2020 IMEKO TC-4 International Conference on
Metrology for Archaeology and Cultural Heritage
Trento, Italy, October 22-24, 2020

Analysing the thermal conditions of historic buildings in Cyprus using archive Landsat satellite data and Google Earth Engine big data cloud platform

Athos Agapiou[1,2], Vasiliki Lysandrou[1,2], Diofantos Hadjimitsis[1,2]

[1] *Department of Civil Engineering and Geomatics, Faculty of Engineering and Technology, Cyprus University of Technology, Saripolou 2-8, Limassol 3036, Cyprus, athos.agapiou@cut.ac.cy; vasiliki.lysandrou@cut.ac.cy; d.hadjimitsis@cut.ac.cy*
[2] *Eratosthenes Centre of Excellence, Saripolou 2-8, Limassol 3036, Cyprus*

***Abstract* – This paper presents the preliminary results of an analysis regarding the thermal conditions of the environment that surrounds two historic clusters in Nicosia and Limassol Districts (Cyprus). This investigation was accomplished by exploiting Landsat 7 ETM+ and Landsat 8 LDCM sensors. A multi-temporal analysis from 2013 onwards over these two clusters was performed using the Google Earth Engine big data cloud platform, as well as the ENVI software for the calibration and analysis of the images. In total, 79 Landsat 7 ETM+ and 70 Landsat 8 LDCM images were downloaded and processed. Images were radiometrically and geometrically corrected, converting thus the Digital Numbers to Brightness Temperature in Kelvin (K). Spatial analysis was further processed to create average seasonal and other temporal statistics.**

***Keywords* – built heritage; thermal analysis; satellite data; Landsat space program; Cyprus**

I. INTRODUCTION

The present work makes part of the Research Project entitled Portal for hERItage buildingS integration into the COntemPorary built environment (in short PERIsCOPE). The project is funded under the scheme of the Research Promotion Foundation Programmes for Research, Technological Development and Innovation "Restart 2016 – 2020", Cyprus. Periscope's overall objective is to design and develop an innovative platform for the identification, classification, documentation, and renovation of heritage buildings which can be exploited by a variety of stakeholders related to the conservation and retrofit activities. PERIsCOPE will enable the exploitation of state-of-the-art techniques in the scientific fields of Building Information Modelling (BIM), remote sensing, terrestrial and aerial 3D modelling techniques, and non-destructive onsite testing, pursued by the leading research and academic institutions of Cyprus in these fields.

The thermal analysis of historic buildings in Cyprus makes part of a holistic, integrated, multi-disciplinary effort to bridge technological innovation with the conservation and restoration of heritage buildings. Within this framework, for the macro-scale analysis of the selected urban testbeds, optical and radar satellite images and ready satellite products will be exploited, to provide multi-temporal thermal information for the two study areas. More specifically, medium resolution multispectral optical thermal images from the Landsat 7 ETM+ and Landsat 8 LCDM sensors have been used. The images received a radiometric and geometric correction to achieve high accuracy results in the post-processing phase of the data. Furthermore, the thermal images were converted from Digital Numbers to Brightness Temperature.

A. State-of-the-art: the Landsat Space Program

The Landsat space program is the oldest space program designed and operating for environmental purposes. Since 1972 several space Landsat sensors have been launched in space and provide valuable multispectral datasets, in a systematic way and with almost global coverage. Landsat is a joint effort of the U.S. Geological Survey (USGS) and the National Aeronautics and Space Administration (NASA) [1]. NASA develops remote sensing instruments and the spacecraft, then launches and validates the performance of the instruments and satellites.

Both Landsat 7 and Landsat 8 satellites, orbit the Earth at an altitude of 705 kilometres (438 miles) in a 185-kilometre (115-mile) swath, moving from north to south over the sunlit side of the Earth in a sun-synchronous orbit. Each satellite makes a complete orbit every 99 minutes, completes about 14 full orbits each day, and crosses every point on Earth once every 16 days. Although each satellite has a 16-day full-Earth-coverage cycle, their orbits are offset to allow 8-day repeat coverage of any Landsat scene area on the globe. Between the two satellites, more than 1,000 scenes are added to the USGS archive each day. Land surface temperatures using satellite datasets have been already explored in the past using these sensors [2,3]

B. Case study areas

Two distinct pilot testbeds have been selected, in two different Districts in Cyprus, namely the old Strovolos core in Nicosia District, and the Cami Cedid and Arnaut historic cores in Limassol District (Figure 1). The logical argument beyond the selection of the two study areas was from one hand the variable and different environmental and climatic conditions, and from the other hand, the fact that both areas include a variability regarding the architectural typology of the historic buildings.

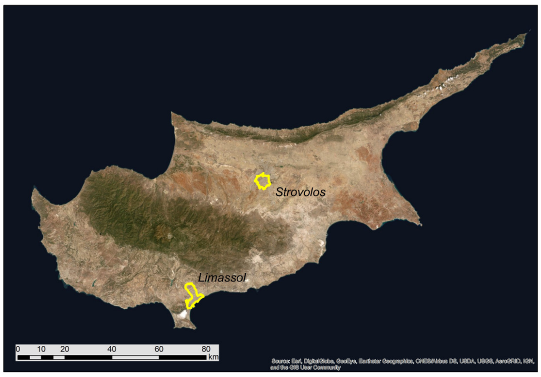

Fig. 1. Map indicating the Old Strovolos core in Nicosia District and the Cami Cedid and Arnaut core in Limassol District, used as cases study areas for the project.

In each of these areas, ten (10) individual buildings will be selected for further investigation. The project consortium members will apply a series of ground investigation techniques and methods including 3-D geometrical documentation, thermal and architectural analysis. Examples from the historic buildings from Limassol are shown in Figure 2 below:

Fig. 2. Examples of buildings to be investigated during the lifetime of the project, from Limassol case study area (photograph sources: Municipality of Limassol©).

II. DATA AND METHODOLOGY

For the needs of the present study, Landsat archives were downloaded through the EarthExplorer platform [4]. On EarthExplorer, Landsat 7 and 8 scenes can be found under the Landsat menu in the "Landsat Collection 1 Level-1" section, in the "Landsat 7 Enhanced Thematic Mapper Plus (ETM+) Level-1" and "Landsat 8 OLI/TIRS C1 Level-1" datasets. Newly acquired Landsat 8 scenes become available for search and download within 24 hours after data acquisition. To view real-time acquisitions of Landsat 8, users can also employ the application EarthNow! Data is delivered from the USGS only in digital format.

The Landsat Collections Level-1 data downloaded from the EarthExplorer platform were rescaled to top of atmosphere (TOA) reflectance and/or radiance using radiometric rescaling coefficients provided in the metadata file that is delivered with the Level-1 product (metadata – MTL file). The metadata file also contains the thermal constants needed to convert thermal band data to TOA brightness temperature.

Landsat Collections Level-1 data products consist of quantized and calibrated scaled Digital Numbers (D.N.) representing the multispectral image data. Landsat 8 products data acquired by both the Operational Land Imager (OLI) and Thermal Infrared Sensor (TIRS) are delivered in 16-bit unsigned integer format. Landsat 1-7 products are generated from single sensor data and are delivered in an 8-bit unsigned integer format.

Specific to Landsat 8, since the satellite's launch in 2013, energy from outside the normal field of view (stray light) has affected the thermal data collected by both thermal bands. The amount of stray light varies throughout each scene, depending upon radiance outside the instrument field of view. The stray light correction applied to Landsat 8 Collection 1 Level-1 data substantially improves image uniformity and absolute calibration in typical scenes.

Prior to the Landsat Collections processing, solar exoatmospheric spectral irradiances (ESUN) values are required to calculate radiance and reflectance of Landsat 1-7 data.

More than 145 satellite images were selected, downloaded, and processed, covering the period between 2013 and 2020. This dataset includes images both from the Landsat 7 ETM+ sensor and the Landsat 8 LDCM sensor. The images were selected upon cloud coverage. For the aims of the study, the Google Earth Engine cloud platform [5, 6] was used to extract the multi-temporal profile for the selected buildings, while the Harris ENVI and ERSI ArcGIS software were used for the image processing at the spatial extent of both municipal areas examined.

III. RESULTS

In order to convert the Digital Numbers of the image to Top of Atmosphere (TOA) radiance and then TOA reflectance, the following equations were implemented in the Harris ENVI environment. The TOA spectral radiance was estimated using the radiance rescaling factors in the metadata file:

$$L_\lambda = MLQcal + A_L L \quad (1)$$

where:

L_λ = TOA spectral radiance (Watts/(m2 * srad * μm))

M_L =Band-specific multiplicative rescaling factor from the metadata (RADIANCE_MULT_BAND_x, where x is the band number)

A_L=Band-specific additive rescaling factor from the metadata (RADIANCE_ADD_BAND_x, where x is the band number)

Q_{cal} = Quantized and calibrated standard product pixel values (D.N.)

Then the spectral TOA reflectance was estimated using the rescaling coefficients in the MTL file:

$$\rho_{\lambda'} = M_\rho Qcal + A_\rho \quad (2)$$

where:

$\rho_{\lambda'}$ = TOA planetary reflectance, without correction for solar angle.

M_ρ=Band-specific multiplicative rescaling factor from the metadata (REFLECTANCE_MULT_BAND_x, where x is the band number)

$A\rho$ =Band-specific additive rescaling factor from the metadata (REFLECTANCE_ADD_BAND_x, where x is the band number)

$Qcal$ = Quantized and calibrated standard product pixel values (D.N.)

TOA reflectance with a correction for the sun angle is then:

$$\rho_\lambda = \frac{\rho_\lambda{}'}{\cos\left(\theta_{SZ}\right)} = \frac{\rho_\lambda{}'}{\sin\left(\theta_{SE}\right)} \quad (3)$$

where:

ρ_λ= TOA planetary reflectance

θ_{SE} = Local sun elevation angle. The scene center sun elevation angle in degrees is provided in the metadata (SUN_ELEVATION).

θ_{SZ} =Local solar zenith angle; θ_{SZ} = 90° - θ_{SE}Thermal band data can be converted from spectral radiance to top of atmosphere brightness temperature using the thermal constants in the MTL file:

$$T = \frac{K_2}{\ln\left(\frac{K_1}{L_\lambda}+1\right)} \quad (4)$$

where:

T = Top of atmosphere brightness temperature (K)where:

Lλ =TOA spectral radiance (Watts/(m2 * srad * μm))

K1 = Band-specific thermal conversion constant from the metadata (K1_CONSTANT_BAND_x, where x is the thermal band number)

K2 = Band-specific thermal conversion constant from the metadata (K2_CONSTANT_BAND_x, where x is the thermal band number)

Through the desk-based analysis the surface temperatures of the areas of interest have been acquired. The achieved conversions and corrections (i.e. conversion to TOA radiance, reflectance and to Top of Atmosphere Brightness Temperature) led to a series of thematic maps, visualizing the results. Figure3, presents an example from both case studies, while Figure 4, an LST profile.

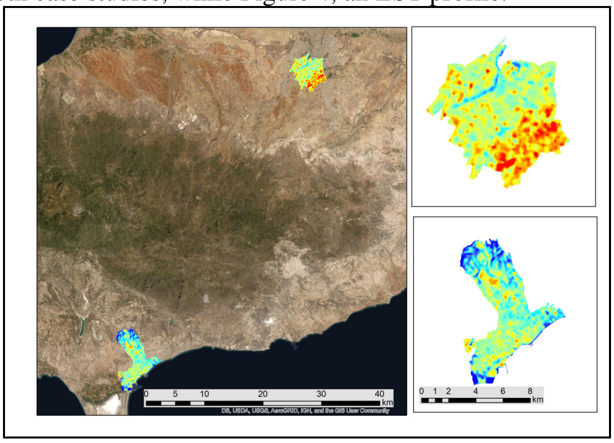

Fig. 3. LST maps over Limassol and Strovolos areas (29/03/2013).

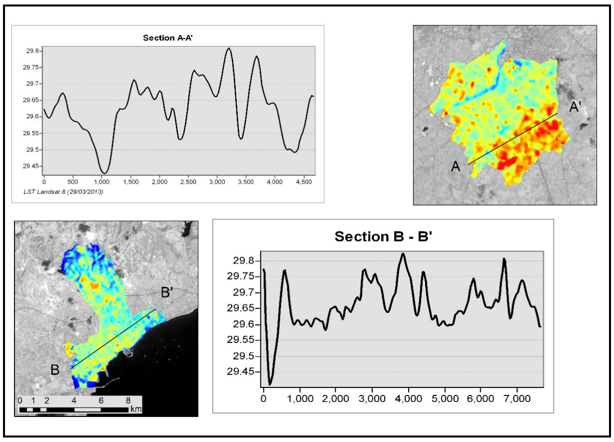

Fig. 4. LST profiles for Landsat 8 and surface temperatures over Limassol and Strovolos areas (29/03/2013).

In addition, through the Google Earth Engine cloud-based interface, it was managed to retrieve per point the temporal variation of the Landsat series (Figure 5). An example from this analysis is shown in Figure 6 below.

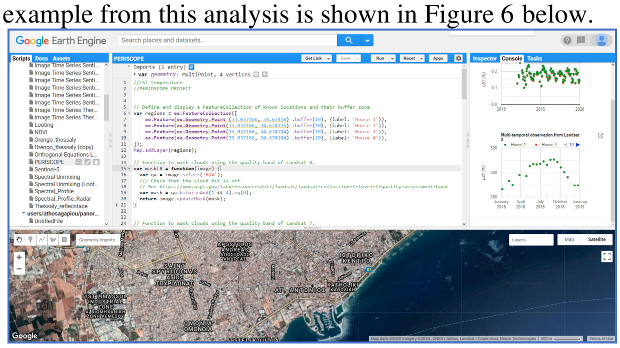

Fig. 5. Google Earth Engine platform used for monitoring temperature variations over specific buildings of Limassol and Strovolos area.

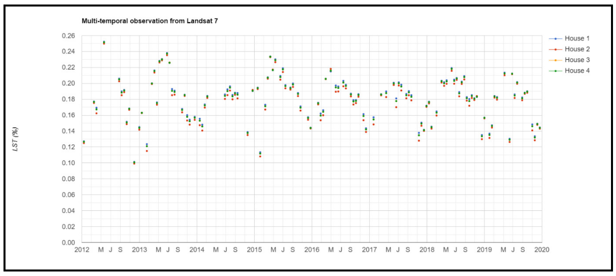

Fig. 6. Multi-temporal observation of Landsat 7 on a house level.

IV. DISCUSSION

This paper presented some preliminary results of an ongoing research project, which aims to monitor historic buildings by using various non-contact technologies (such as satellite sensors), and to integrate this information into a Building Information Modelling, acting as a single point for further elaboration.

The overall methodology, regarding the collection of the satellite data, namely the Landsat 7 and 8 sensors, and some preliminary results through a GIS environment and a big data cloud platform, were presented. A long-term productive and efficient positive aspect of the presented work is that once the research project's platform is set, the remote monitoring of entire historic clusters will be feasible for the platform's users/cultural heritage stakeholders.

The authors will continue elaborating the results and further process the data. Further data processing, results elaboration and statistical analysis are foreseen, which will include hot spot analysis and seasonal thermal mean values, to better understand the regional, temporal conditions of these historic zones.

V. ACKNOWLEDGMENTS

The Project PERIsCOPE INTEGRATED/0918/0034 is co-financed by the European Regional Development Fund and the Republic of Cyprus through the Research & Innovation Foundation. Acknowledgements are also extended to the Eratosthenes Research Centre of the Cyprus University of Technology. The Centre is currently being upgraded into a Centre of Excellence, through the H2020 Teaming Excelsior project (www.excelsior2020.eu).

REFERENCES

[1] Landsat—Earth Observation Satellites, https://pubs.usgs.gov/fs/2015/3081/fs20153081_ver1.2.pdf (accessed on 27th of July 2020)

[2] Ren, H., R. Liu, Q. Qin, W. Fan, L. Yu, C. Du, "Mapping finer-resolution land surface emissivity using Landsat images in China, J. Geophys. Res. Atmos., 2017, v. 122, 6764–6781.

[3] X. Meng,J. Cheng, S. Zhao, S. Liu, Y. Yao, "Estimating Land Surface Temperature from

Landsat-8 Data using the NOAA JPSS Enterprise Algorithm", Remote Sens. 2019, vol. 11, 155.
[4] EarthExplorer platform, https://earthexplorer.usgs.gov (accessed on 27th of July 2020)
[5] Google Earth Engine cloud platform, https://earthengine.google.com (accessed on 27th of July 2020)
[6] S.L. Ermida, P. Soares, V. Mantas, F.-M Göttsche, I. F. Trigo, "Google Earth Engine Open-Source Code for Land Surface Temperature Estimation from the Landsat Series", Remote Sens. 2020, v. 12, p. 1471