Investigating and comparing the urban signature on heavy precipitation in Istanbul and Ankara

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A wide range of climate projection studies underlines the possibility of a surge in the frequency and magnitude of extreme precipitation around parts of the world due to warming. However, not many of them put urban growth at the core of their study. As more than half of the world population is expected to reside in urban areas by the middle of the century, exploring the impact of urbanization on climate becomes indispensable in assessing Climate Change-related vulnerabilities. Prominent among the cities of Turkey are Istanbul and Ankara, which have experienced a rapid increase in urbanization, becoming vulnerable to the potential impacts of hazardous weather events such as extreme precipitation. Our objective is to investigate and compare the changes in the rainfall due to the urban land use in Istanbul and Ankara, both from physical and thermodynamic perspectives, taking the coastal and inland features of each city into account. Employing a case study approach, we choose two specific precipitation events and exploit the weather research and forecast model (WRF) to simulate the events. Most of the literature demonstrated that urbanization affects the summer convective rainfall in particular. Therefore, the selected events in this study are from the summer season, which is characterized by convection and pronounced urban heat island phenomenon in Istanbul and Ankara. We integrated the CORINE Land Cover (CLC) data into the WRF to better represent urbanization in the simulations and next run the model with-and-without urban land use over the cities. The results agreed with the literature and suggested that urban signature modifies the thermodynamic variables such as temperature, sensible heat, and latent heat, inducing temporal and spatial changes in the rainfall events. The simulation with urbanization included portrays similar higher temperature values over the urban extent of Istanbul and Ankara. However, the observed changes in the precipitation pattern differed for the selected cities, owing to their distinct geographical and climatological features. For example, in the urban simulation scenario, the precipitation amount in the central urbanized portion increased in Ankara but decreased in Istanbul. In addition, the upwind regions of both cities supported an increase in the vertical velocity. Given that the urban signature has a reasonable impact on the meteorological description of the present-day convective precipitation events in two of the crowdest cities of Turkey, climate projection studies should elaborate on further comprehending the urbanization impacts on the extreme weather events.

Keywords: Urbanization, Extreme Precipitation, Turkey, Urban Climate

1. INTRODUCTION

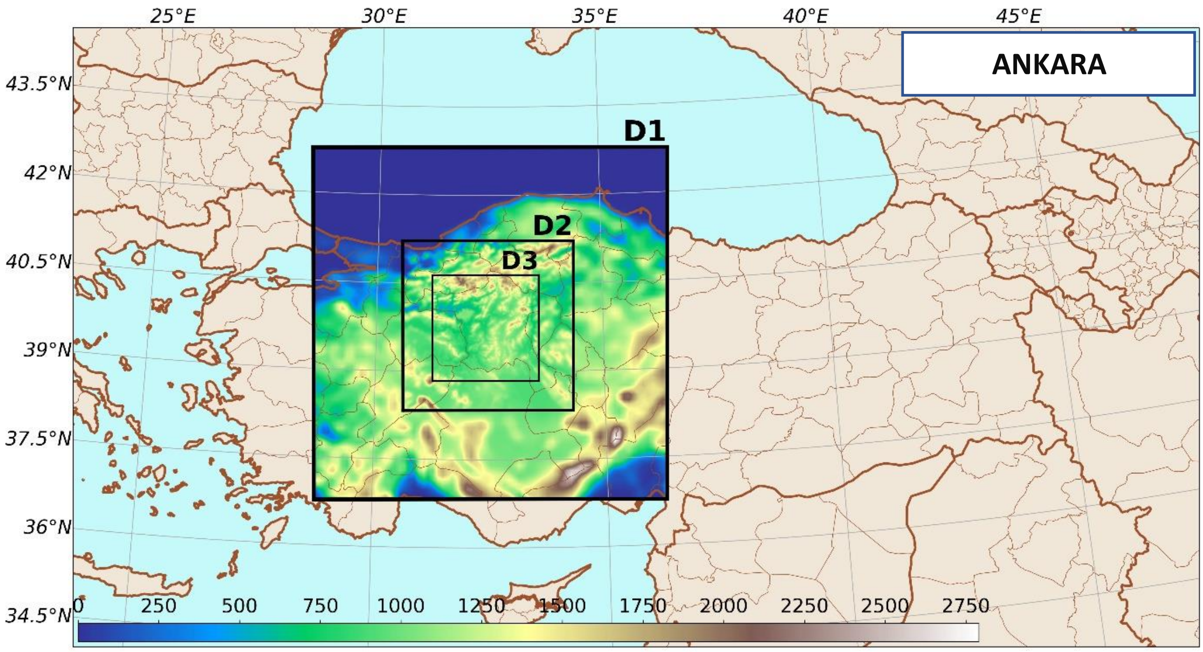
As the world population increases, demand for accommodation, food, and other human needs enforces the earth to get urbanized rapidly. The report from United Nations emphasizes that, by 2050, the population living in urbanized areas is to reach almost 70 percent (UN DESA, 2018). Thus, detecting the possible vulnerabilities arising from rural-to-urban transformation is critical for humans to endure secure life. There are plenty of natural phenomena which endanger daily life such as, long-lasting drought conditions, short-time extreme precipitation. Considering the increase in urbanization combined with Climate Change, these phenomena may become stronger and have more devastating effects. The modification in urban land use adjusts the energy balance of these areas (Oke et al., 2017). Converting land cover features from natural to urban leads to distinct thermal behaviors. The resulting phenomenon is Urban Heat Island (UHI) which accounts for the difference in temperature in urban and surrounding rural areas. The UHI measurements can be made in four ways (subsurface, surface, canopy layer, boundary layer) (Oke et al., 2017). In this article, we choose one of the most commonly used ways of measuring UHI by utilizing 2m air temperature. Istanbul, the most populated city of Turkey, and Ankara, the second most populated city of Turkey, holds a UHI feature demonstrated many times in the literature (Unal et al., 2019; Karaca, Anteplioglu, Karsan, 1995; Basar, Kaya, Karaca, 2008; Çiçek, Doğan, 2005). Apart from UHI, urbanization may also alter the airflow passing over the urban area. Thus, UHI and modified airflow together constitute the urban signature. The impact of urbanization on heavy precipitation has been investigated several times in the literature. Bornstein & Lin (2000) found that the convergence area has been created by the urbanization and resulting Urban Heat Island (UHI) in the summertime, Atlanta, which caused convective storms. Kishtawal et al. (2009) showed that the probability of extreme precipitation amounts to be experienced in urban are higher than that in rural. Niyogi et al. (2011) revealed in their study investigating thunderstorm climatology of urban Indianapolis that the precipitation patterns are affected while moving over urban areas. Lin et al. (2020) demonstrated that near-shore and inland urban regions in China feature distinct impacts on precipitation events as urban areas on near-shore (inland) experience a decrease (increase) in precipitation amounts, possibly due to Urban Dry Island (UDI). Fowler et al. (2020) conclude from a climatological study in Kuala Lumpur that, compared to rural areas, urban areas have led short-time heavy precipitations to be more severe. Niyogi et al. (2017) revealed that the summer precipitation amounts are improved in the downwind urban-rural edge and reduced over the city.

There are not enough studies demonstrating the urban effect on heavy summer precipitation in any city in Turkey. Therefore, we ask this simple question: how does urbanization alter precipitation amounts and patterns in Istanbul and Ankara. In order to answer this question, we choose one specific precipitation event both from Istanbul and Ankara and investigate them from an urbanization-precipitation perspective. In the following section, we define our experimental design. In the third part, we are revealing our results, and in the last part, we are concluding our findings and suggesting further research.

2. EXPERIMENT DESIGN

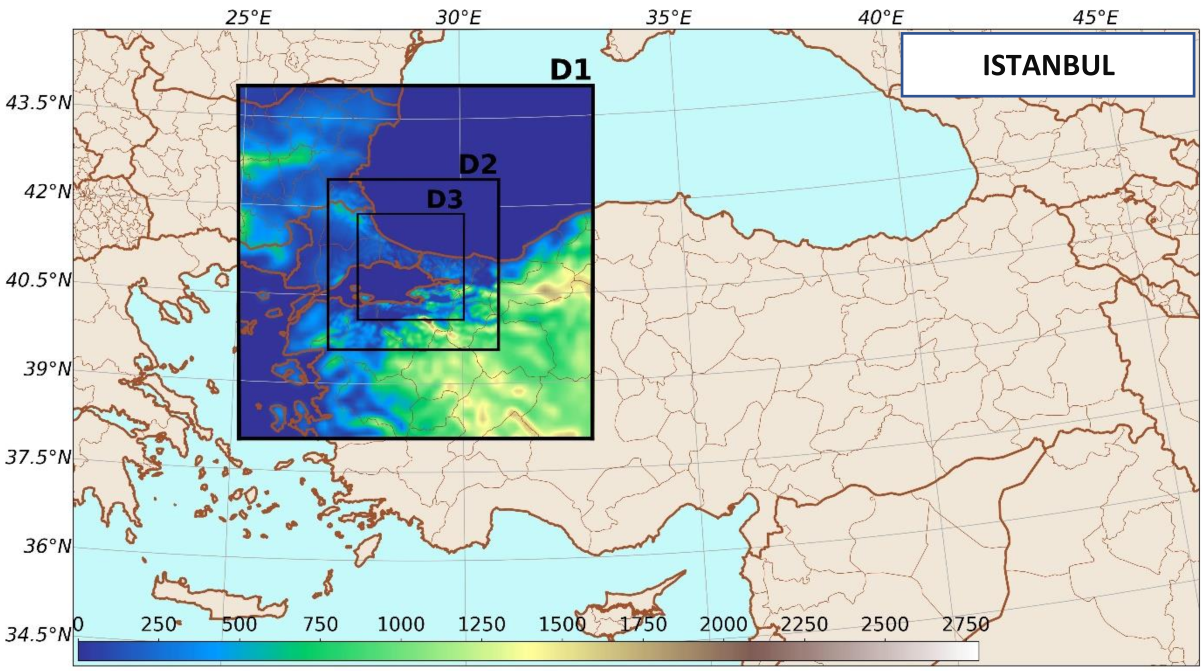
In this study, we chose two summer rainfall events that occurred in Istanbul (18 July 2017) and Ankara (28 August 2016), with similarities in their characteristics. Both events are summertime convective precipitation events with a prominent Urban Heat Island (UHI) effect before the heaviest rainfall hours.

Figure 2.1 : Three nested domains for Ankara used by WRF (Colors represent altitudes in meters).



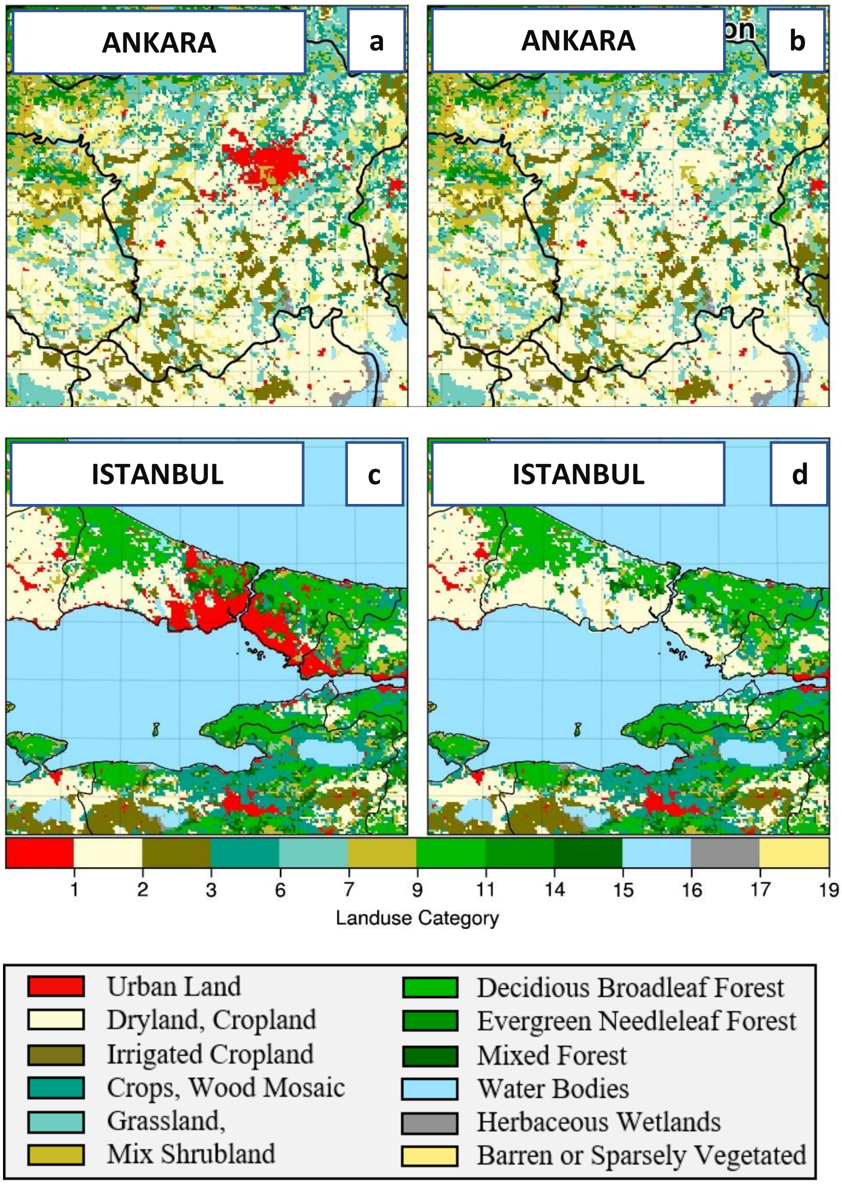
We used the Weather Research and Forecast Model (WRF) to simulate each event using three different microphysical parameterizations: Purdue Lin Scheme (Chen and Sun, 2002), Thompson Scheme (Thompson et al., 2008), and WRF single-moment 6-class (WSM6) (Hong and Lim, 2006). For planetary boundary layer (PBL) physics option Yonsei University Scheme (YSU) (Hong et al., 2006).

Figure 2.2 : Three nested domains for Istanbul used by WRF (Colors represent altitudes in meters).



The remained physics options are the Rapid Radiative Transfer Model (RRTM) Longwave Radiation Scheme (Mlawer et al., 1997), Dudhia Shortwave Scheme (Dudhia, 1989), Unified Noah Land Surface Model Scheme (Tewari et al., 2004), Revised MM5 Surface Layer Scheme (Jimenez et al., 2012). We defined three nested domains (9km: 3km: 1km) centered at Ankara (Figure 2.1) and Istanbul (Figure 2.2). The main aim was to simulate the events in ensembles and to find the best microphysical parametrization in terms of their ability to represent the precipitation amounts. Evaluating ensemble members revealed that WSM6 and Thompson microphysical parameterization schemes were the most successful ones over Istanbul and Ankara, respectively, explaining the actual rainfall accumulations.

Figure 2.3 : Land cover configurations using a high-resolution and up-to-date Corine 2018 land-use dataset for Ankara (First panel row), and Istanbul (Second panel row). The (a, c) corresponds to Urban configuration; (b, d) corresponds to Nourban configuration.



After determining the best representations, we attempted to analyze the urban signature in Istanbul and Ankara by applying two different land cover configurations using a high-resolution and up-to-date CORINE 2018 land-use dataset. In the first configuration (Urban configuration), we included the urban land cover in both metropolitan areas. However, in the second configuration (Nourban configuration), we replaced the urban land cover to dry/cropland (Figure 2.3). By doing this, we purposed to unearthing the impact of urbanization alone on both precipitation events.

3. RESULTS

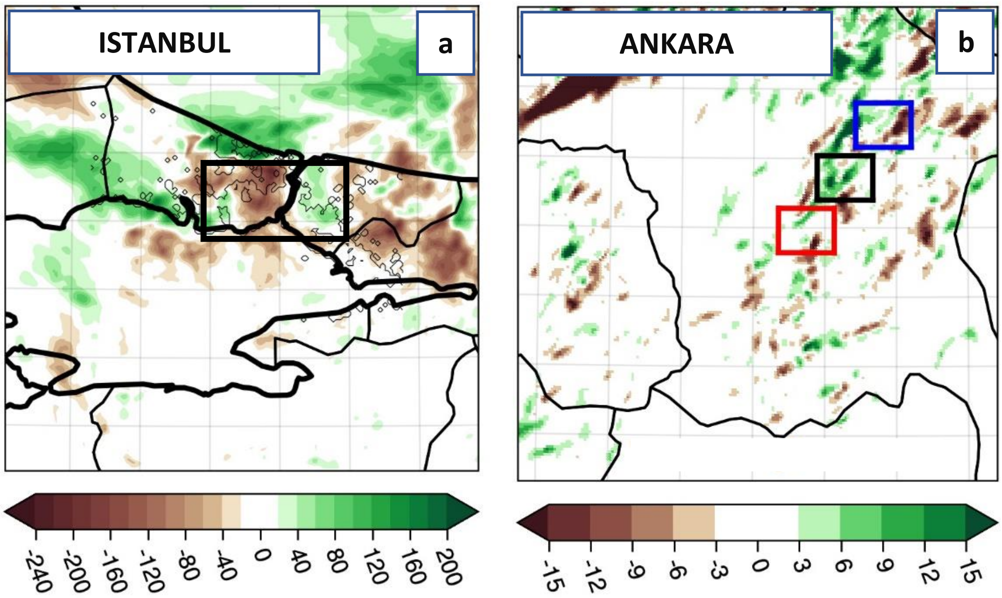
We utilize four meteorological variables (i.e., precipitation, sensible/latent heat, vertical velocity) to investigate the potential urban influence on the precipitation events in Istanbul and Ankara. The observed changes in these variables during the event days between Urban and Nourban configurations are compared to each other. Namely, we analyze the differences between the simulations configured with urban land use and without urban land use.

3.1. Precipitation Analysis

Figure 3.1 reveals the simulated differences in the daily total precipitation (mm) amounts between Urban and Nourban configurations for the Istanbul and Ankara cases. The larger (smaller) values represent a precipitation increase (decrease) in the simulation with (without) urban land use included. The black boxes in Figure 3.1 portray the approximate urban center in Istanbul and Ankara.

For the precipitation event in Istanbul (Figure 3.1a), we observe a decrease in the daily total precipitation over the urban center. In other words, the rainfall amount is suppressed with the urbanization in Istanbul. However, for the Ankara case (Figure 3.1b), there is an increased daily total precipitation over the urban center in the Urban configuration. This finding is similar to what Su et al. (2021) and Lin et al. (2020) found in their study.

Figure 3.1 : Simulated differences in the daily total precipitation (mm) amounts between Urban and Nourban configurations for the Istanbul (a) and Ankara (b) cases. The black boxes represent the urban center in each city.

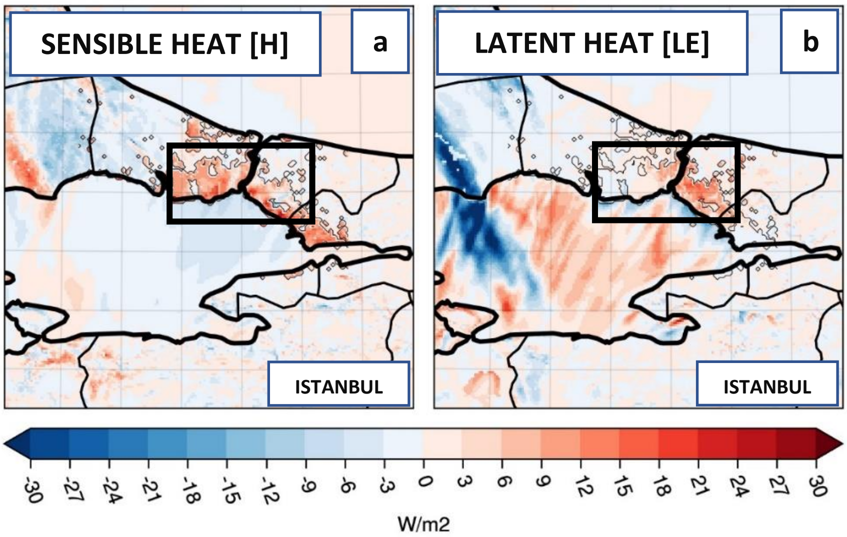


The corresponding decrease and increase in the precipitation amounts in Istanbul and Ankara cases might be related to the geographical characteristics of each city. Namely, the absence of a large body of water (e.g., sea, lake) in Ankara and its complex topography can contribute to the observed precipitation differences between the cities.

3.2. Sensible/Latent Heat Analysis

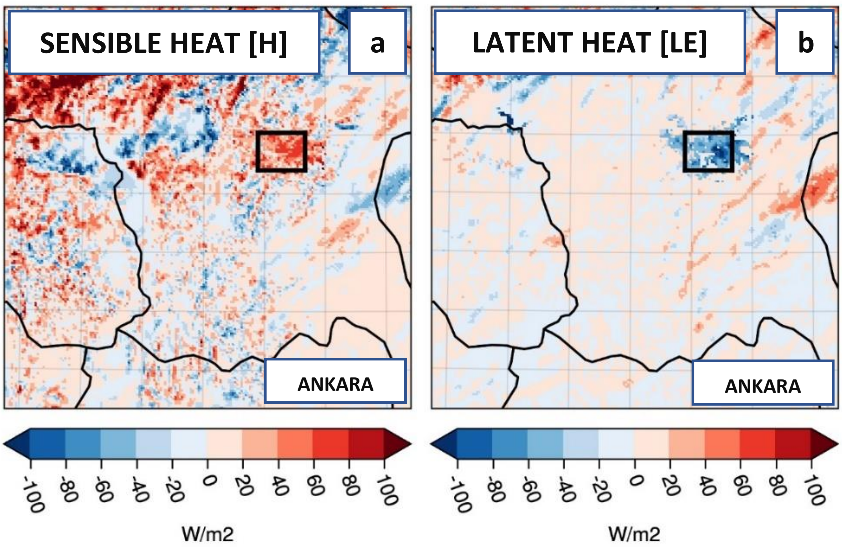
Most of the studies, which investigated the urban signature on the meteorological environment of cities, have used the sensible and latent heat variables to unleash the impact of urban land use given how important they are in depicting the energy exchange between surface and atmosphere. Similarly, we analyze the simulated changes in the average sensible and latent heat fluxes between the Urban and Nourban configurations in both cities.

Figure 3.2 : Sensible (a) and latent heat (b) differences (Urban configuration – Nourban configuration) averaged over the four hours before the heaviest rainfall hour in Istanbul. The warmer colors represent an increase in the variable's value in the Urban scenario, while the colder colors represent a decrease.



Figures 3.2 and 3.3 represent the sensible (a) and latent heat (b) differences (Urban – Nourban) averaged over the four hours before the heaviest rainfall hour in Istanbul and Ankara, respectively. The black boxes in the figures correspond to the urban centers. The warmer shades depict an increase in the variable's value, while the colder colors represent a decrease.

Figure 3.3 : Same as Figure 3.2, but for Ankara.

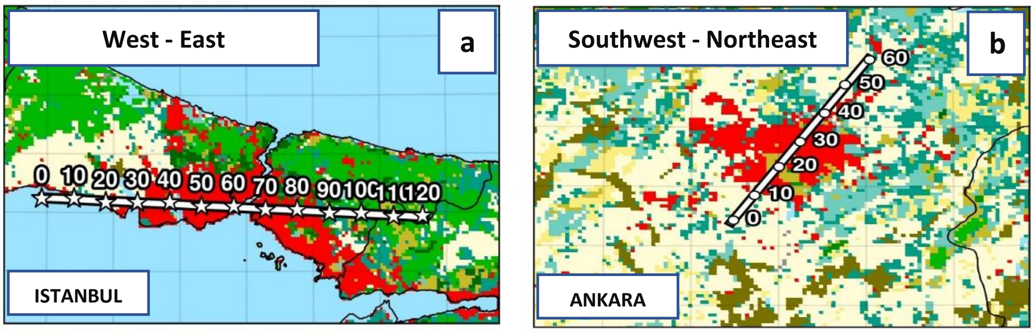


In the simulations of both Istanbul and Ankara precipitation events, we observe the prominent effect of the urban signature on the distribution of the sensible and latent heat values. The urban land use in both cities similarly supported an increase in the sensible heat values (Figures 3.2a and 3.3a) over the urban extent (black boxes). However, this is not the case for the latent heat variable. Namely, the simulation results with the Urban configuration reveal an increase in the latent heat values over the urban center of Istanbul but a decrease over the urban extent of Ankara (Figures 3.2b and 3.3b). These higher latent heat values over Istanbul, in the Urban simulation scenario, possibly contributed to the suppression of precipitation over the urban center of Istanbul (see the previous subsection).

3.3. Vertical Velocity Analysis

Lastly, we examine vertical velocity changes in each city along a particular cross-section. The utilized cross-sectional directions can be seen in Figure 3.4. We structured the cross-sections for Istanbul and Ankara such that each of them approximately portrays the movement direction of the precipitation systems and takes the urban-rural interaction into account. The red color in Figure 3.4 depicts the urban land use, whereas the yellow and green colors represent the rural locations with different land uses. The numbers in the figures are the references for the location of the urbanized region in the vertical cross-section figures below.

Figure 3.4 : The cross-sectional directions for Istanbul (west-east) (a) and Ankara (southwest-northeast) (b) utilized in the vertical velocity analysis.



Figures 3.5 and 3.6 reveal the vertical velocity values one hour before the heaviest rainfall in each city. The narrow red lines on the x-axes of the figures correspond to the urban land use, referencing the numbers in Figure 3.4. The warmer (colder) shades portray the increased upward (downward) motion.

What is striking is that in both Ankara and Istanbul precipitation cases, we see an increased upward motion, in the Urban scenario, over the entrance region (upwind) of urban land use considering the movement direction of the precipitation systems. However, the upward motion of air in the Istanbul case did not result in a precipitation increase over the urban center, whereas the increased upward movement in Ankara, shown with the red colors, contributed to the precipitation increase over the urban center. This dissimilarity in Istanbul and Ankara cases might have resulted from the complex interaction between the analyzed meteorological variables as well as topographical settings of the cities.

Figure 3.5 : Vertical velocity values one hour before the heaviest rainfall in Istanbul for Urban (a) and Nourban (b) scenarios. The warmer (colder) shades portray the upward (downward) motion. Narrow red lines on the x-axes of the figures correspond to the urban land use.

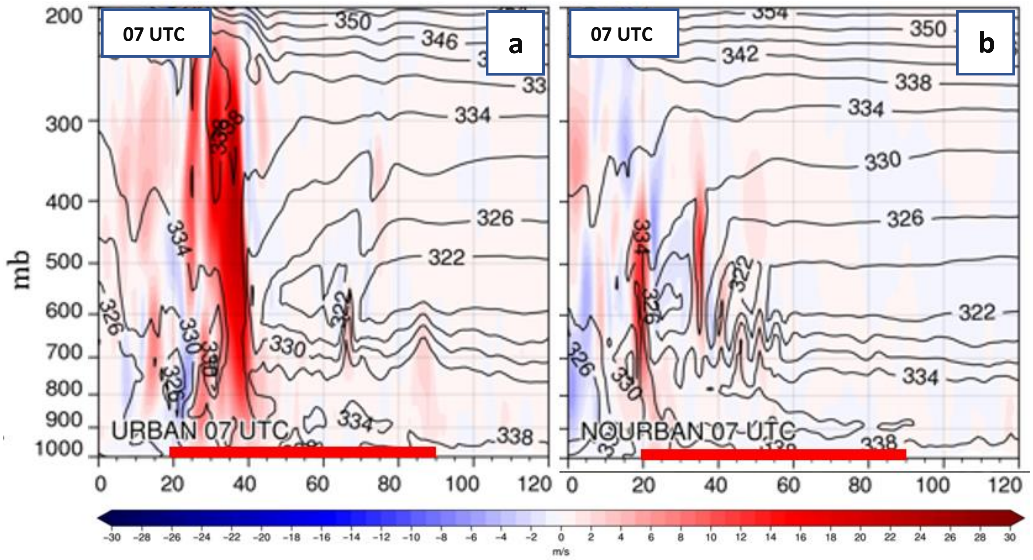
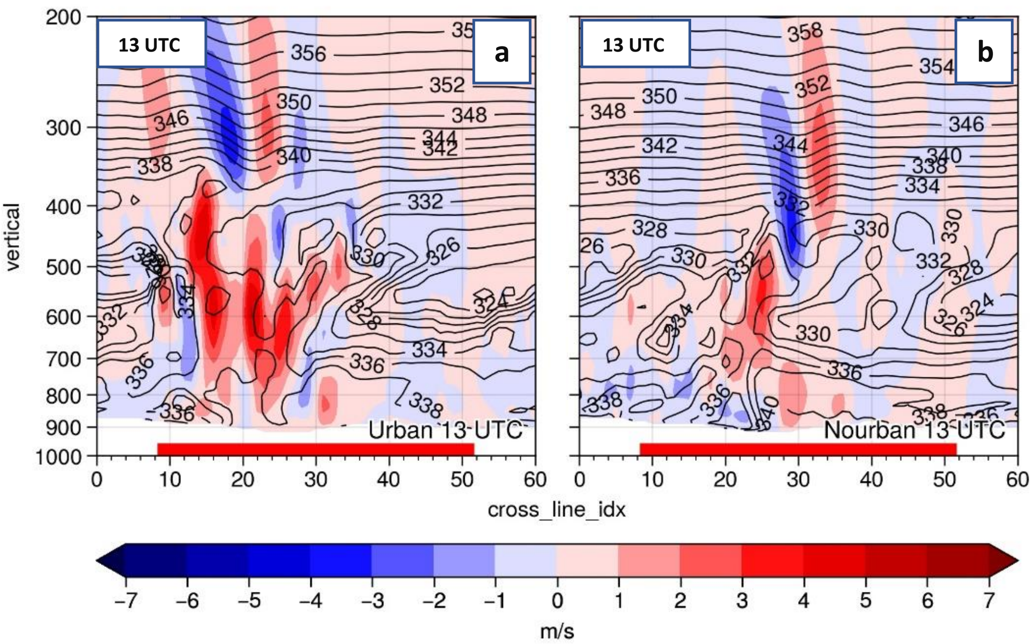


Figure 3.6 : Same as Figure 3.5, but for Ankara.



4. CONCLUSION AND RECOMMENDATION

The essential aim of this study is to ask this question: How does urban signature alter precipitation patterns in Istanbul and Ankara? Choosing one specific summer rainfall occurrence, which is characterized by convective activities with a prominent urban heat island effect before the heaviest rainfall, from both cities, we simulate the events with-and-without urban land use in the cities and compare the results to each other.

The findings reveal a notable impact of urbanization on the selected precipitation incidences of both cities. However, the observed changes in the rainfall pattern and amount are not the same in Istanbul and Ankara. Namely, the urban signature supported a decrease in daily total precipitation amount (mm) over the urbanized region of Istanbul, while the opposite was observed for the Ankara case. Suppression of rain over urbanized Istanbul might be an indirect outcome of the higher latent heat values over the urban center, unlike the general literature, which emphasizes that the urban land use lowers the latent heat over the urbanized area. Also, the difference might be related to the changes of the local circulation between city centers and surroundings due to urbanization. In Istanbul, existence of Marmara Sea on the south and Black Sea on the north and channeling effect of Istanbul Bosphorus significantly modify the urban circulation.

In addition to the precipitation changes, we demonstrate the impact of urban land use on certain meteorological variables such as temperature, vertical velocity, and sensible heat. For example, urban signature triggers an increase in upward motions over the upwind parts of the city center.

Note that the findings presented in this study rely on a single synoptic pattern for both cities. In other words, it may not be appropriate to generalize the urban impacts depicted in our work for Istanbul and Ankara. Therefore, the exploitation of a larger sample of precipitation occurrences analyzed with related statistical methods can assist in generalizing the results on two of the most populated cities of Turkey: Istanbul and Ankara.

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