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Urban Heat Island: Understanding the Heat of Our Cities

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Rapid urbanization is altering the characteristics of the land surface and its climatic environment. One of the results of this change is the Urban Heat Island (UHI) phenomenon, whereby urban areas are typically warmer than their surrounding rural places, especially under favorable meteorological parameters. This happens because replacing vegetation and farms with concrete, asphalt, buildings, and other impervious surfaces leads to changes in the surface energy balance, radiation, evapotranspiration, heat storage, and turbulent processes.

Introduction

Cities are often warmer than the area surrounding them, especially under calm weather conditions. This is called the Urban Heat Island (UHI) effect. Urbanization replaces natural vegetation, cropland, and bare soil with roads, buildings, parking lots, and other artificial surfaces. This leads to changes in the way solar energy is absorbed and released at the Earth's surface (Oke, 1982). It is important to note that the UHI is not merely due to the presence of lots of buildings and people. It is closely related to changes in the surface energy balance, radiation, evapotranspiration, eddies, wind, and storage of heat. Such processes are at the core of micrometeorology, making UHI a good case of land–atmosphere interactions (Arnfield, 2003). In terms of micrometeorology, the cause of UHI is that urban surfaces use energy differently than natural ones. Reduced evapotranspiration, increased sensible heat flux, heat storage in buildings and roads, and heat emissions from anthropogenic processes lead to urban warming. Remote sensing data regarding Land Surface Temperature (LST) are essential for identifying urban thermal hotspots and studying the relationship between land-use/land-cover changes and surface temperature. Urban heat has an impact on human comfort, energy consumption, water consumption, and agriculture in peri-urban areas. Increasing vegetation, preserving water bodies, using reflective materials, and applying climate-sensitive urban planning can help mitigate urban overheating.

Factors Causing Cities to Heat Up

1. **Concrete and asphalt:** The thermal behavior of surfaces in the city is very different from surfaces that naturally exist in the countryside. City surfaces such as concrete roads, sidewalks, and roofs absorb solar energy and store heat in them. After sunset, the heat stored in the city surfaces is released, making the city quite warm (Oke, 1982).
2. **Loss of vegetation:** Vegetation has the capacity to cool the surface through the evapotranspiration process. Plants transfer moisture from the soil and vegetation into the atmosphere. The energy is consumed as latent heat and not used to increase the temperature of the surface. Once surfaces appear in place of vegetation, the evapotranspiration process stops, and the area will have more energy in sensible form, which increases the temperature of the surface and air.
3. **Urban buildings and radiation:** The urban structure is a three-dimensional space made of buildings. The buildings, which line closely to each other, create urban canyons and

affect solar radiation, longwave radiation, and wind flow. Radiation can bounce between buildings several times, while limited skylight exposure can slow nighttime cooling.

4. **Anthropogenic heat:** The heat given off as a result of human activities is also a variable contributing to the urban climate. Emissions from vehicles, industrial activities, air-conditioning systems, urban construction, and power harnessing add heat to urban areas. Such human-made heat forms part of the phenomenon that is referred to as anthropogenic heat.
5. **Changes in the wind and turbulence:** The presence of buildings in a particular area increases the roughness of the surface and alters the wind movement. The development of buildings alters the turbulent transfers of heat and moisture from the ground to the atmosphere (Arnfield 2003).

Urban Heat Island from a Micrometeorological Perspective

The concept of UHI can be expressed through the surface energy balance, which is given by the equation:

$$Rn = H + LE + \Delta Qs + QF$$

Where,

Rn = Net radiation; H = Sensible heat; LE = Latent heat; ΔQs = Ground/storage heat; QF = Anthropogenic heat

The contribution of factors usually varies over time, type of weather, and surface type. Therefore, in a vegetated agricultural field, a substantial part of energy might be transformed into latent heat because of evaporation. In contrast, in a dry urban area, most of the energy is transformed into sensible heat rather than latent heat. This is a significant physical reason for temperature differences in urban and rural areas (Oke, 1982; Arnfield, 2003). UHI also varies during the day. City surfaces heat because of the intense solar radiation during the day but release their heat in the evening. The advantage of rural vegetation and soil is that they cool off more efficiently under favorable conditions, which means that urban-rural temperature differences are most pronounced at night. Despite this, the intensity of UHI is volatile. Factors that affect its intensity include wind, humidity, atmospheric stability, season, and surface moisture.

Varieties of Urban Heat Island

Three types of UHI are typically mentioned:

1. **Surface Urban Heat Island:** The term describes the difference in land surface temperature in urban areas in comparison to the temperature in surrounding areas, which can be assessed through thermal satellite photography.
2. **Canopy layer UHI:** This phenomenon occurs in the air layer between the ground level and the level of buildings and tree canopies. It is also the environment in which people who live and work in the city exist.
3. **Boundary layer UHI:** This form of urban heating is related to urban heating affecting the layer of the atmosphere situated above the city center.

From these definitions, we can conclude that UHI is a combination of surface and atmospheric features.

Urban Heat Island and Land Surface Temperature

Land Surface Temperature (LST) is an important parameter to study urban thermal conditions. Unlike the air temperature, which is measured using a thermometer, LST refers to the temperature of the land surface detected using thermal infrared equipment. Remote satellite sensing serves as a good tool to study the spatial distribution of LST over wide territories. Landsat and MODIS thermal sensing data provide a possibility to distinguish the hot built-up areas from cooler green and water areas (Voogt & Oke, 2003). There are many studies that confirm that there is a solid link between land cover and LST. Estoque et al. (2017) found, for example, that while impervious surfaces usually have wide LST, green areas have a cooling effect in big cities of Southeast Asia. Hence, connecting the information on LST with land use or land cover allows for detecting the areas with increasing levels of thermal stress due to urbanization.

Integration of Urban Structure and Local Climatic Zones

The heat distribution is heterogeneous throughout any urban area. Thus, a particular commercial district may have very high temperatures due to the long buildings built and the absence of greener surfaces compared to the neighboring residential zone with trees and parks. To aid with this classification, Stewart and Oke (2012) introduced the Local Climate Zone (LCZ) system with the purpose of characterizing land in urban areas, including the distribution of height, density, land surface, and vegetation. Hence, such classification enables us to understand why different zones of the same city have diverse thermal environments. Furthermore, urban planners should also consider the spatial arrangement of vegetation and urban features rather than treating the whole city as a uniform area.

Impact on Agriculture and the Environment

The urban heat island phenomenon influences the surrounding region. A lot of cities are located near agricultural areas, and as a result, city development can turn agricultural fields into built-up surfaces. Among other effects, urban heat island impacts the needs for water and evaporative demand of crops. Increased temperature can create heat stress or, in other words, can impact plant growth, flowering, ripening, and yield. Additionally, fluctuations of local temperature and humidity can also impact pests and diseases. From the perspective of agricultural meteorology, the transformation of agricultural fields into built-up areas disrupts the local energy and water balance. The effect of urbanized areas also causes the need for increased energy for the cooling process. The accompanying extreme heat waves lead to even greater discomfort and risks of urban heat island impact.

What Steps Are There to Alleviate Urban Heat Issues?

It is possible to mitigate urban warming with adequate land use and climate-sensitive construction methods:

- **Planting trees:** trees provide shade and lower temperatures in the vicinity due to evaporation.
- **Establishment of parks and green corridors:** green zones are capable of cooling areas inside the urban environment and improving the quality of the environment.
- **Green roofs:** green tops can regulate roof temperatures and create even more ecological benefits.
- **Cool roofs and pavements:** the use of reflective materials minimizes the amount of sunlight absorbed by urban surfaces.
- **Water bodies protection:** lakes and ponds definitely affect the local environment since it allows evaporation to take place and should be considered in urban planning.
- **Improvement in urban development:** it is important to take into account the configuration of buildings, their height, orientation, space between them, presence of plants and ventilation in order to best facilitate air circulation and prevent heat from being accumulated.

According to Santamouris (2015), one needs to pay special attention to urban vegetation, the application of reflective surfaces, and cool pavements in alleviating the urban heat phenomenon.

Conclusion

UHI is an excellent example of how changes in land surface features may influence the atmosphere. Urbanization leads to replacement of vegetation and agricultural ground surfaces with buildings, asphalt, and other non-permeable materials. From a micrometeorological point of view, the UHI is primarily related to energy and water transfer from land surface to atmosphere. Decrease of evapotranspiration, increase in sensible heat, heat retention in urban structures, and human-generated heat all lead to warming of urban areas. Remote sensing provides a way to monitor land surface temperature and detect urban heat islands, whereas micrometeorological studies help in understanding the main reasons behind this phenomenon. With cities continuing to grow, the need for vegetation, water, reflective materials, correct building designs, and knowledge of land-atmosphere processes is growing. It is not only a question of urban planning, but also an area of micrometeorological importance.

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