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Determining the Climate Future Projection of Erzurum City with the UrbClim Model

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Abstract

The negativities brought by climate change, which is among the crisis agendas today, directly affect the cities. According to the UN, the rate of urbanization in the world is increasing rapidly. It is estimated that it will reach 6.4 billion in 2050. The UrbClim model is also used to project future climate in cities. For the province of Erzurum, where the climate negatively affects living things, the climate data of the city for the first 10 days of July 2016, 2017, and 2018 were analyzed using the UrbClim model. This study, it is aimed to analyze the exemplary cities with cold climates in the world, which will set an example in the determination of climate change and support sustainable and livable urbanization, use energy efficiently, and to produce climate adaptation strategies at the point related to landscape.

***Keywords:** Future climate change, UrbClim, planting design, global climate model, Erzurum.*

UrbClim Modeli ile Erzurum Kentinin İklim Gelecek Projeksiyonunun Belirlenmesi

Öz

Günümüzde kriz gündemleri arasında yer alan iklim değişikliğinin getirdiği olumsuzluklar doğrudan şehirleri etkilemektedir. UN'e göre dünyada kentleşme hızı hızla artmaktadır. 2050 yılında 6,4 milyara ulaşacağı tahmin edilmektedir. UrbClim modeli şehirlerdeki iklim tahminleri için de kullanılmaktadır. İklimin canlıları olumsuz etkilediği Erzurum ili için 2016, 2017 ve 2018 Temmuz aylarının ilk 10 gününe ait kentin iklim verileri UrbClim modeli kullanılarak analiz edilmiştir. Bu çalışma ile dünyada soğuk iklime sahip örnek şehirlerin iklim değişikliğinin belirlenmesinde örnek teşkil edecek, sürdürülebilir ve yaşanabilir kentleşmeyi destekleyecek analiz edilerek enerjinin verimli kullanılması ve peyzaj ile ilgili noktada iklim uyum stratejilerinin üretilmesi amaçlanmaktadır.

***Anahtar kelimeler:** Gelecek iklim değişikliği, UrbClim, bitkisel tasarım, iklim modeli, Erzurum.*

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1. Introduction

The IPCC stated in 2007 that climate change associated with global warming is a reality. He demonstrated with 90% reliability the existence of the temperature increases experienced by the effect of this change, that is, the human being in the leading role of the increasing temperature. This situation and the human impact on global climate change were also confirmed by the IPCC, and it was confirmed that the 30-year period between 1983 and 2012 was the hottest in the last 1400 years (IPCC Synthesis Report, 2014).

According to the evaluation report "Climate Change 2021: The Physical Science Basis" published by the IPCC in August 2021, it is certain that scientists do not have any doubts about the warming of the world and that the changing parameters are human-induced actions. According to all the scenarios studied, it is predicted that the world temperature increase will be above 1.5 °C. It is stated that since 1970, global surface temperatures have risen faster than 50-year periods in the last 2000-year timeframe (IPCC, 2021).

Understanding the urban climate is crucial due to the unique climate conditions found in urban areas, such as higher levels of heat stress during heat waves. To gain a better understanding of the urban climate, Caluwaerts et al. (2020) emphasize the importance of obtaining detailed insights into urban environments. In this regard, Hooyberghs et al. (2016) have used the UrbClim model to generate temperature maps for London, providing an evaluation of the current climate as well as future projections for the period 2081-2100. Analyses have been conducted using the UrbClim model in Colombo, Sri Lanka.

The greening simulations show that increasing green space by up to 30% in urban areas can decrease the average air temperature by 0.1 °C (Maheng et al., 2019).

Reducing urban heat island effects helps to mitigate the harmful effects of climate change. In England, a temperature increase of 3.0 °C is expected until 2080. As an adaptation strategy, different types of green areas have been created in local areas of the city, and their relationship with energy demand has been investigated to reduce the effects of urban heat islands. According to simulations conducted, energy savings of up to 4.8% have been achieved (Skelhorn et al., 2016). In a study conducted for Ankara, the urban heat island changes were identified between 1985-2002. Based on these findings, measures have been proposed to reduce the urban heat island effect under the headings of wind, sunshine, and vegetation at both the micro and macro scales (Yüksel & Yılmaz, 2008; Nazarian & Lee, 2021).

Climate change through urbanization is accepted as an important indicator of human pressure on the environment. Urban centers and cities are often several degrees warmer than the surrounding areas and rural areas, making them vulnerable to changing climatic conditions (Figure 1). Thermal comfort in urbanization is associated with high surface and air temperature, often referred to as an urban heat island. The low albedo (reflection) of building roofs, asphalt roads, wide squares, and dense hard ground surfaces in cities, the trapping of radiation in the urban canopy, the heat storage of urban components, and the decrease in evapotranspiration due to impermeable surfaces cause heat island formation in cities. In addition, the intensive use of urban infrastructure components such as transportation and energy at small spatial scales leads to intense anthropogenic heat releases that can increase up to 1.0°C in urban heat islands. Due to the urban heat island (UHI) increase, cities are particularly vulnerable to heat waves (Oke, 1978; Ohashi et al., 2007; Gabriel & Endlicher, 2011; Tremeac et al., 2012; Uzun & Gül, 2021).

In this paper, the UrbClim numerical model is used to simulate urban heat accurately at a fast rate and high spatial resolution for the cities of Johannesburg and Ekurhuleni, South Africa (Souverijns et al., 2022).

A decade-long measurement dataset has been created in Milan, Italy. These data were used to obtain thermal areas with medium to high resolution close to the surface using grid cells. In this study, the UrbClim and ERA5 models, which are used to determine future temperature, were compared. During the winter and summer segments, a comparison was conducted between different datasets with overlapping periods of available data. The findings show a general agreement in both cases, but there is a consistent underestimation of the impact of BSI on Milan. On average, the bias can be measured at -2.0 °C, but in certain sections considered, this underestimation range could exceed 10.0 °C (Frustaci et al., 2022).

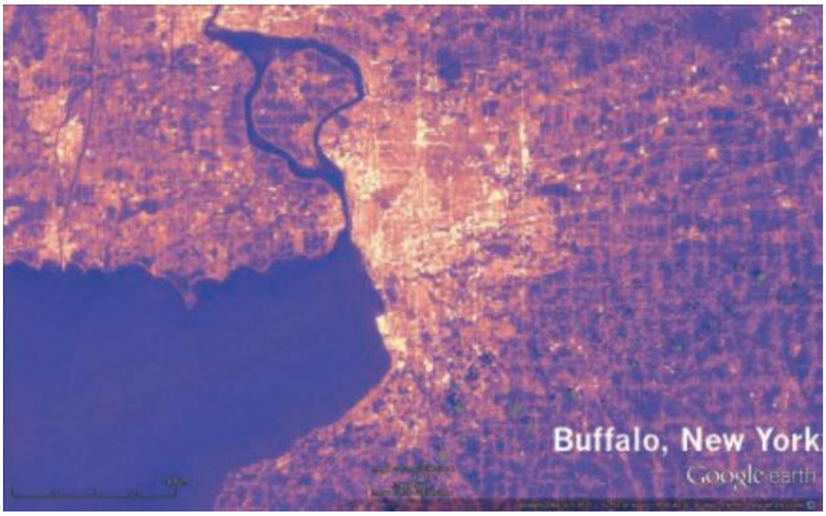

Figure 1. Urban heat islands measured by NASA satellites in Buffalo, New York (Rosenzweig et al., 2018)

To evaluate common artificial urban boundaries and related climate hazards such as high temperatures in built environments, an urban analysis is necessary at various spatial scales, including meso, local, and micro scales. This approach can be applied in different urban planning phases, from zoning areas to designing urban canyons, and it can provide urban design recommendations at various levels. However, due to the high computational cost of numerical models used in this approach, it also has limitations. Improvements in the accuracy of numerical modeling capabilities at different scales can make multi-model coupling more feasible. In this regard, it is becoming increasingly common to impose boundary conditions on microclimate models (Lobaccaro et al., 2021),

There are academic studies on effective and functional urban uses for reducing the Urban Heat Island (UHI) effect that occurs in global areas. Urban parks that have the feature of reducing the UHI effect (Arellano et al., 2020; Jamali et al., 2021; Yilmaz et al., 2022; Menteş et al., 2023), plants (Irmak et al., 2018; Yilmaz et al., 2023), water surfaces (Wang et al., 2018; Qiu and Jia, 2019), street orientation (Mutlu et al., 2018; Yilmaz et al., 2021), and eco-friendly materials in ground-building surface coverings (Irmak et al., 2017; Ranagalage et al., 2017) is known to be effective measures in terms of energy and economic efficiency (Arnfield, 2003; Taleghani, 2018; Santamouris, 2020; Kim et al., 2021).

The city's social services sectors, such as energy and health, are easily affected by the UHI effect. A study of a small city in western Greece found that the city center needs more/less cooling/heating in summer/winter than in the surrounding countryside (Vardoulakis et al., 2013). In Shanghai, China, a study on the heat island found increased heat-related deaths in urban areas with the negative effects of high temperatures on health (Tan et al., 2010). Considering the combined effects of increased heat waves due to climate change and research on the UHI effect, it poses serious health risks for the urban population (Li & Bou-zeid, 2013).

A comprehensive understanding of the urban climate system is the starting point for the climate risk assessment process. Critical to this is the need for long-term, quality-controlled, observed climate data. Without long-term historical records, the role of climate variability cannot be adequately defined and climate change projections cannot be supported by a strong historical basis. Even where a long-term record is available, there is often content to expand urban climate monitoring networks to better understand urban changes and raise awareness of climate risks. (Blake et al., 2011; Rosenzweig et al., 2018).

2. Material and Method

This study will be carried out in Erzurum, which has extreme climate characteristics in Turkey. Erzurum is known as the only large settlement in the Eastern Anatolia Region, located at an altitude of 1959 meters (Figure 2). The settlements, located in the southwestern part of a high plateau, are located on a plain reaching up to 2000 meters. There are the Dumlu Mountains in the north of the city and the Palandöken Mountains in the south. Its area is 25,355 km^2, and Erzurum 2020 population is known to be 758,279. Erzurum is connected to every part of the country by land, air, and railway transportation network (Anonymous, 2021a; Anonymous, 2021b).

UrbClim is the first and current urban climate model with enough capacity to cover a long period for creating urban climate projections. It has been confirmed to comply with international scientific standards. The model was first tested for a short period in Toulouse and Ghent cities (De Ridder et al., 2015a; Hooyberghs et al., 2016).

The UrbClim numerical model is designed for high-resolution and precise meteorological output, including temperature, humidity, heat fluxes, and soil parameters, over an extended period at the city level. It comprises a detailed land surface scheme with simplified urban physics and a 3-D atmospheric boundary layer model. This makes the model ideal for long-term integrations, especially for urban climate projections. Studies have shown the model to be effective for this purpose (Souverijns et al., 2022; Hooyberghs et al., 2016).

Understanding the urban climate system is accepted as the beginning of the climate risk assessment process. Critical, therefore, is the need for long-term, quality-controlled, observed climate data. Without long-term historical records, the role of climate variability cannot be adequately defined, and climate change projections cannot be supported by a strong historical basis (Blake et al., 2011; Rosenzweig et al., 2018).

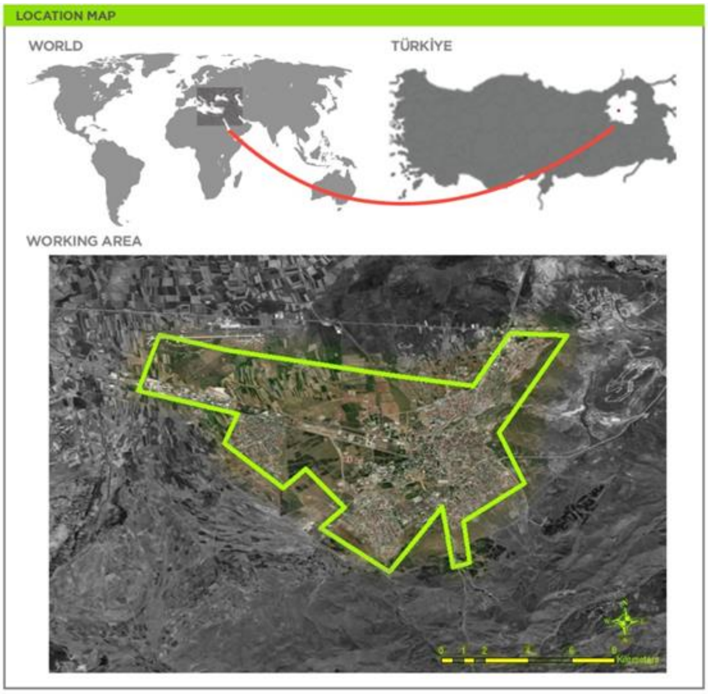

Figure 2. Erzurum location map, working area

The UrbClim model, which will be used in the city of Erzurum, which is a cold climate city, for a comprehensive understanding of the urban climate system and the initiation of the climate risk assessment process and forecasting for the future; It is designed to simulate temperature and heat stress on a city scale. The UrbClim model, which was designed in 2013 to determine the effect of temperature change and sustainable urbanization on an urban scale, is implemented in many European cities. This model is a combination of a three-dimensional atmospheric boundary layer and simplified urban physics. UrbClim generates very high-resolution spatial local climate data by dividing information about urban building components (vegetation, soil isolation, typology, land use and land cover) into forward-looking 100 m grids, combining a physics approach to urban scales. Each grid cell has its energy balance and corresponding thermal behavior (De Ridder & Schayes, 1997; De Ridder et al., 2015a; García-Díez et al., 2016; Martinez et al., 2017; Lauwaet et al., 2017; Verdonck et al., 2018; Ingole et al., 2020) (Figure 3).

The structure of the model includes a comprehensive scheme for the land surface that incorporates simplified urban physics, as well as a 3-D atmospheric boundary layer model. The land surface scheme is based on De Ridder & Schayes' (1997) soil-vegetation-atmosphere scheme, which has been adapted for urban physics by integrating the inverse Stanton number. For further information on the UrbClim numerical model, including its efficiency compared to full mesoscale models, please refer to (De Ridder et al., 2015a; García-Díez et al., 2016; Souverijns et al., 2022).

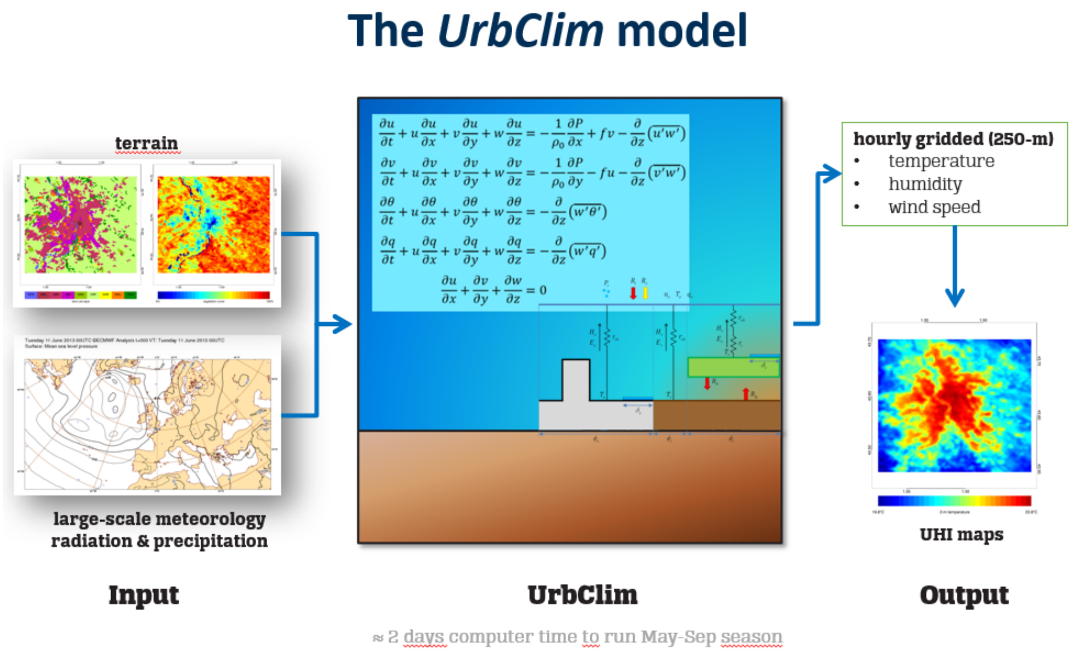

Figure 3. Working principle of UrbClim Model (De Ridder et al., 2015b)

The model has been validated by studies in the cities of Barcelona (Spain), Toulouse (France), Brussels, and Ghent (Belgium).

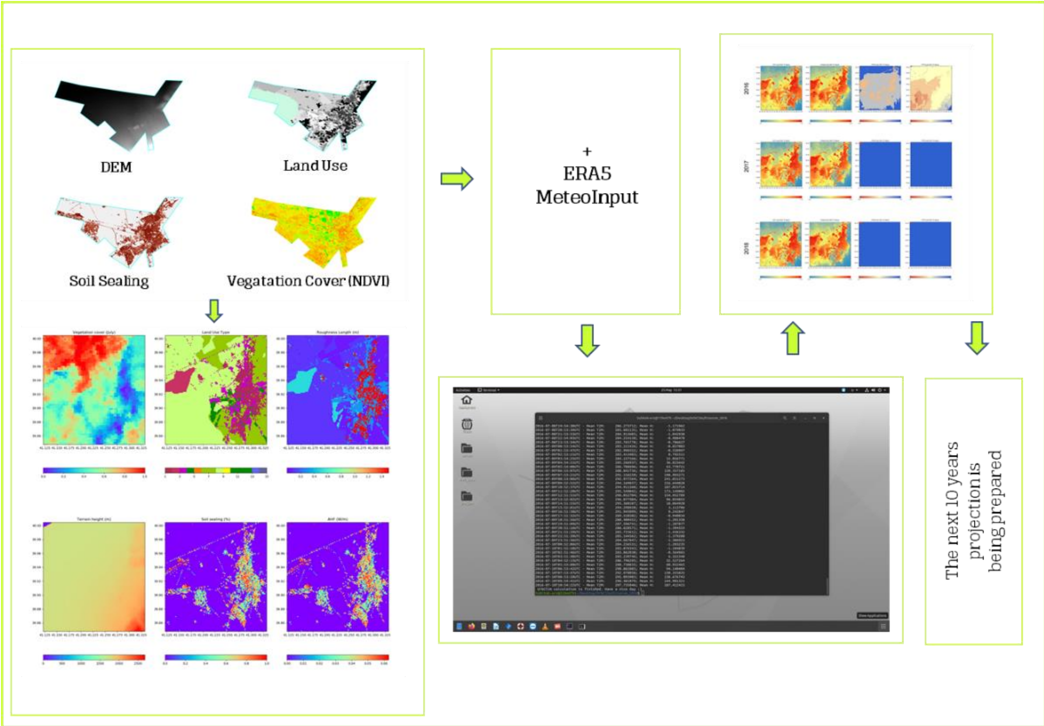

Figure 4. UrbClim model steps in the workspace

In this study, first, maps of the study area were created. DEM map was created from the USGS database. A Land Use Map was created from the Urban Atlas Database. The vegetation cover map was created from MODIS NDVI Landsat 8 database. A soil sealing map was created from the Copernicus database. These maps were run with the scripts provided by the UrbClim model manufacturer VITO company and a total of 6 surface maps were created: Vegetation Cover, Land Use, Roughness Lengths, Terrain Height, Soil Sealing, and AHF maps (Figure 4).

Secondly, meteorological data for the first 10 days of July 2016, 2017, and 2018 were collected from the ERA5 database.

According to the working principles of the UrbClim model, the data entries were completed and the analysis was started.

3. Findings and Discussion

Finally, images of UHI, tMean, HWD, HTD maps were produced using new scripts as a result of the analysis (Figure 5). The findings of 2016 were different compared to other years. This is because, according to the UrbClim model standards in 2017 and 2018, the threshold for hot days is 35.0 °C; the up threshold for heat wave day is 35.0 °C; the bottom threshold for heat wave day is 25.0 °C parameters are used. But in 2016, when Erzurum was a cold climate city, its parameters were threshold for hot days 25.0 °C; up the threshold for heat wave day 25.0 °C; 15.0 °C bottom threshold for heat wave day parameters taken. For this reason, as seen in Figure 5, the maps for 2016 yielded different results compared to other years. Regardless of the climate model used, UHI exists and is increasingly affecting living organisms (Frustaci et al., 2022). Various climate models simulate future scenarios (Ren et al., 2017).

The UrbClim model is presented as an urban climate model designed to study the urban heat island effect at a spatial resolution of several hundred meters. UrbClim is known to be both simpler and at the same level of accuracy when compared to complex and sophisticated models. It also works much faster than high-resolution medium-sized climate models. Therefore, the model is well suited for long-term integrations, especially for applications in urban climate projections (Hooyberghs et al., 2016).

As in this study, the UrbClim model was used in Barcelona. The comparison between heat exposure index maps detailed directly from the temperature outputs produced by the UrbClim model and those produced from the LCZ cartography is well suited for simulating heat exposure index maps for scenarios corresponding to temperature percentages between 50% and 90% (Gilabert et al., 2021).

Urban areas absorb higher amounts of thermal energy during the day and release slowly in the evening (Oke et al., 2017). The predicted results obtained in UrbClim were also observed in the UHI study for Belgium and the city of Bilbao. The correlation coefficient between simulated and observed data was recorded as 0.95 and 0.90, respectively (De Ridder et al., 2015a).

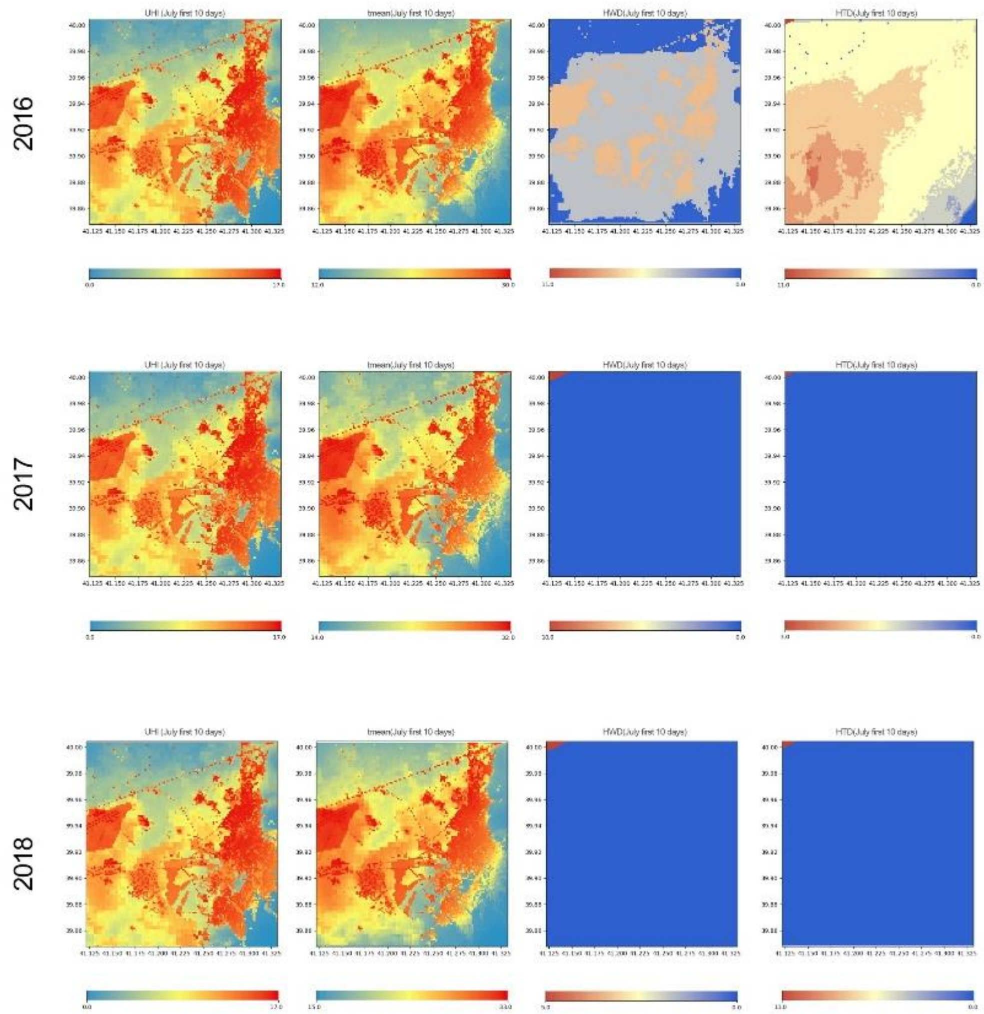

Figure 5. Map findings created from the data of the first 10 days of July in 2016-2017-2018

4. Conclusion and Suggestions

Hot stress is experienced more intensely in urban areas compared to rural settlements, and projections indicate that the effects of climate change on human health will increase. In this study, the UrbClim numerical model was applied to enable a high level of detailed analysis of urban climate over long periods at limited computational costs.

With this research, considering the changing climate parameters, it is necessary to reveal the necessity of climate projection to reduce the physical and psychological stress of the dense population formed in Erzurum and cold cities with similar extreme climate parameters and to make sustainable and ecological plans. In addition, the necessity of reducing the negative effects of urban density on human life and increasing the quality of life is adopted. Manufacturers design and effectively implement plans and projects in the current climate change situation, which is a very complex issue in cities. In future studies, the implementation of urban planning projects in the model enables the quantitative evaluation of the impact of spatial changes on heat stress. This will be an important step towards a thorough and detailed knowledge of the urban climate to address climate change resilience. When the natural data of the planned area are taken into consideration in the design, it may have a positive effect on outdoor thermal comfort.

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The paper complies with national and international research and publication ethics. Ethics committee approval was not required for this manuscript.

Author Contribution and Conflict of Interest Declaration Information

All authors contributed equally to the article. There is no conflict of interest.

References

Arnfield, A. J. (2003). Two decades of urban climate research: a review of turbulence, exchanges of energy and water, and the urban heat island. International *Journal of Climatology: A Journal of the Royal Meteorological Society*, 23(1), 1-26.

Arellano Ramos, B., Roca Cladera, J. & García Haro, A. (2020). The cooling effect of urban parks in the metropolitan region of Barcelona: the sample of Viladecans, Gavà, and Castelldefels urban continuous. In Planning post carbon cities: 35th PLEA conference on passive and low energy architecture, A Coruña, 1st-3rd September 2020: proceedings (pp. 570-575). Universidade da Coruña.

Anonymous. (2021a). Erzurum Geography: Erzurum Accessed date: April 4, 2021, from https://www.erzurum.bel.tr/IcerikDetay-cografi_ozellikleri/1046/I.html

Anonymous. (2021b). Erzurum provincial directorate of Population. Accessed date: April 4, 2021, from https://www.nufusu.com/il/erzurum-nufusu

Blake, R., Grimm, A., Ichinose, T., Horton, R., Gaffin, S., Jiong, S., Bader, D. & Cecil, D. W. (2011). Urban climate: Processes, trends, and projections. In Rosenzweig, C., Solecki, W. D., Hammer, S. A., and Mehrotra, S. (eds.), Climate Change and Cities: First Assessment Report of the Urban Climate Change Research Network (43–81). Cambridge University Press.

Caluwaerts, S., Hamdi, R., Top, S., Lauwaet, D., Berckmans, J., Degrauwe, D., ... & Termonia, P. (2020). The urban climate of Ghent, Belgium: A case study combining a high-accuracy monitoring network with numerical simulations. *Urban Climate*, 31, 100565.

De Ridder, K. & Schayes, G. (1997). The IAGL land surface model. *Journal of Applied Meteorology*, 36(2), 167–182.

De Ridder, K., Lauwaet, D. & Maiheu, B. (2015a). UrbClim – A fast urban boundary layer climate model. *Urban Climate*, 12, 21–48.

De Ridder, K., Lauwaet, D. & Maiheu, B. (2015b). https://urban-climate.be/c/urbclimDescription/

Frustaci, G., Pilati, S., Lavecchia, C. & Montoli, E. M. (2022). High-resolution gridded air temperature data for the urban environment: The Milan data set. *Forecasting,* 4(1), 238-261.

Gabriel, K. M. & Endlicher, W. R. (2011). Urban and rural mortality rates during heat waves in Berlin and Brandenburg, Germany. *Environmental pollution*, 159 (8-9), 2044-2050.

García-Díez, M., Lauwaet, D., Hooyberghs, H., Ballester, J., De Ridder, K. & Rodo, X. (2016). Advantages of using a fast urban boundary layer model as compared to a full mesoscale model to simulate the urban heat island of Barcelona. *Geosci. Model Dev.*, 9, 4439–4450.

Gilabert, J., Deluca, A., Lauwaet, D., Ballester, J., Corbera, J. & Llasat, M. C. (2021). Assessing heat exposure to extreme temperatures in urban areas using the Local Climate Zone classification. *Natural Hazards and Earth System Sciences*, 21(1), 375-391.

Hooyberghs, H., Maiheu, B., De Ridder, K., Lauwaet, D. & Lefebvre, W. (2016). Assessing Climate Change in Cities Using UrbClim. In Air Pollution Modeling and its Application XXIV (pp. 425-430). Springer International Publishing.

Irmak, A., Yilmaz, S., Mutlu, E. & Yılmaz, H. (2018). Assessment of the effects of different tree species on urban microclimate. *Environmental Science and Pollution Research*, 25 (16): 15802-15822, doi.org/10.1007/s11356-018-1697-8

Irmak, M. A., Yilmaz, S. & Dursun, D. (2017). Effect of different pavements on human thermal comfort conditions. *Atmósfera,* 30(4), 355-366.

Ingole, V., Marí-Dell'Olmo, M., Deluca, A., Quijal, M., Borrell, C., Rodríguez-Sanz, M. & Ballester, J. (2020). Spatial Variability of Heat-Related Mortality in Barcelona from 1992–2015: A Case Crossover Study Design. *International Journal of Environmental Research and Public Health*, 17(7), 2553.

IPCC Synthesis Report. (2014). https://archive.ipcc.ch/pdf/assessment-report/ar5/syr/SYR_AR5_Final_full_wcover.pdf (Accessed date: 03 July 2021).

IPCC. (2021). AR6 WGI Report: Climate Change 2021: The Physical Science Basis (Accessed date 02 November 2021).

Jamali, F. S., Khaledi, S. & Razavian, M. T. (2021). Seasonal impact of urban parks on land surface temperature (LST) in the semi-arid city of Tehran. *International Journal of Urban Sustainable Development*, 1–17. doi:10.1080/19463138.2021.1872083

Kim, D., Yu, J., Yoon, J., Jeon, S., & Son, S. (2021). Comparison of Accuracy of Surface Temperature Images from Unmanned Aerial Vehicle and Satellite for Precise Thermal Environment Monitoring of Urban Parks Using in Situ Data. *Remote Sensing*, 13(10), 1977.

Lauwaet, D., De Ridder, K., Hooyberghs, H., Lefebre, F. (2017). Urban Boundary-Layer Climate Model UrbClim USER GUIDE V1.0. Vıto Vision on Technology, Mol-Belgie.

Lobaccaro, G., De Ridder, K., Acero, J. A., Hooyberghs, H., Lauwaet, D., Maiheu, B., ... & Govehovitch, B. (2021). Applications of models and tools for mesoscale and microscale thermal analysis in mid-latitude climate regions—*A review. Sustainability*, 13(22), 12385.

Li, D. & Bou-Zeid, E. (2013). Synergistic interactions between urban heat islands and heat waves: The impact in cities is larger than the sum of its parts. *Journal of Applied Meteorology and Climatology,* 52(9), 2051–2064.

Martinez, G.S., Gimeno, L., Hooyberghs, H., Lauwaet, D., De Ridder, K., Linares, C., Carmona, R., Ortiz, C., Kendrovski, V., Aerts, R.; et al. (2017). Heat and health in Antwerp under climate change: Projected impacts and implications for prevention. *Environ. Int.* 111, 135–143.

Maheng, D., Ducton, I., Lauwaet, D., Zevenbergen, C. & Pathirana, A. (2019). The Sensitivity of Urban Heat Island to Urban Green Space—A Model-Based Study of City of Colombo, Sri Lanka. Atmosphere, 10(3), 151.

Menteş, Y., Yilmaz, S., Qaid, A. & Yilmaz, H. (2023). Assessment of the impact of the different settlement patterns on the summer land surface temperature: Elazığ. *Environmental Science and Pollution Research*, 1-26. doi.org/10.1007/s11356-022-24341-6

Mutlu, E., Yilmaz, S., Yilmaz, H. & Mutlu, B. E. (2018, May). Analysis of urban settlement units by ENVI-met according to different aspects in cold regions. In the 6th annual International Conference on Architecture and Civil Engineering (ACE 2018), oral presentation (Vol. 14, p. 15).

Nazarian, N. & Lee, J. K. (2021). Personal assessment of urban heat exposure: a systematic review. *Environmental Research Letters*, 16(3), 033005.

Ohashi, Y., Genchi, Y., Kondo, H., Kikegawa, Y., Yoshikado, H. & Hirano, Y. (2007). Influence of air-conditioning waste heat on air temperature in Tokyo during summer: Numerical experiments using an urban canopy model coupled with a building energy model. *Journal of Applied Meteorology and Climatology*, 46(1), 66–81.

Oke, T. R. (1978). Boundary Layer Climate. Routledge.

Oke, T. R., Mills, G., Christen, A. & Voogt, J. A. (2017). Urban climates. Cambridge University Press.

Qiu, K. & Jia, B. (2019). The roles of landscape both inside the park and the surroundings in the park cooling effect. *Sustainable Cities and Society*, 101864. doi:10.1016/j.scs.2019.101864

Ranagalage, M., Estoque, R. C. & Murayama, Y. (2017). An urban heat island study of the Colombo metropolitan area, Sri Lanka, based on Landsat data (1997–2017). *ISPRS International Journal of Geo-Information*, 6(7), 189.

Ren, C., Fung, J. C. H., Tse, W. P., Wang, R., Wong, M. F. & Xu, Y. (2017). Implementing WUDAPT product into urban development impact analysis by using WRF simulation result-A case study of the Pearl River Delta Region (1980-2010).

Rosenzweig, C., Solecki, W. D., Romero-Lankao, P., Mehrotra, S., Dhakal, S. & Ibrahim, S. A. (Eds.). (2018). Climate change and cities: Second assessment report of the urban climate change research network. Cambridge University Press.

Santamouris, M. (2020). Recent progress on urban overheating and heat island research. Integrated assessment of the energy, environmental, vulnerability, and health impact. Synergies with global climate change. *Energy and Buildings*, 207, 109482.

Skelhorn, C. P., Levermore, G. & Lindley, S. J. (2016). Impacts on cooling energy consumption due to the UHI and vegetation changes in Manchester, UK. *Energy and Buildings*, 122, 150-159.

Souverijns, N., De Ridder, K., Veldeman, N., Lefebre, F., Kusambiza-Kiingi, F., Memela, W. & Jones, N. K. (2022). Urban heat in Johannesburg and Ekurhuleni, South Africa: A meter-scale assessment and vulnerability analysis. *Urban Climate*, 46, 101331.

Tan, J., Zheng, Y., Tang, X., Guo, C., Li, L., Song, G., Zhen, X., Yuan, D., Kalkstein, A., Li, F. & Chen, H. (2010). The urban heat island and its Impact on heat waves and human health in Shanghai. *International Journal of Biometeorology,* 54(1), 75–84.

Taleghani, M. (2018). Outdoor thermal comfort by different heat mitigation strategies-A review. *Renewable and Sustainable Energy Reviews*, 81, 2011-2018.

Tremeac, B., Bousquet, P., de Munck, C., Pigeon, G., Masson, V., Marchadier, C., Merchat, M., Poeuf, P. & Meunier, F. (2012). Influence of air conditioning management on heat island in Paris air street temperatures. *Applied Energy*, 95(0), 102–110.

Verdonck, M. L., Demuzere, M., Hooyberghs, H., Beck, C., Cyrys, J., Schneider, A., ... & Van Coillie, F. (2018). The potential of local climate zone maps as a heat stress assessment tool, supported by simulated air temperature data. *Landscape and Urban Planning*, 178, 183-197.

Vardoulakis, E., Karamanis, D., Fotiadi, A. & Mihalakakou, G. (2013). The urban heat island effect in a small Mediterranean city of high summer temperatures and cooling energy demands. *Solar Energy,* 94, 128-144.

Wang, X., Cheng, H., Xi, J., Yang, G. & Zhao, Y. (2018). Relationship between Park Composition, Vegetation Characteristics, and Cool Island Effect. *Sustainability,* 10(3), 587. doi:10.3390/su10030587

Uzun, Ö. F. & Gül. A. (2021). Bitkisel tasarımda kullanılabilecek bilgi sistemi ve yazılımların karşılaştırılması. *Journal of Architectural Sciences and Applications*, 6(1), 141-152.

Yılmaz S., Mutlu B. E., Aksu A., Mutlu E. & Qaid A. (2021). Street design scenarios using vegetation for sustainable thermal comfort in Erzurum, Turkey. *Environmental Science and Pollution Research*, 28 (3): 3672-3693. DOI 10.1007/s11356-020-10555-z

Yılmaz, S., Irmak, M. A. & Qaid, A. (2022). Assessing the effects of different urban landscapes and built environment patterns on thermal comfort and air pollution in Erzurum City, Turkey. *Building and Environment,* 219, 109-210.

Yılmaz, S., Vural, H. & Yilmaz, H. (2023). Effects of botanical gardens on student environmental perception. *Ecological Informatics*, 73, 101942.

Yüksel, Ü. D. & Yılmaz, O. (2008). Ankara kentinde kentsel ısı adası etkisinin yaz aylarında uzaktan algılama ve meteorolojik gözlemlere dayalı olarak saptanması ve değerlendirilmesi. *Gazi Üniversitesi Mühendislik Mimarlık Fakültesi Dergisi*, 23(4).