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Urban topo climatic factors effects on heating Islands based on high-resolution Digital Surface Models

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ABSTRACT

Urban surface morphology is an important key factor in determining the temporal variation of thermal anisotropy. This study uses drones based high-resolution Digital Surface Models (DSM) to explore the impact of morphological urban variability expressed by terrain factors such as diurnal anisotropy patterns, sky view factor, solar radiation and solar duration effects on the urban heating island. The goal of this study is to build a topo-climatologic map from the terrain factors and determine its effects on the Urban Heating Islands. a test area of 2 square km was selected, including open grasslands, forests, and built-up areas. Itinerant measurements are made using portable sensors to measure temperature and wind direction in the study area. the measurement points are chosen according to the result of the topographic map and the topo climatologic map. the measures taken allowed us to study the temperature of the region during the day and at night and to detect the urban heat island of the region.

Keywords :

Urban heating Island, Dinual Anisotropic Heating, Sky View Factor, Digital Surface Models.

Effets des facteurs topoclimatiques sur l' îlot de chaleur urbain à partir des modèles numériques de surface (MNS) à haute résolution

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RESUME

La morphologie de la surface urbaine est un facteur clé pour déterminer l'ampleur et la variation temporelle de l'anisotropie thermique. Cette étude utilise des modèles numériques de surface (MNS) à haute résolution basés sur des drones pour explorer l'impact de la variabilité morphologique urbaine exprimée par des facteurs de terrain tels que les modèles d'anisotropie diurne, le facteur de vue du ciel, le rayonnement solaire et les effets de la durée solaire sur l'îlot de chaleur urbain.

Le but de cette étude est de construire une carte topo-climatologique à partir des facteurs de terrain et de déterminer ses effets sur les îlots de chaleur urbain. Une zone d'essai de 2 km^2 a été sélectionnée, comprenant des terres herbeuses ouvertes, des forêts et des zones bâties.

Les mesures itinérantes sont effectuées à l'aide de capteurs portables pour mesurer la température et la direction du vent dans la zone d'étude. Les points de mesure sont choisis en fonction du résultat de la carte topographique et de la carte topo climatologique. Les mesures prises nous ont permis d'étudier la température de la région de jour comme de nuit et de détecter l'îlot de chaleur urbain de la région

Mots clés :

Ilot de chaleur urbain, Chaleur anisotrope diurne, Facteur de vue du ciel, Modèles de surface numériques

1. INTRODUCTION

The urban climate is imposed by the notion of comfort, but also of constraint, the rise in temperature, and the urban heat island two essential and urgent factors to study nowadays especially concerning the energy and water on the urban environment. This study is based on the assumption that during weather conditions radiations, the urban climate, and in particular the temperature distribution, is conditioned by the local characteristics of the surface urban, because of localized interactions between incident solar radiation and this one. This conditioning is permitted by the stability of the so-called atmospheric situation radiative (weak or no wind and cloudiness) which limits horizontal and vertical mixing in the air mass. This results in a variation spatial and temporal distribution of

temperatures between the different sectors of urbanized space. We will see in this article how to use GIS and databases urban areas (BDU) to achieve specialization different indicators allowing characterize the establishment and maintenance of urban heat island phenomenon (UHI) (Cantat, 2004; Carrega, 1994; Charabi, 2001; Dahech, 2005, Bridier, 2017).

This study investigates the effects of terrain factors on heating Island, some studies use high-resolution 3D building databases (Kastendeuch, 2013), as the high-resolution Digital Surface Model (DSM) containing detail urban morphology (buildings and trees height) it is also a 3D representation of the terrain morphology and could form a research foundation for the generation of terrain factors.

The use of 3D city models expressed in DSM is increasing rapidly, because of the low costs and fast time required to build these models by new automatic data collection technologies, such as LiDAR and Drones photogrammetry. Dirksen et al (2019) in their paper tested SVF at multispatial resolution and prove that SVF is changing with the spatial resolution, High-resolution DSM has also been used frequently to calculate the SVF (De Wolff, 2008; Gál et al., 2007; Kastendeuch, 2013).

A big number of researches showed the relationship between urban morphology and temperature (Chen et al., 2012). To describe the urban heating Island, the Dinual Anisotropic heating (DAH) and sky view factor (SVF) plays a key role (De Morais et al., 2018).

Beside DAH and SVF, Solar radiation (SR) and Solar Duration (SD) also are morphological factors based influencing on UHI. Our study merges the four main morphological factors generated from terrain datasets to develop a Topo-Climatologic map. The generated Topo-Climatologic map could be used to assess the viability of the location solar-energy plant and could be used as a solar farm susceptibility map.

This work aims to develop a topo-climatic map based on DSM and to test its effect on Urban Heating Island based on microclimate simulations. To approach the research question, the paper is structured as follows: A detailed Climatological description of the study area; Details of the data set and methodology are presented in material and methods; results and discussion; and conclusion.

2. Materials and Methods

The study area situated on the Mediterranean Sea in the Lebanese Republic the village of Zouk Mosbeh with an interval of elevations above the Sea level ranging from 0 to 300 meters.

The village is characterized by its urbanization of touristic places near the Sea, residential, green areas, and industrial zones.

The study area benefited like the entire Lebanese coast located to the west of the Mediterranean Sea from a situation of summer stability for 6 months due to the effect of the subsiding part of the Hadley cell and the high subtropical pressures which influence around 500 hPa and cause stability over Lebanon. the study region will benefit from the alternation of thermal breezes and diurnal and nocturnal thermal differences between the city and the surrounding regions.

The establishment of a mobile measurements campaign at the micro-local scale carried out on August 2, 2019, was made first of all to have a study area with a greater number of measurement points to highlight the distribution temperature in the region, during the day and night. This day is characterized by a stable situation with a weak night-wind of 3 m / s and diurnal wind of 6 m / s on average. 12 surface measurement points (figure. 2 d) 2 meters above the ground using 6 Voltcraft DL-120 temperature and humidity data loggers. Its recording interval is adjustable from 2 s to 24 h. The measurements were taken between the coast and the heights east of the city at the foot of Mount Lebanon. During the day, the measurements are taken between 8:00 a.m. and 10:45 a.m. (L.T) and between 1:00 and 2:00 a.m. during the night phase (August 3, 2019). GPS is used to select the same measurement points between night and day. These points were chosen to make a comparison of the temperature in a very dense urban fabric and areas with a complex topography (figure 2 a). Roving measurements are carried out using a recordable wind vane anemometer to detect thermal breezes. 3 measurement points taken at different altitudes made it possible to make maps of night and day winds. Daytime measurements are taken at 10:30 a.m. and nighttime measurements from 1:00 a.m. for the same date.

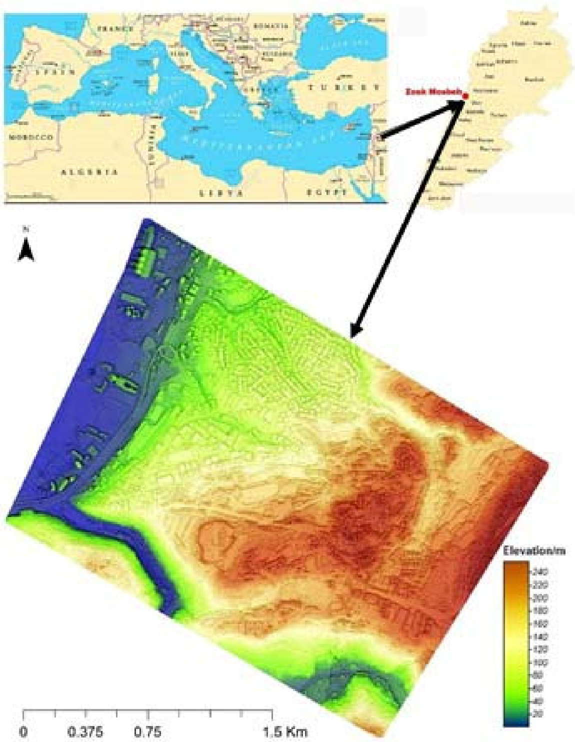

Fig. 1: Study area location and DSM

To carry out the research, a digital elevation model of the study area was created based on drone's photogrammetry for the generation of the Digital Surface Model and a Digital Ortho Model.

The generated DSM comes with a spatial resolution of 40 centimeters.

Since the drone used contains a Real-Time Kinematic receiver the datasets were corrected at a sub-centimeter accuracy.

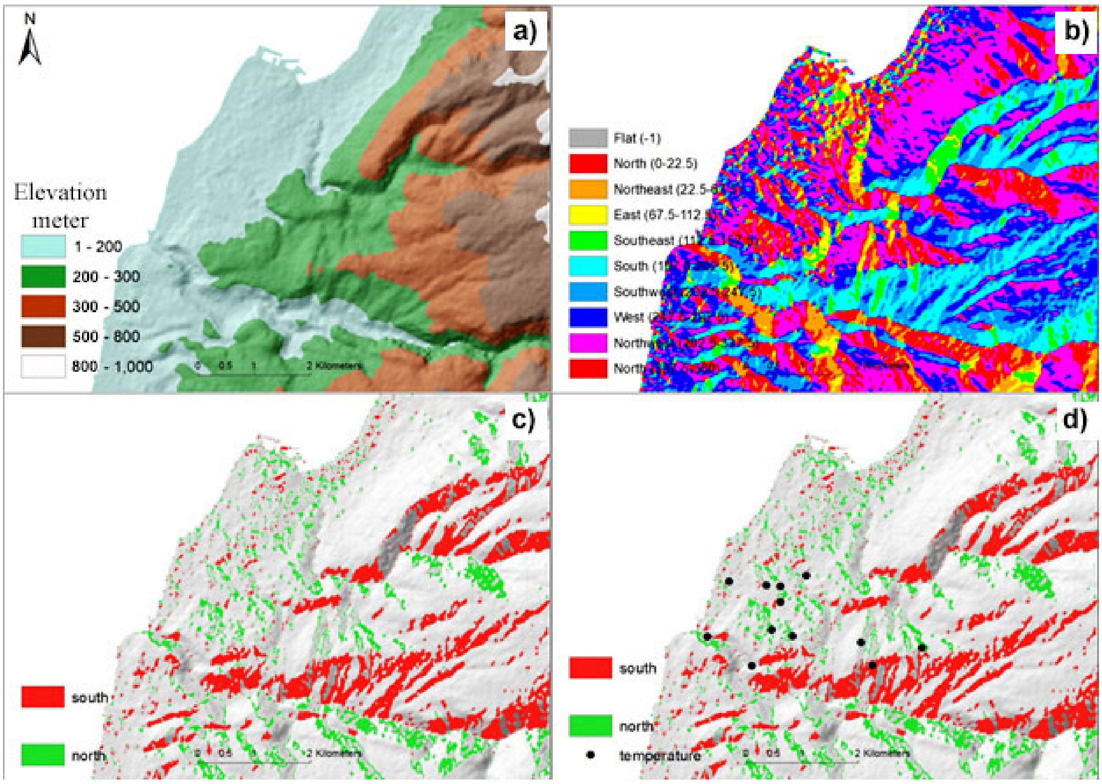

Fig. 2.: a) the topography of the study region, b) the orientation of slopes of the study region, c) the North and South orientation of slopes, d) the measurements campaign of temperature data

2.1 Topo-climatic factors

- *Dinual Anisotropic Heating*

Diurnal anisotropic heating (DAH) is a dimensionless index showing the quantity of heating on the slope, taking into account the asymmetry of the daily energy balance (Böhner, Antonić 2009).

$$DAH = \cos(\propto_{max} - \propto) \times \arctan(\beta) \quad (1)$$

Where $\propto_{max}$ is the exposure of the slope defining the aspect with the maximum excess heat surplus, $\propto$ is the slope exposure and β is the slope angle (Hengl & Reuter 2009).

- *Sky View Factor,* the sky view factor (SVF) plays an important role in the analysis, and the identification of the urban micro-climate (Jérémy et al. 2018).

There are several ways to calculate SVF, with the use of fish-eye photos (Gál et al., 2007; Middel et al., 2017), this method is not feasible for large areas.

The best way of SVF calculation is the use of a points grid it could be a global scale Digital Elevation Models (DEM) and at the local scale the case of our study a Digital Surface Models (DSM).

The relationship between SVF and UHI leads to the determination of thermal comfort, energy budget, air temperature, and surface radiation balance (Theeuwes et al., 2017; Zeng et al., 2018. Al-Sudani et al.,2017)

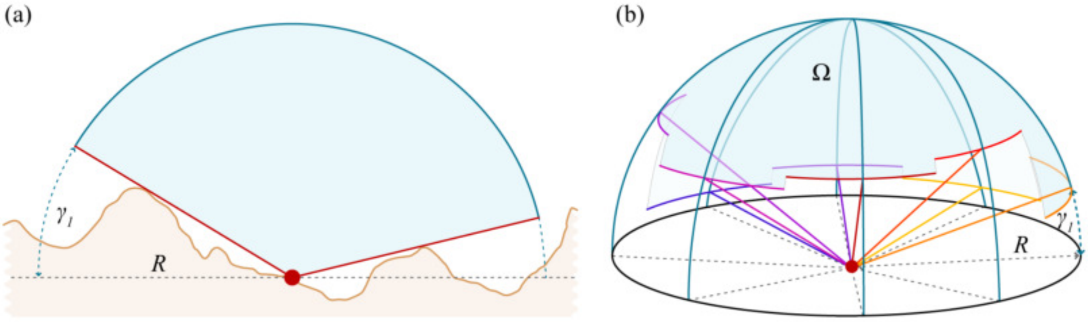

Fig. 3. SVF is defined by the visible sky (Ω) above the surface, and it computes the vertical elevation angle of the horizon γi in n directions to the specified radius R. a) section view. b) perspective view (Zakšek et al. 2011).

Therefore, SVF can be considered as the ratio of the visible sky that can be seen from a location in the urban space to the whole skydome containing visible and obstructed sky figure 3.

The amount of light projected onto a location on the DSM is generally associated with the amount of sky that is visible at this location. This is similar to a mountain peak which is brighter than steep valleys because it receives more illumination from the surrounding sky. The easiest

approach for SVF calculation is to measure its angle figure 3a, which represents the projected area of the hemisphere over the location in a unit of space. In our case, the radius R was set 10 meters 25 times larger than the DSM spatial resolution.

The angle γ_i is computed by observing the horizon vertical elevation in a chosen number of 36 directions in the case of our study.

The SVF is calculated in the following equation (Zakšek et al. 2011).:

$$SVF = 1 - \frac{\sum_{i=1}^{n} \sin \gamma_i}{n} \qquad (2)$$

SVF ranges between 0 no sky is visible and 1 the entire hemisphere is visible

The areas with high SVF have more efficient radiative cooling because these areas can radiate their energy unobscured into space. (Zakšek et al. 2011)

- *Solar radiation,* the terrain factors used for the estimation of daily solar radiations are slope, aspect, sky clear factor, shadow, and coordinates, are calculated from the DSM.

Using the following equation (Böhner & Antonić 2009, Lukovic et al. 2015).:

$$SR = \sum_{i=1}^{n} \omega_i . \frac{S}{\sin \theta_i} \cos \gamma_i \qquad (3)$$

Where S represents hourly topographic direct radiation, ω is the shadow binary mask (0 =shadow, 1= non-shadow), θ is the elevation angle of the sun over the horizon, γ is the solar illumination angle and n is the number of hours of daily radiation, in our study n is 18 hours between 5 a.m to 11 p.m.

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- *Duration insolation,* Incoming solar radiation is usually expressed through the duration of sunshine hours.

2.2 Urban Heat Island

The urban climate can be defined as a local alteration of the regional climate. It exists a change in the regional climate, in urbanized space. The modification may focus on temperature, humidity, wind, and air quality. However, it is the choice of the scale that will define the nature and intensity of the observed climate change. We can detect the effect of urbanized space in the topo climatic scale (100 m to 10 km) because of the nature of the surface changes between space urbanized and natural, agricultural, or aquatic areas located nearby. But it is also possible to observe scale variations microclimatic (1 cm to 100 m) between areas with variations in density and type of construction, urban form, exposure, use of spaces, presence of vegetation, and surface water. Also, since it mainly concerns the interaction between solar radiation and the surface in question.

The city is built on a fairly narrow coastal zone limited by the Mediterranean Sea to the east and framed to the west by mountain ranges and deep valleys. The distribution of land use is roughly concentric with a gradual decrease built density and a presence growing vegetation going towards the periphery on the heights. Flat spaces are built and used in full, then that the reliefs and slopes are less densely busy. Large spaces natural areas are located on the outskirts of surrounding massifs. So the city center overall appears very closed and mineral, while the periphery is very open and vegetable. We can, therefore, expect a concentric temperature distribution (UHI) but the effect of the sea, as well as that thermal breezes, can alter this theoretical distribution. However, within this general organization, there are local variations in temperature due to the presence of vegetation and the diversity of urban form.

To study the spatial variation of the urban heat island, we are going to analyze the relief, land use, presence of vegetation and water on the surface and built structures, in passing from the topo climatic scale to the scale microclimatic. There are simultaneous effects on the scale of the urbanized territory and its periphery, and very local effects at the scale of the morphological island and the street. several factors are studied to determine the urban heat island. The first recognized factor of variation of temperatures in the land/water distribution, for questions of the speed of warming and specific heat of materials. Indeed, the earth is changing rapidly temperature under the action of radiation direct solar power while the water masses are more thermally stable due to the specific heat of water which is higher. The second recognized factor is the relief distribution, due to the effects of orientation and inclination between the surface and direct solar radiation. For a city, the Mediterranean by the sea, lean-to in relief, the combination of the earth/sea and the effects of differential exposure in the relief constitutes a large part characteristic of the local daytime climate as at night (thermal gradient, sea breezes compensation, and gravity). The third recognized factor is the nature of land use. The differences between the structures and materials present in the surface cause differences in the albedo (fraction of radiation visible incident reflected), so in the absorption possible solar energy. The specific heat of materials is there still different depending on the materials be natural or artificial. Finally, the presence/absence of evaporable water (vegetation, plan of water) contributes to the release of energy absorbed as latent heat flux (evaporation accompanied by a drop in temperatures) or sensible heat flow (perceptible heating of the surface for dissipating the absorbed energy)

3.DISCUSSIONS AND RESULTS

Zouk Mosbeh a Lebanese village, leaning against the relief Mount Lebanon (figure 2a) characterized by high altitude peaks as well as inclined plateaus and carved by steep-sloping valleys that surround the city, the effects of differential exposure in the relief and the orientation of the slopes (figure 2b) constitute a large part of the characteristics of the local climate day and night in terms of temperature and thermal breezes. The valleys channel gravity breezes in radiative weather. The valley surrounding the study area is the valley of Nahr El Kalb.

The exposure effects of the high and well-oriented slopes favor significant thermal gradients (Figure 2c), causing the development of compensating thermal breezes along the valley. It is well known that the slopes facing north are in the shade while those facing south are well exposed to the sun and on the other hand experience higher temperatures.

The time of arrival of the sea breeze on the mainland depends on the seasons (time of sunrise) and the distance from the sea. The sea breeze rises about two or three hours after sunrise near the shoreline, when the land/sea, valley/mountain thermal contrast becomes sufficient. The arrival of the sea breeze is marked by a pulse in the speed of the wind and a sudden deviation of its direction. In summer, in Beirut's coastal resorts, located by the sea near the town of Zouk Mosbeh, the earlier sea breeze appears between 8 a.m. and 10 a.m. (local time) (Sakr, 2017).

On August 2, 2019, the breeze first appeared around 8:30 a.m. at the coast stations, data provided by the Beirut airport weather station. At 10:00 am, a traveling measurement campaign is carried out using a recordable wind vane anemometer to measure the direction and speed of the wind in the city and its progression towards heights. The sea breeze registers high speeds on the coasts and heights ranging from 6 to 4.5 m / s, while it is weaker as it progresses the city and the first hills.

The temperature measurement points are chosen after an analysis of several indices SVF, SR, DI, and DAH to bring out a topo-climatic map of the region.

The objective of these treatments is both to have elements to understand the temperature distribution in a medium very heterogeneous urban, but also of power characterize the sites likely to be equipped with weather sensors. The urban environment is indeed too complex to be able to be equipped according to standard rules of the World Meteorological Organization. Therefore, we will be able to understand the influences of local effects on sensors and to decide on the location of measuring instruments.

Figure 4a the map of the Sky View Factor shows low values around building in shadow areas with the closed sky, otherwise open spaces of non-built areas and roofs have higher values of SVF, the resulting SVF values depend on DSM spatial resolution, search radius, and several. Figure 4b of the dinual anisotropic heating related to the ubac and adret of the terrain, DAH shows high values in adret slopes or at the southern orientations. Figure 4c the map of the duration of insolation with high durations of 13 hours in open areas and low durations in closed areas for examples around buildings and obstacles. High solar radiation values give long durations of insolation figure 4d un the solar radiation map.

visually figure 4a and 4d are very similar and to more understand the similarity degree between topo-climatic factors we run a correlation analysis table1.

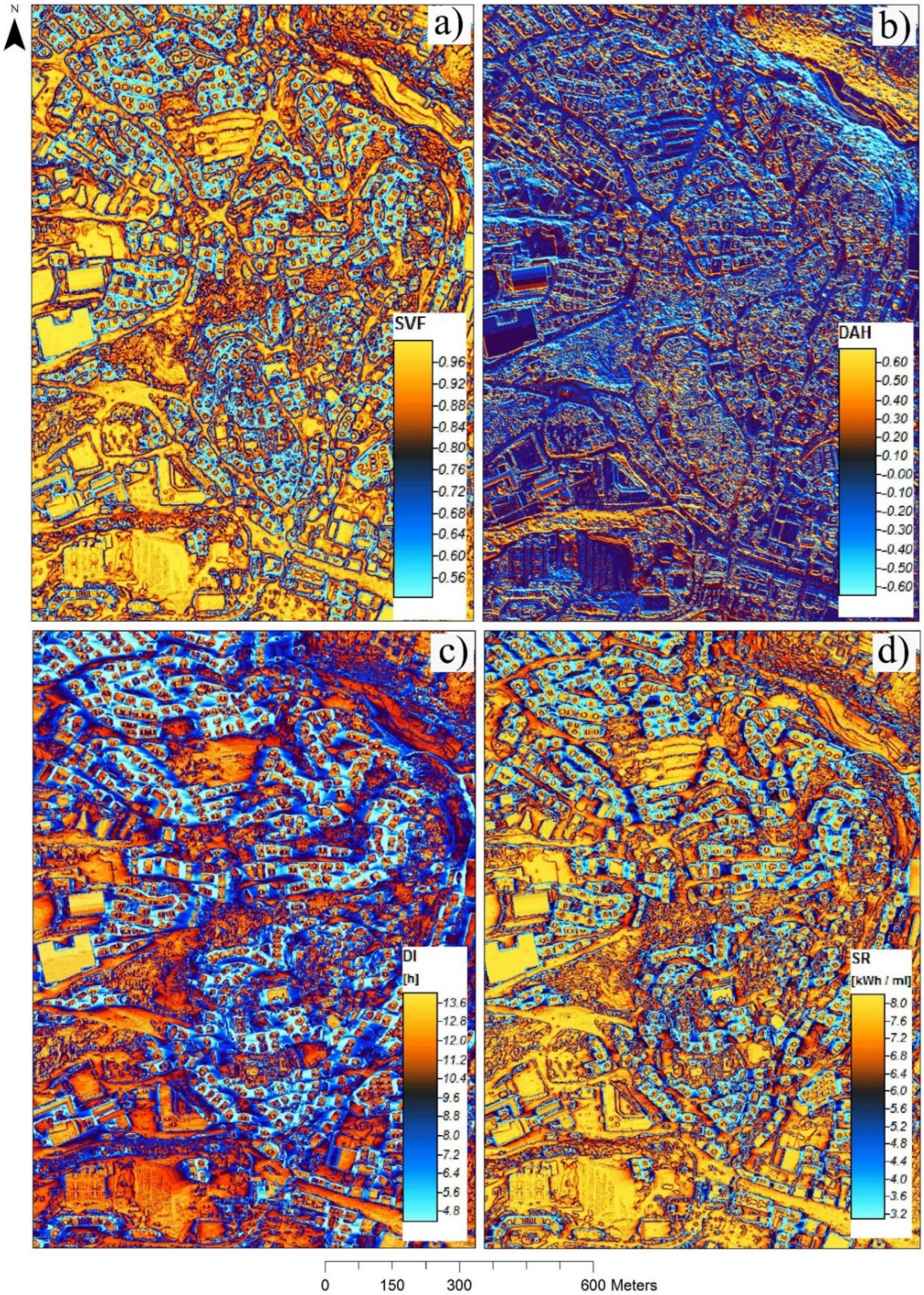

Fig.4. Topo-climate factors maps, a) Surface View Factor map, b) Dinual Anisotropic heating map, c) Duration Insolation Map d) Solar Radiations map.

Table 1: correlation matrix of the topo-climatic factors.

-1,0 … 1,0

	DAH	DI	SVF	SR
DAH		-0,07	-0,03	0,09
DI	-0,07		0,73	0,84
SVF	-0,03	0,73		0,88
SR	0,09	0,84	0,88	

The correlation matrix of table 1 proves the visualization similarity between SVF and SR with an R2 value of 0.88, the duration insolation also is related to SVF with a correlation value of 0.73, the dinual anisotropic heating is not correlated with the other climatic factors.

Based on the correlation matrix result, we understood that the effect of these factors is not influencing the same way to the Urban Heating island to make equilibrium in the application of these factors.

We decided to use the weighted overlay approach to create a composite map "Topo climatic map" possible for the study of the terrain effects on UHI based on various attributes.

The scores used in the weighted analysis are distributed based on the correlation matrix of table 1, SVF 40% SR 30% DI 20%, and DAH 10% after classification in five classes from higher to lower values.

The land use of the region shows a dense and contiguous urban fabric which spreads over the narrow plain bordering the sea, the heights located to the west of the city at the foot of Mount Lebanon contain a less dense urban fabric as well as villages to higher altitudes and vegetation cover in valleys and on hills. Thus the differences between the structures and the materials present on the surface having a different albedo directly influence the absorption of solar energy depending on the nature of the soil. The mobile measurements campaign carried out on August 2, 2019, at 2 meters above the ground between 8:00 a.m. and 10:45 a.m. local time show heterogeneity in the temperature distribution figure 6. We notice a difference of 2 ° C between the points measured on the coasts and those taken in the heart of the dense urban zone. This gap between the coast and the city is due to the appearance of the sea breeze around 8:00 am at the weather station at Beirut airport, which acts as a thermal regulator. The arrival of the sea breeze on the mainland causes the air temperature to drop (or delay the maximum daily peak) which, in hot climates, has a beneficial effect on individuals (Sakr, 2017).

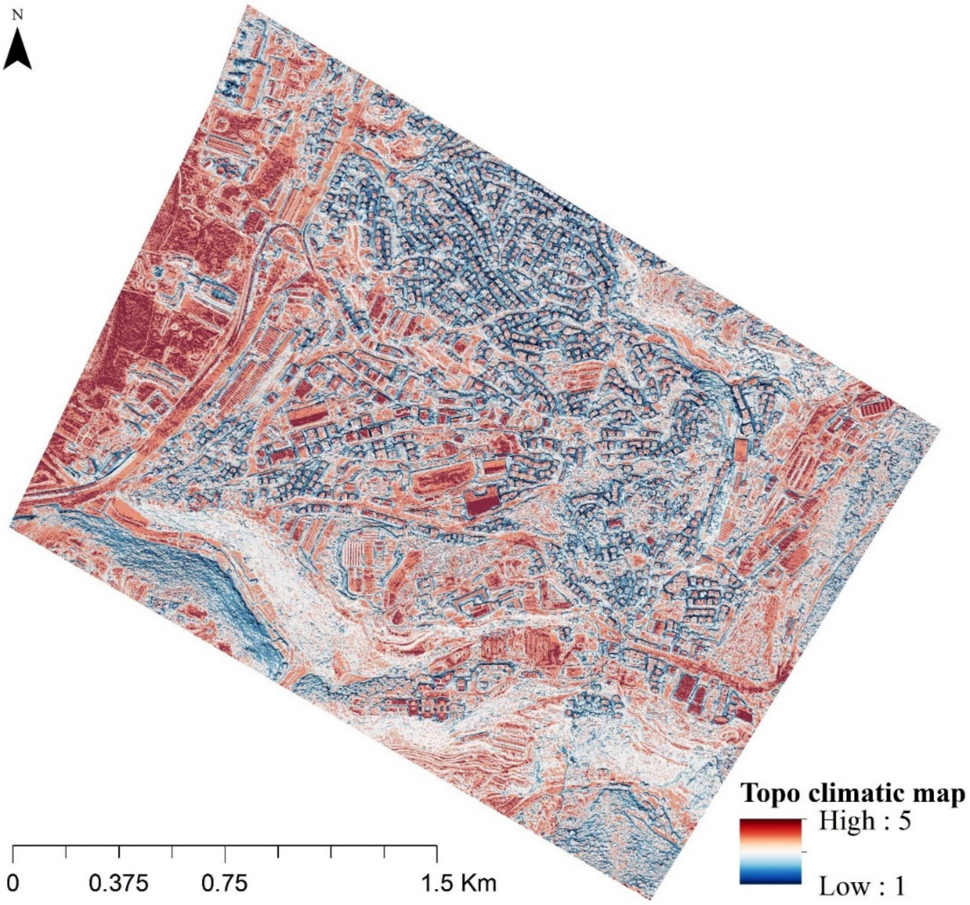

Fig 5: the generated topo climatic map.

Figure 5 of the resulted Topo climatic map showed high values for the expected areas of high temperature such as rooftops and open areas.

In the East, the temperatures measured are high compared to the coast, two factors are highlighted: the land use urban less dense and partly sunny, in the Mediterranean region, the thermal behavior of the often stony and arid countryside summer, is not far from that of the city. The latter warms up more slowly in the morning with the shadow of the buildings.

The UHI, considered on the surface, is not very visible during the day: the surrounding countryside is in places significantly warmer or registers the same temperature on the surface than the city center.

For a better knowledge of the urban nocturnal thermal field, a mobile measurement campaign was organized during the night of August 3, 2019, at 01:00 am by type of radiative weather. Examination of the nocturnal roving measurements at 2 m above the ground (12 measurement points, figure 7) shows variations in temperature values in Zouk Mosbeh and its surroundings at night and the existence of a heat island on densely urbanized areas. The maximum deviation from the surrounding countryside is 4 ° C.

A clear individualization of the urban mass is observed concerning rural spaces. On the scale of the agglomerated zone, the differences remain below 2 ° C. In fact, green or open spaces that are regularly watered constitute islands of freshness by lowering the temperature by around 1.5 ° C, as is the case with the measurement point near urban green spaces where we recorded 26 ° C and 26.5 ° C against

28 ° C located in a dense urban fabric. Towards the west, the sea also appears to be a thermal discriminating factor by acting through its strong thermal inertia. It is for this reason that the temperature rises from 27 to 28 ° C at the coast.

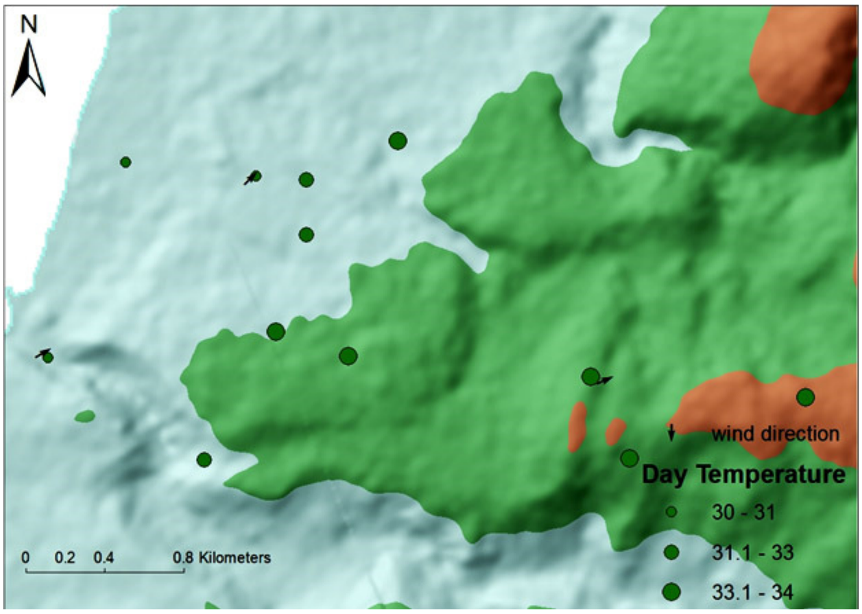

Fig. 6: distribution of daily temperature and wind direction on 2 august 2019.

Towards the east, the temperature drops gradually, the topography characterized by hills and deep valleys, is very favorable to the installation of thermal inversions by radiative cooling and airflow. cold (valley breeze) from the mountains of Mount Lebanon (figure 7).

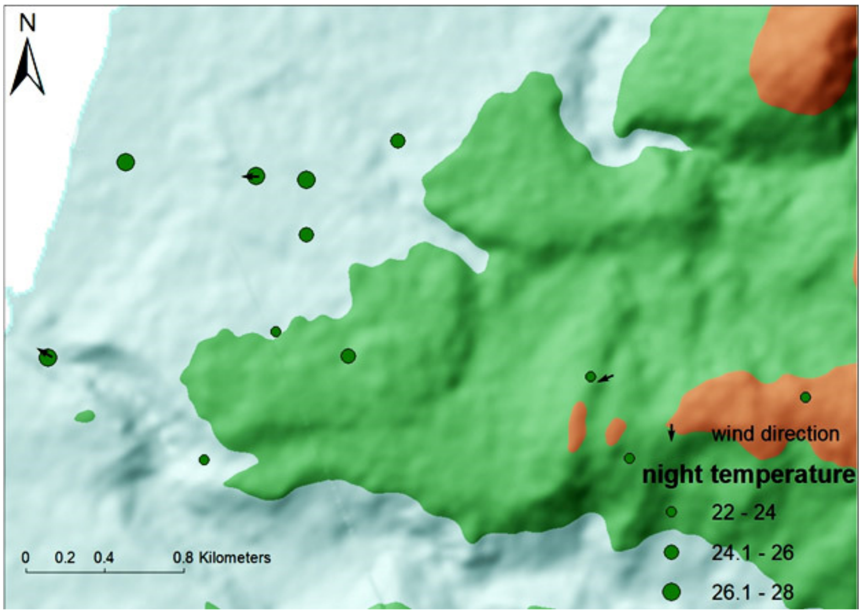

Fig. 7: distribution of night temperature and wind direction on 3 august 2019.

Itinerant measurement campaign is carried out between 1 a.m. and 2:30 a.m. (August 3, 2019) using a recordable wind vane anemometer. The sky was clear on the night of 2/3 August 2019 so that the temperature differences were exacerbated and the synoptic wind was weak enough to let the breezes express themselves and not erase their effects (dynamic subtropical high pressures prevailed at the level of 500 hpa favoring very stable weather). The measurements covered areas at high altitudes and in the city. South-easterly sloping breezes were recorded towards the heights, a channeled breeze was detected in the valley with a considerable speed of 3 m/s and land breezes recorded in the city with a speed of less than 2 m/s arriving on the coast. The slope breezes which are due to the cooling of the summits and the slopes, small jerks linked to the topographical irregularity of the places descend the slopes (katabatic breezes) and cause a feeling of freshness.

4. CONCLUSION.

The realization of the top climatic map of the region of Zouk Mosbeh provided us with reliable data for good implantation of the measurement sensors to better study and understand the temperature of the cities. the measurements taken show that the surface temperatures of dense neighborhoods are higher than those of the surrounding vegetated areas of the Zouk Mosbeh region. The roving measurements of the air temperature, two meters above the surface, revealed a UHI of the intensity of about 2 ° C between areas with a continuous urban fabric and areas with an urban fabric less dense. Night temperatures recorded towards the heights show a greater difference in the order of 4 ° C to 5 ° C.

Daytime temperatures showed a more heterogeneous result, at the city level a difference of 2 ° C to 3 ° C is measured between neighborhoods in shade and surrounding neighborhoods in full sun. Regions with a sparse urban fabric and green spaces located at high altitudes recorded temperatures similar to the city.

The measurements taken so far remain ad hoc in time and space. Additional fieldwork is therefore required to better characterize the spatial distribution of temperature and its intensity. We want to increase the number of itinerant measurement campaigns to better understand the distribution of night and day temperatures, especially during the summer period.

5. ACKNOWLEDGMENT

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6. FUNDING

NO FUNDING

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8. KEY TERMS AND DEFINITIONS

Digital Surface Model (DSM): are commonly implemented geospatial features generated with UAV mapping systems containing both the natural and built/artificial features of the environment, DSM represent the Bare-Earth and all of its above-ground features, their use is widely applied in fields such as urban planning and they are influencing on Urban Heating Islands.

Real-time kinematic (RTK): are implemented in drones to improve the accuracy of GNSS data and correct the location of drone mapping data, bringing absolute accuracy down to cm range.

Subtropical pressures: Is a high pressure causing stability over the Middle East during summer season

Thermal breeze: is generated from temperature difference between land and Sea valley and mountains during a day of stability.