Thermopolis 2009 campaign

# The effect of urban landscape on land surface temperature: study of the Athens metropolitan area using very high spatial resolution data

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## Overview

The **Land Surface Temperature (LST)** is a reliable indicator of urbanization, since it directly affects the air temperature of the lower urban atmosphere and a key variable for characterising the **urban thermal environment** and the **surface Urban Heat Island (UHI)** effects [1,2]. UHIs refer to the characteristic heating of the atmosphere and the lithosphere in urban centres compared to their surrounding rural areas and is observed in almost all urban areas as a reflection of the individual microclimatic changes caused by anthropogenic effects on the natural environment. Restricted spaces, lack of green areas and of water resources to evaporate, and conductivity of structural and surface materials intensify this phenomenon.

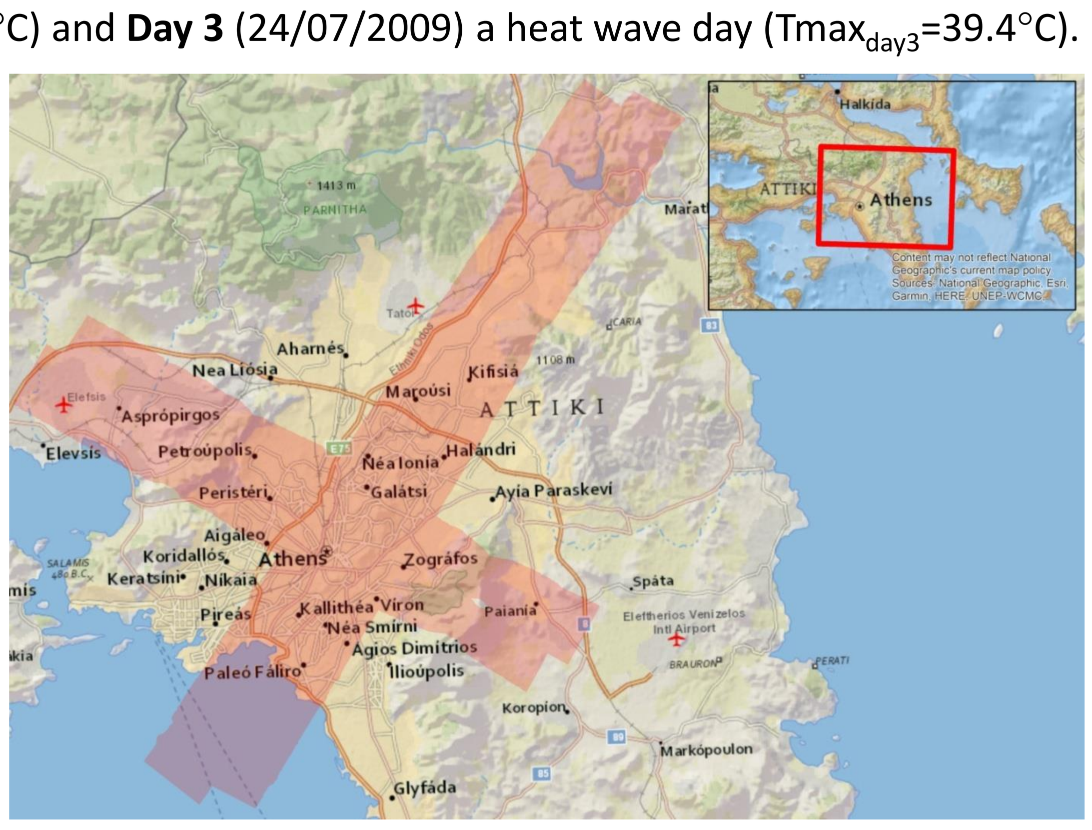
The UHI of Athens has been systematically studied [e.g. 3,4], so as to explore the intensity of the phenomenon and its variation in space and time. Studies in Athens face increased difficulties due to the fact that the temperature and the microclimatic conditions depend on the altitudinal differences, the distance from the sea and the air circulation affected by the surface morphology and the urban topography.

Due to the impact of the urban thermal environment on the health, wellbeing and safety of the urban population, the management and monitoring of atmospheric UHIs and surface UHIs is of prime importance. To that end, this study attempts to **identify the relationship between very high resolution LST**, as a modulator of urban climate, **and the LCLU for the city of Athens in Greece**, taking also under consideration **the prevailing weather conditions.**

## Study area & Campaign period

The geographic area from west to east (Elefsina - Koropi) and north to south (Penteli - Saronikos) is studied (shaded area in Fig. 1) for three typical summer days (Fig. 2); **Day 1** (18/07/2009) a relatively warm July day ($Tmax_{day1}$=36.4°C), **Day 2** (21/07/2009) with strong Etesian winds lower temperatures ($Tmax_{day2}$=33.4°C) and **Day 3** (24/07/2009) a heat wave day ($Tmax_{day3}$=39.4°C).

**Fig. 1. The Athens metropolitan area. The sampling area is denoted by the red shaded area.**



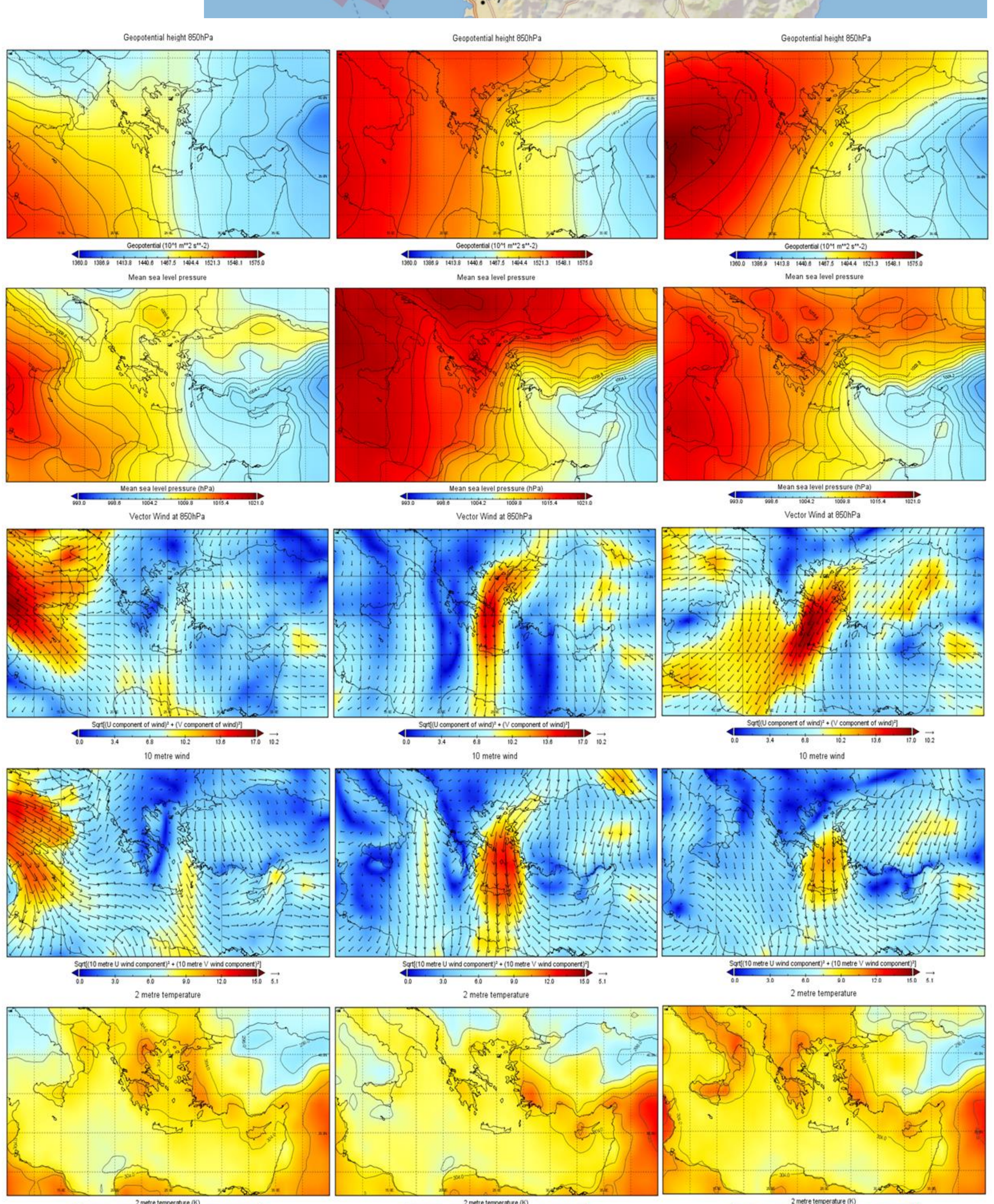



**Fig. 2. Weather conditions for the three monitoring days. Top to bottom: Geopotential height at 850hPa, MSLP, Vector wind at 850hPa, Vector wind at 2m, Temperature at 2m. Left to right: 18/7/2009, 21/7/2009 and 24/7/2009 at 1200UTC (data from ERA- Interim).**

**References:** [1] Keramitsoglou et al. 2017, doi:10.1016/j.scs.2017.06.006; [2] Sismanidis et al. 2016, doi:10.3390/rs8040274; [3] Keramitsoglou et al. 2011, doi:10.1016/j.rse.2011.06.014; [4] Founda et al. 2015, doi:https://doi.org/10.1016/j.atmosres.2015.03.016

## Data

❑ During the **Thermopolis campaign** in **summer 2009**, **airborne and satellite observations concurrently to ground measurements** were collected for the Athens Metropolitan Area. Here, we used high-resolution Airborne Hyperspectral Scanner (AHS) **thermal images (4m) depicting LST**, recovered using a Temperature Emissivity Separation (TES) algorithm with 9 thermal zones. The images are nighttime and are taken from 4 different directions of aircraft flights (see Fig. 1).

❑ A **land cover/land use (LCLU) map** was constructed using high-resolution data (2.5m) from the **European Urban Atlas** (GMES/Copernicus Land Monitoring Service). We retained **12 LCLU classes**, from the denser urban fabric (Continuous Urban Fabric with Surface Land > 80%) to Forest and Water.

❑ The **2016 European Settlement Map (ESM)** was also used, which is a spatial dataset (resolution of 10m) of the human settlements, provided by the **Copernicus Land Monitoring Service**. ESM is derived from satellite images and represents the **built-up coverage rate of the residential area per spatial unit**.

## Methods

❑ LST and ESM values were spatially averaged over the European Urban Atlas polygons, retaining a single LST and ESM value for each polygon, also characterised by one LCLU class.

❑ Applying geostatistical methods, local statistics were calculated to locate statistically **significant hotspots and coldspots**. The analysis of hot and coldspots can reveal where features with either high or low values (here, high and low LSTs) cluster spatially.

❑ Given the significant importance of the urban building rate on the land surface temperature, we examined the **LST-ESM relationship**, with the aid of **OLS and GWR regression models**, to uncover potential spatial variations of LSTs under the ESM influence.

## Results

The LSTs exhibit statistically significant differences (Fig. 3):
- **among the urban fabrics** having the highest LST for "Continuous Urban Fabric (S.L.> 80%)" and the lowest for "Forest" and
- **among the experimental days** (with average LSTs: $LST_{day1}$=303.8K, $LST_{day2}$=300.9K and $LST_{day3}$=304.1K)

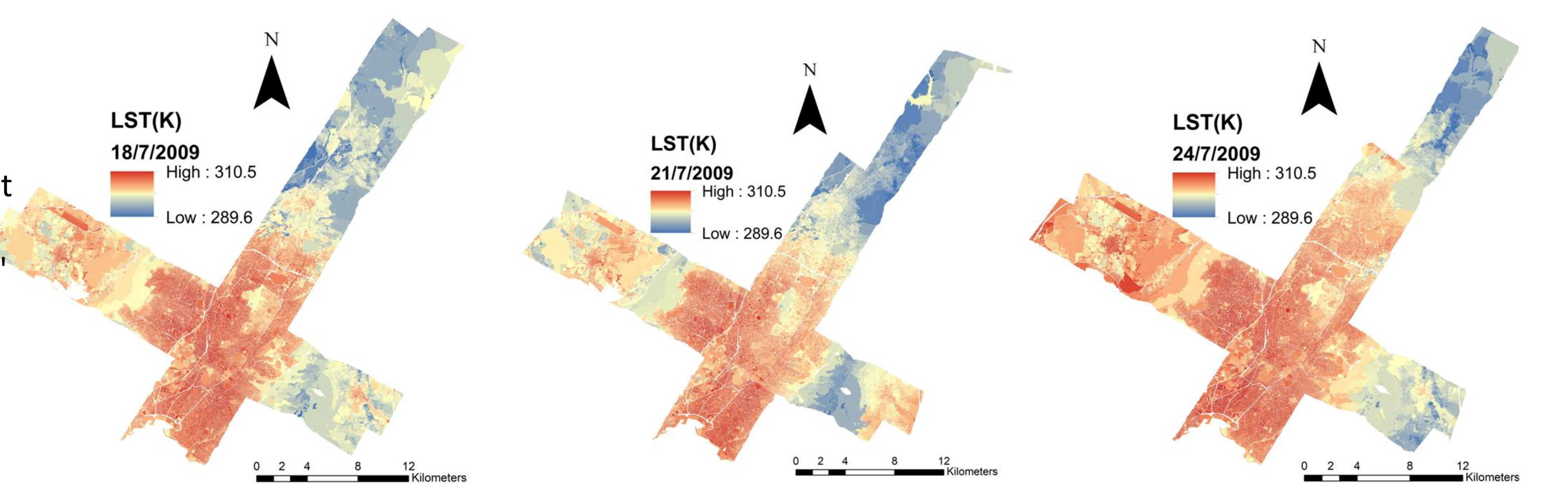



**Fig. 3. Spatial distribution of the LSTs for the three monitoring days.**

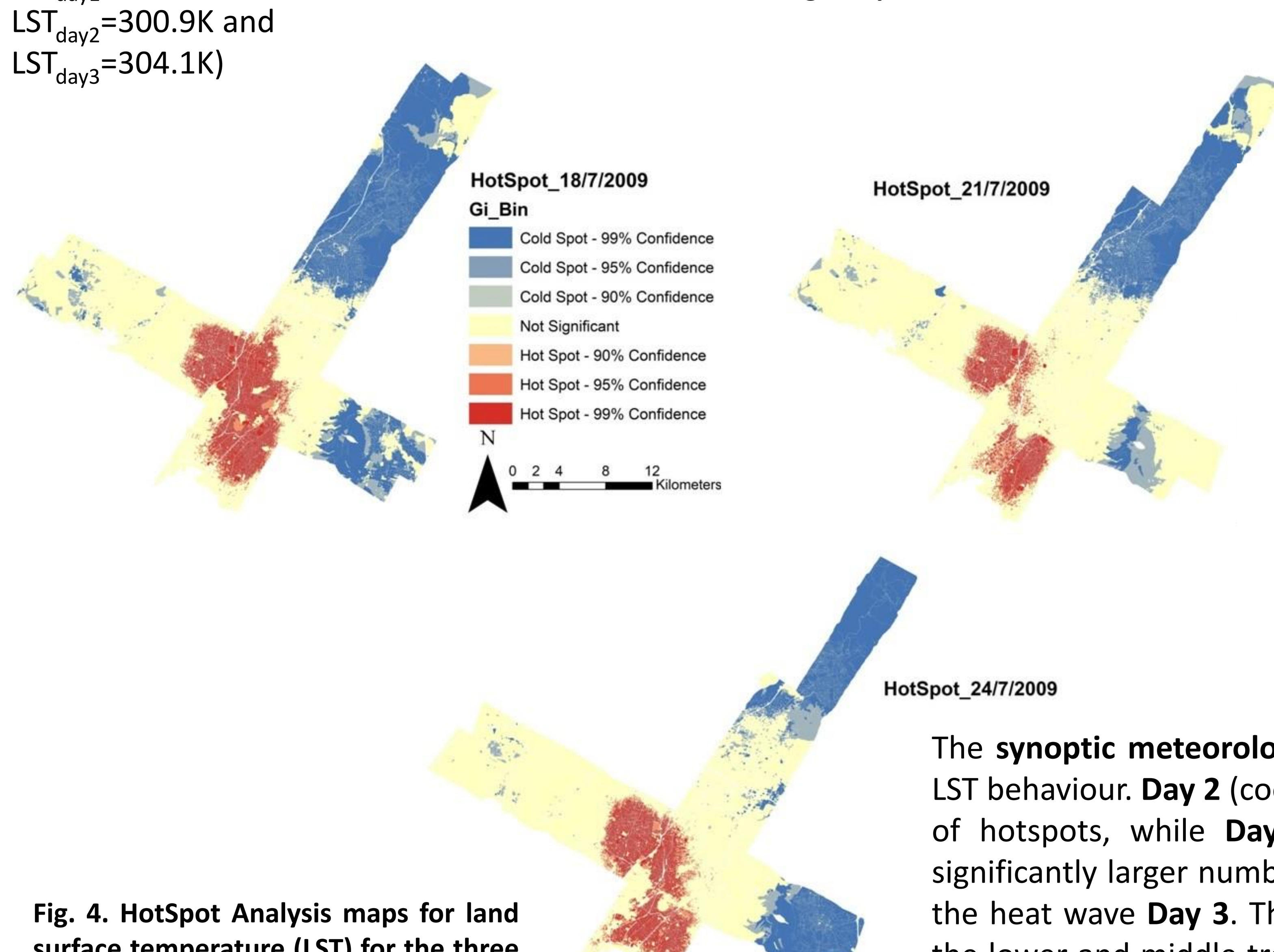



**Fig. 4. HotSpot Analysis maps for land surface temperature (LST) for the three monitoring days.**

The **spatial autocorrelation analysis** showed that LSTs do not follow a random distribution (at p<0.01), **the data are clustered** (Moran's I index >0) forming islands with a particular behaviour, thus, a further analysis for the identification of hot and coldspots was performed.

The **hotspot analysis** (Getis-OrdGi* statistic), showed that for all three days (Fig. 4), **hotspots appear in the centre and southwest of Athens**, where the percentage of urban tissue is known to be high. On the contrary, **coldspots are located in the northern and eastern areas**, which are either mountainous or vegetated.

The **synoptic meteorological conditions** have evident impact on the LST behaviour. **Day 2** (coolest and windier) exhibits the lowest number of hotspots, while **Day 1** (relatively warm and windless) have a significantly larger number of hotspots and coldspots as compared to the heat wave **Day 3**. The notable difference of the wind patterns at the lower and middle troposphere between **Day 1** and **Day 3** (Fig. 2), seems to play important role on the development of hotspots. **The reduced ventilation may lead to a hotspots build up, even though the air temperature is significantly lower.**

For the **impact of the urban building rate (via ESM values) on the LST**, an **OLS model** was constructed, explaining 34%, 26.9% and 30% of the LST variability, for each day, respectively, that **dictates the possible omission of other interpretive variables**.
The **GWR model** explains 86.9%, 88% and 87% of the LST variability with ESM as explanatory variable, for each day, respectively, providing **a better adjustment to the observed data**.

## Conclusions

❑ The geostatistical analysis for the relationship between the Athens urban fabric and the LSTs showed that the LSTs exhibit statistically significant differences among the different urban land cover/land use (LCLU) classes and among the three experimental days.

❑ Apart from the LST distribution, the prevailing weather conditions affect the development and extent of the hot and coldspots. The hotspots coincide with the city centre area of dense fabric and the coldspots with the northern and eastern elevated and vegetated areas.

❑ Both air temperature and wind act on the clustering of LSTs, in opposite directions, i.e. increased winds and, thus, ventilation, prevent the LST clustering, while increased air temperatures enable it. Whilst the three experimental days have distinct meteorological characteristics, more cases are needed to solidify this finding.

❑ A modelled global relationship between LST and landscape can be constructed, though is seems that more explanatory variables are needed for building a robust global model. The results also indicate the existence of particularly pronounced spatial variations.

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