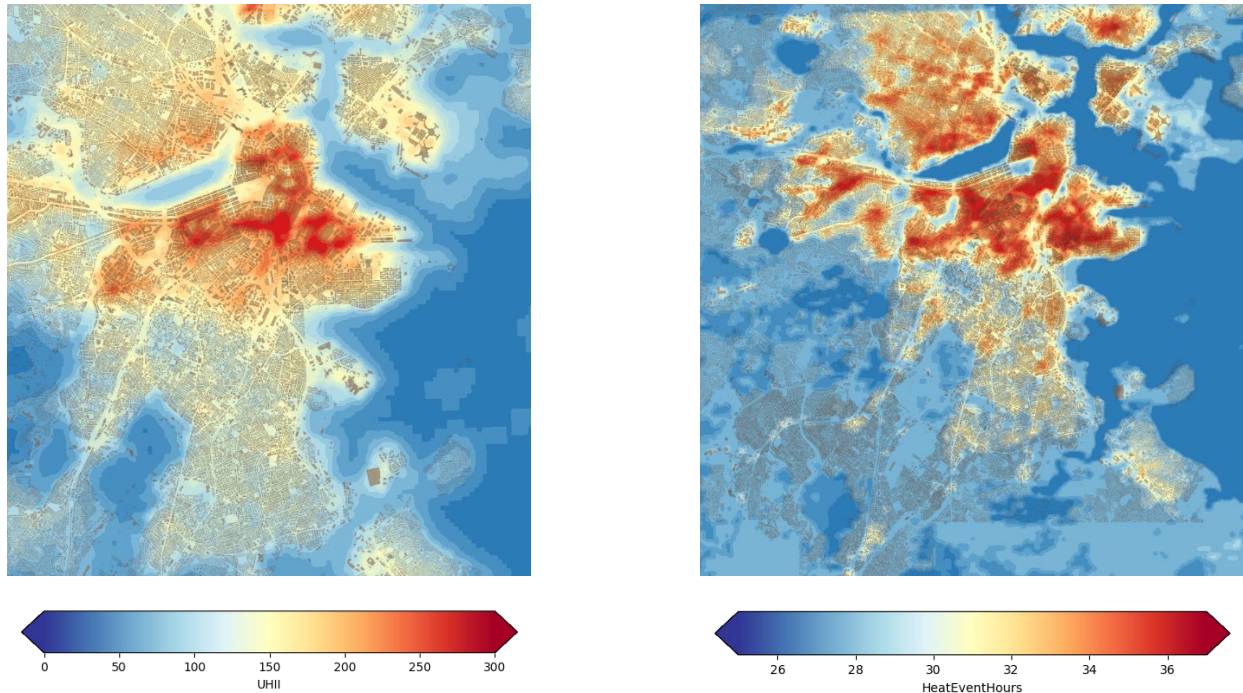


Figure 6: (Left) Urban Heat Island Intensity ($^{\circ}\text{F}\text{-hours/day}$) and (right) Heat Event Duration (Hours/week) for Boston on July 22, 2019.

Figure 7 shows the near surface air-temperature map for July 22, 2019 for four periods during the day namely night (3am), morning (10am), afternoon (3pm) and evening (9pm). This highlights the change of air temperature during the course of one day during the very hot conditions of July 20-22, 2019. Cooler daytime temperatures are modelled for areas within the deeply shaded spaces of the denser urban centre with its tall massing. Daytime temperatures within solar exposed areas with significant hardscape are the highest. During night-time, the suburban outskirts cooled down faster compared to the dense urban core which retains the most heat and becomes the warmest area. One of the main reasons for warmer temperatures occurring within the city core during the night and into the early morning, compared to the cooler outlying suburban and forested areas, is the slower release of heat stored within the urban massing and its land surface. In more exposed areas the heat is released quickly due to the higher night sky exposure and enhanced open area ventilation. The comparably warmer night-time and morning temperatures and cooler afternoon temperatures within the denser urban cores were also found in Portland by Voelkel et al. (Voelkel, 2017).

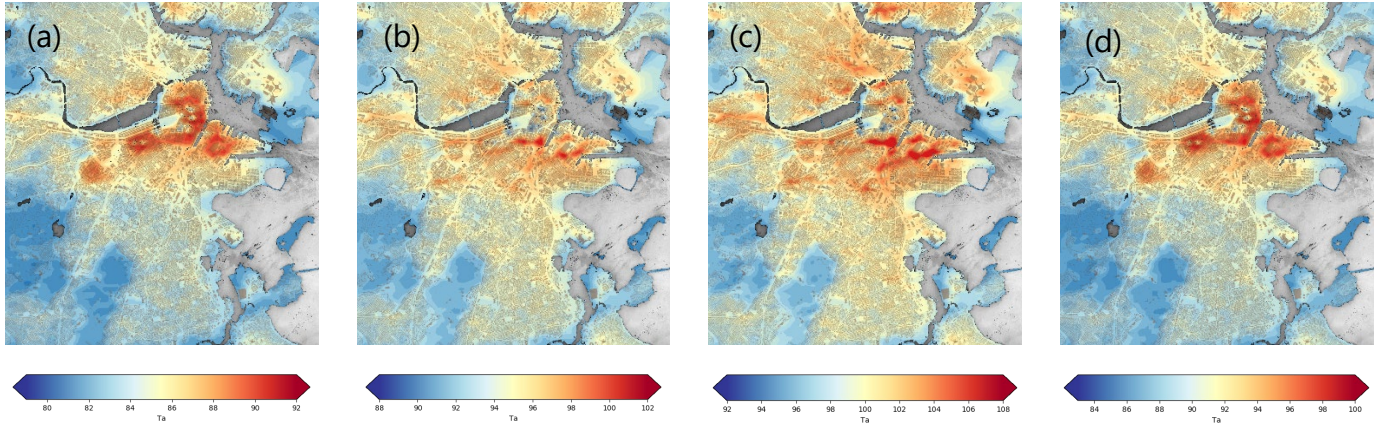


Figure 7: Near surface air temperature (°F) on July 22, 2019 for (a) 3am, (b) 10am, (c) 3pm and (d) 9pm

4. Summary

This report highlights the urban canopy modelling methodology used as part of the City of Boston Heat Resilience Study. It describes the main heat characteristic indices, exported as georeferenced data layers, employed to help visualise the urban heat characteristics across the Boston Municipality and in the neighbourhood focus area heat analysis and mitigation work. The final data layer output and visualisations are provided and discussed in more detail for key Boston neighbourhoods in the main report by the design team.

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