

Proceeding Paper

The Use of Satellite TIR Time Series for Thermal Anomalies' Detection on Natural and Urban Areas [†]

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Abstract: In this work, the land surface temperature time series derived using Thermal InfraRed (TIR) satellite data offers the possibility to detect thermal anomalies by using the PCA method. This approach produces very detailed maps of thermal anomalies, both in geothermal areas and in urban areas. Tests were conducted on the following three Italian sites: *Solfatara-Campi Flegrei* (Naples), *Parco delle Biancane* (Grosseto) and *Modena* city.

Keywords: thermal anomaly; time series analysis; geothermal site; urban heat island



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1. Introduction

Thermal anomalies, i.e., areas where the surface temperature has a value significantly different from the background, are potentially related to the underground energy sources or to land use and coverage variations in urban areas where the urban heat island (UHI) phenomenon can be observed. Current satellite missions, providing imagery in the Thermal InfraRed (TIR) spectral region at 90–100 m of spatial resolution, provide the potential to estimate the land surface temperature (LST) and highlight the main surface thermal anomalies [1–6]. In this work, two case studies were carried out. The first case study is the detection of thermal anomalies on geothermal active areas (volcanic or not). The second focuses on the detection of UHIs [7,8]. Both the studies are based on the remote sensing LST time series. In both the case studies, the thermal anomalies' detection is also inspected using the principal component analysis (PCA) of the LST time series.

2. Materials and Methods

All the analyses are based on the following two types of data: Advanced Spaceborne Thermal Emission and Reflection Radiometer (ASTER) and the Landsat 8 satellite data, with a 90-m and 100-m pixel spatial resolution, respectively, in TIR channels (8–12 μm) and a temporal resolution of 16 days.

In the first study, nighttime ASTER and TIRS/Landsat 8 time series have been processed using the following two different methodologies: the Temperature and Emissivity Separation (TES, [9]) algorithm for ASTER and the Single Channel Algorithm (SCA, inverting radiative transfer equation, already tested in [10,11]) for Landsat 8. Two LST time series have been obtained and the results are cross-compared and validated with ground measurements. TES and SCA are well-known methodologies and have been used to evaluate LST on the following two different test sites with different geological features: the volcanic area of *Solfatara-Campi Flegrei* (near Naples, Italy) and the geothermal area of *Parco delle Biancane* (near Grosseto, Italy).

The second case study has been addressed to the characterization of the UHI of the city of *Modena* (Italy). The analysis is based on nighttime TIRS/Landsat 8 image time series processed using the SCA methodology.

The availability of a substantial number of these satellite data for the three test sites (as reported in Table 1) offered the possibility of obtaining three LST time series over a long period (Figures 1–3), thus allowing an accurate analysis of thermal anomalies.

Table 1. LST processed for three test sites.

Data	Number of Processed Images		
	<i>Solfatara-Campi Flegrei</i>	<i>Parco delle Biancane</i>	<i>Modena City</i>
LST-ASTER	40	20	NA
LST-Landsat 8	55	40	43
TOTAL LST	95	60	43

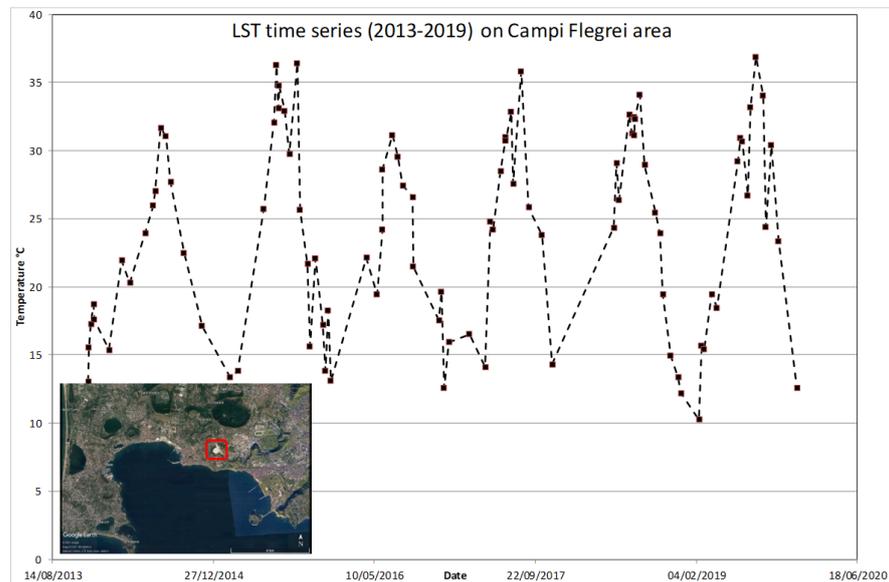


Figure 1. LST Time series on *Solfatara-Campi Flegrei* test site. Plot referred to is the red box area.

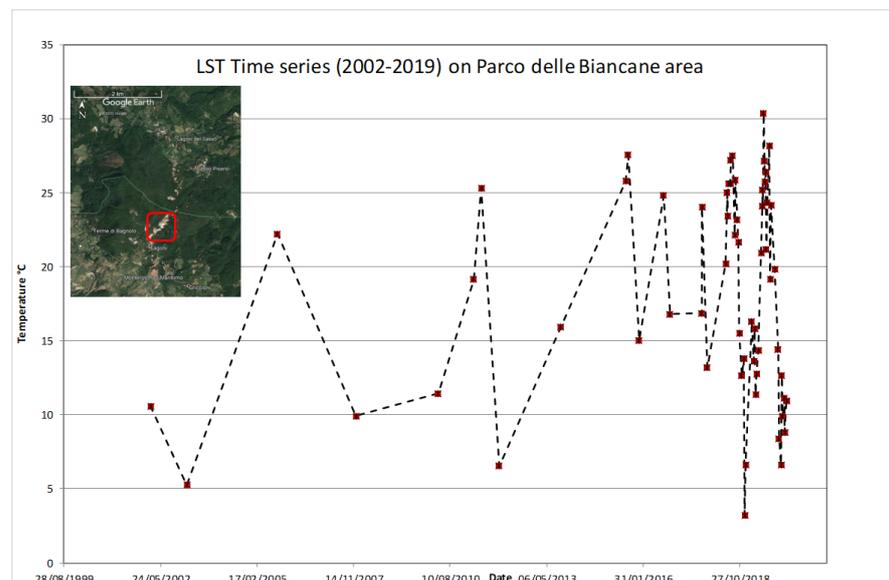


Figure 2. LST Time series on *Parco delle Biancane* test site. Plot referred to is the red box area.

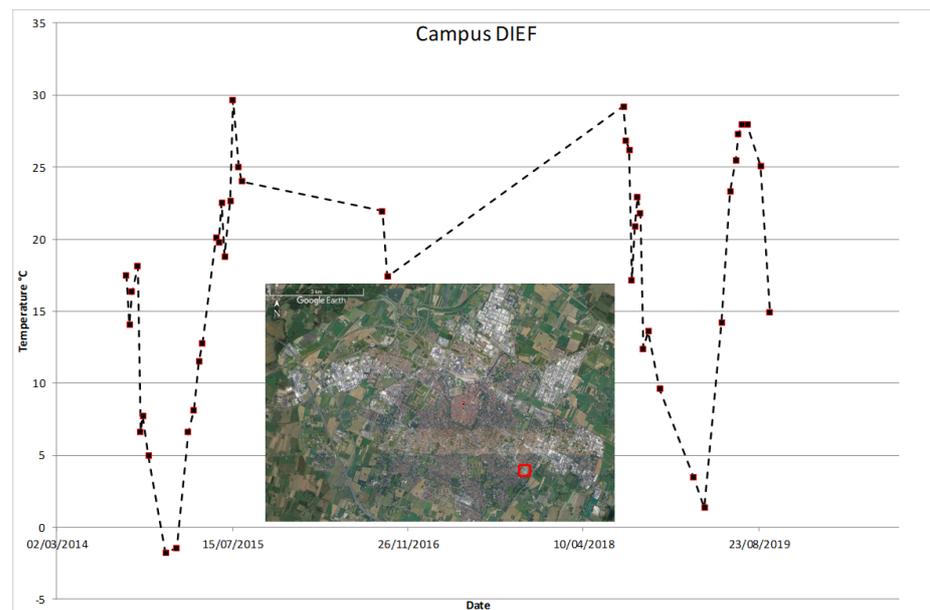


Figure 3. LST Time series on *Modena* city (Campus-DIEF) test site. Plot referred to is the red box area.

The relative accuracy of the LST estimates can be assessed in comparison to the ground measures provided by the ground network that operates independently of the satellites. Alternatively, the accuracy can be estimated by a cross-validation between the products obtained with different LST retrieval algorithms and/or for different sensors, even if largely complicated by the spatial scale mismatch between the satellite sensors and/or the ground-based sensors. In fact, the areas observed by ground radiometers usually cover small areas, whereas satellite measurements in the thermal infrared typically cover between 1 and 100 km². In this case, the following data have been used for the validation steps:

- for *Solfatara-Campi Flegrei*, the ground measurements collected by permanent thermal cameras installed in *Solfatara* volcano. The images have been reprojected to have the same point of view as the satellite;
- for *Parco delle Biancane*, the TIR images acquired using thermal cameras mounted on drones and collected during three separated field campaigns synchronized with satellite passages;
- for *Modena*, weather stations at the 4 stations around Modena city.

3. Results and Discussion

In both case studies (natural and urban areas), the thermal anomalies' detection is inspected using the principal component analysis (PCA) on the LST time series obtained by processing the satellite data. In this work, analysis on the use of PCA has demonstrated the possibility of detecting thermal anomalies in studied sites, neglecting the seasonality effect present in long LST time series. The use of nighttime data has been considered to remove the "noise" due to the solar irradiation that is strong during the day.

PCA allowed the extraction of the dominant patterns within the time series as the detection of thermal anomalies, offering a good and easy way to produce very detailed maps of thermal anomalies, both in geothermal areas and in urban areas (UHI). Thermal anomalies were detected by considering the first two PCs and selecting three sets of pixels from the clusters used as endmembers for the maximum likelihood classification. The position of the cluster, which has been selected considering the PC1 and PC2, is approximately the same in the three scatter plots (Figure 4). The thermal anomaly points (geothermal or UHI), background points (rural areas for UHI) and water points (sea, lakes, rivers) are grouped in distinct sectors of the scatter plots. This leads to the conclusion that thermal anomalies can also be individuated using this combination of PC components of the time series of temperature images derived from satellite imagery.

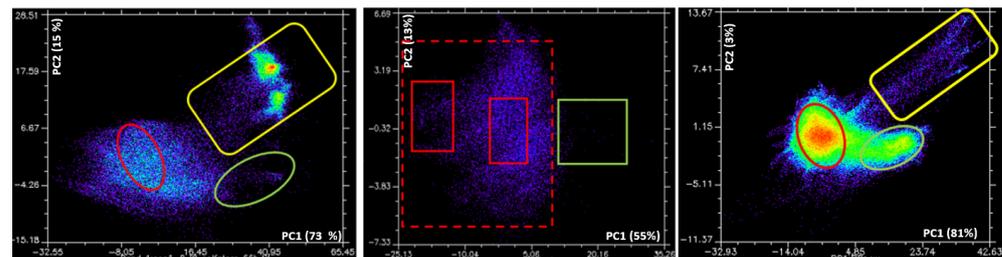


Figure 4. PC1 vs. PC2 cluster: *Campi Flegrei* (left), *Parco delle Biancane* (middle), *Modena City* (right). Yellow line represents the water cluster, red line the background (land, rural areas) and green line represents the thermal anomaly or warm area due to UHI.

In Figure 5, the main warm areas are the *Solfatara* volcano and the lakes that have a temperature greater than the land during the night.

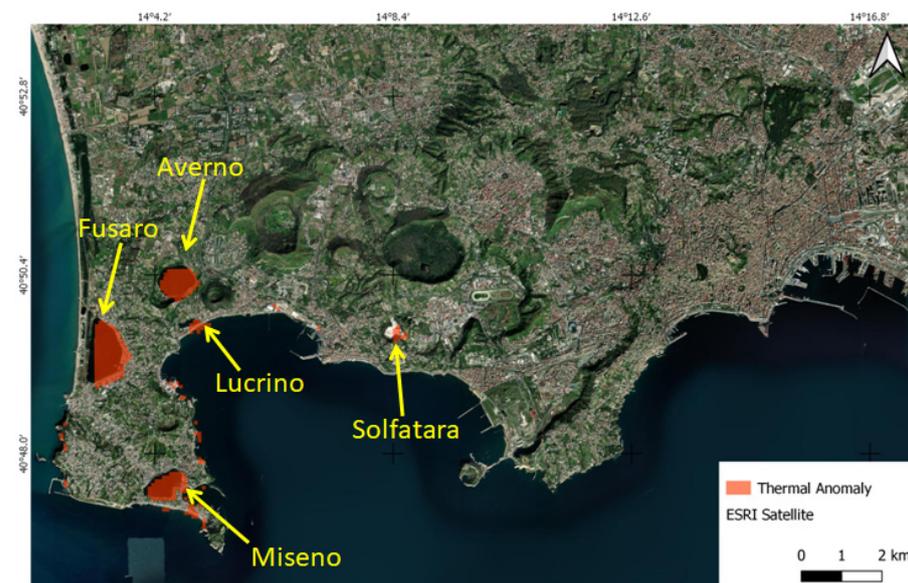


Figure 5. The red areas represent the results obtained for Landsat 8 data in the *Solfatara-Campi Flegrei* area.

A comparison with a different methodology is also presented, confirming that satellite data can be a very powerful tool to study surface thermal anomalies quantitatively.

In fact, the result obtained by using PCA (Figure 5) is in agreement with the one obtained using a different methodology, as described in [11]. In particular, in [11], the process of removing the seasonal component of temperature time series is considered. The existence of a thermally anomalous area at the *Campi Flegrei* site is analyzed by considering the land surface Median Temperature values greater than a Threshold Value (MTTV) on a de-seasonalized time series. In [11], the threshold values of $+1\sigma$ (16.36 °C for ASTER and 17.01 °C for Landsat 8), $+1.5\sigma$ (17.19 °C for ASTER and 18.02 °C for Landsat 8) and $+2\sigma$ (18.03 °C for ASTER and 19.04 °C for Landsat 8) allowed us to obtain the results showed in Figure 6. The use of PCA confirms that the process of removing seasonality, applied in MTTV (Figure 6), is not necessary. The spatial distribution of the thermal anomalies detected using PCA and MTTV is coincident, as shown in Figures 4 and 6.

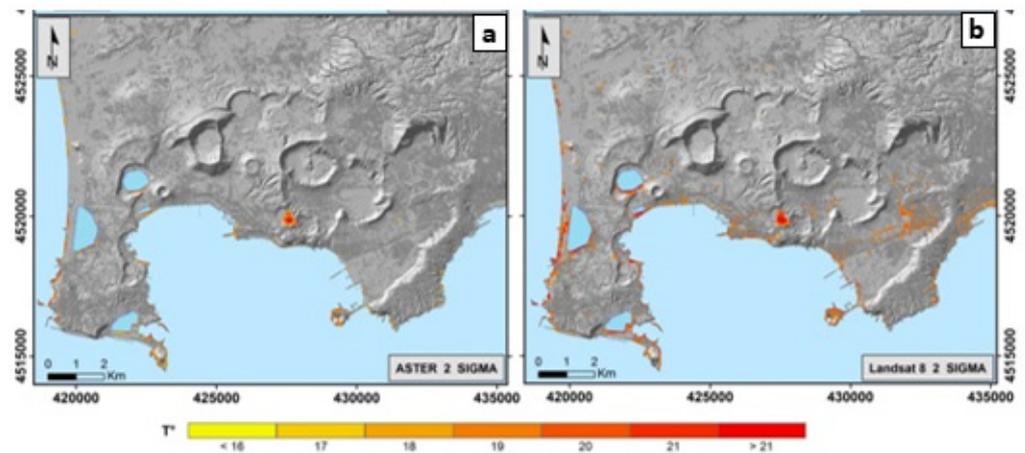


Figure 6. Maps of MTTV of temperature satellite frame with temperature threshold at $+2\sigma$ (a,b); modified after [11].

A similar approach to that taken in *Solfatara-Campi Flegrei*, using PCA as showed in Figure 4, has been adopted for the *Parco delle Biancane* area, where validation data are lacking. An example of the result obtained with Landsat 8 for *Parco delle Biancane* is shown in Figure 7. The red areas cover *Parco delle Biancane*’s geothermal areas that have a temperature greater than the land during the night. Moreover, the *Valle Secolo* and *Nuova San Martino* Enel Green Power central are also detected. Even though there are several geothermal centrals in the area analyzed, the two power plants detected as “thermal anomalies”, together with the *Parco delle Biancane* area, are, indeed, those with a high rated power.

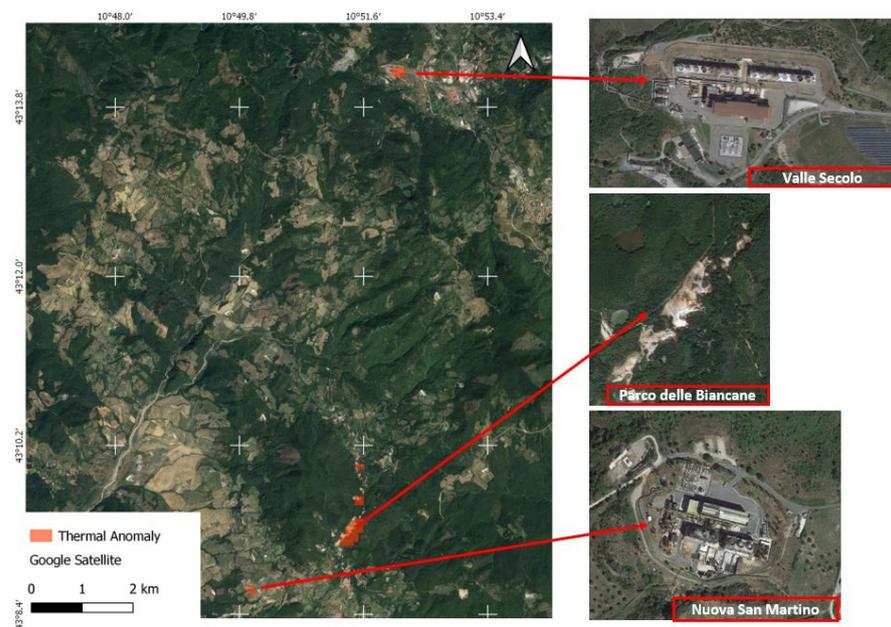


Figure 7. Landsat 8—The red polygons represent the results in the *Parco delle Biancane* area.

Moreover, concerning a UHI, PCA was able to separate the statistics for the rural environment, built areas and water surfaces without additional information on land cover (e.g., the classification obtained using VIS/NIR imagery or other land cover databases). In Figure 8, the results of the UHI phenomenon in *Modena* city are shown. In particular, in Figure 8, green represents water (warm) and red represents built (warm) pixels. The warm areas are included inside the “0” isoline that represents the line that separates

warm and cold surfaces (15.4 °C has been assumed as the reference). Similarly, the isoline corresponding to +2 °C of difference (higher than the reference) has been added and marked as “2” (dashed line).

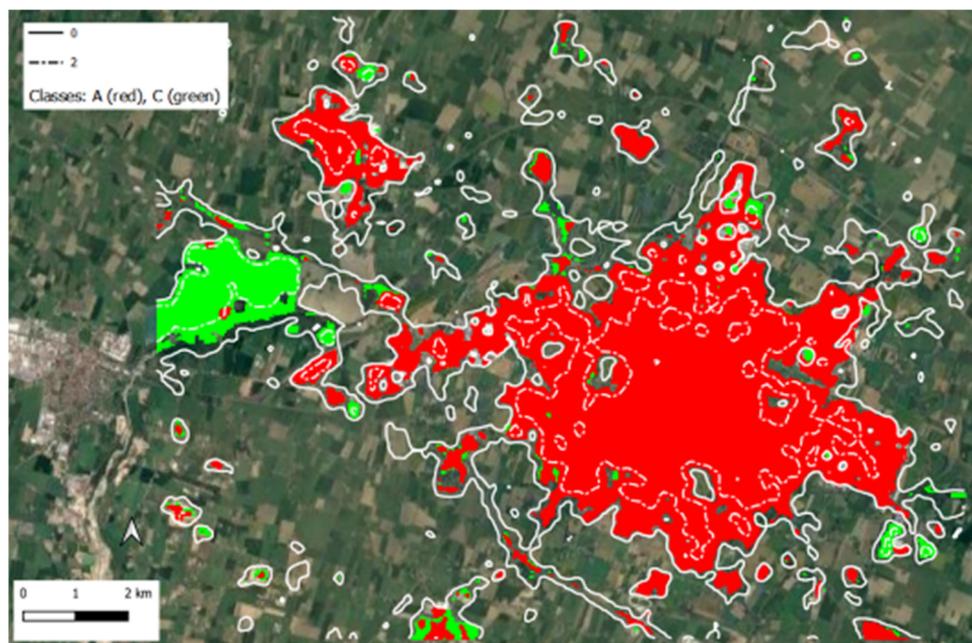


Figure 8. Modena city test site: the classes representing warm areas are reported in green and red.

4. Conclusions

The results of these studies furnished some important considerations, as follows:

- the methodologies used to obtain LST also produce reliable temperature estimates in the very particular case of geothermal anomalies and are usable for near ground air temperature trends' analysis;
- the PCA allows us to extract the dominant patterns within the time series to detect thermal anomalies, offering a good and easy way to produce very detailed maps of the thermal anomalies in both geothermal areas and in urban areas (UHI);
- the PCA allows for the differentiation of the surface cover without using other re-mote sensing images in VIS/NIR or auxiliary classification products. This differentiation improves the analysis of the thermal behavior of the surfaces.

The two studied cases represent two more demonstrations of the potential of satellite observations in TIR for environmental applications.

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Conflicts of Interest: The authors declare no conflict of interest.

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