Analysis of Albedo Influence on Surface Urban Heat Island by Spaceborne Detection and Airborne Thermography

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Abstract. Urban environment overheating is gaining growing importance for its consequences on citizens comfort and energy consumption. The surface albedo represents one of the most influencing parameters on the local temperature, therefore, its punctual and large scale detection could give a significant contribution to the urban microclimate assessment. A comparison of satellite data with airborne infrared thermography images is proposed for the city of Florence, starting from temperature analyses and moving to surface albedo assessments. It is shown that, despite the aircraft surveys higher resolution, their area covering limitation, sporadic availability, and high cost make the satellite retrieved data competitive, considering that the current 30 m pixel size of the Landsat images seems to be already suitable for the construction material classification.

Keywords: Albedo · Urban heat island · Infrared thermography · Satellite observations

1 Introduction

The urban overheating during summer months may constitute a public health threat, with people living in cities having more elevated health risks when temperature and humidity increase [1]. A relation seems arising between the discomfort due to climate conditions during the summer heat wave and an overall increase in human mortality, especially amongst the elderly.

The metropolitan heating effect is mainly due to the increase of the urbanization process, with a reduction of the vegetation, together with the raise of city air pollution and anthropogenic heat sources. The urbanization process replaced natural land cover with artificial construction materials and building structures that trap solar radiation during the day, releasing the energy slowly at night. For these reasons, especially on summer, this effect could be dangerous for human health.

The detection of the surface urban heat island (SUHI) and the identification of the surface thermal and optical properties (albedo, in particular, which is a measure of a surface capacity to reflect solar radiation, and it is consequently connected with the surface temperatures) play therefore a crucial role on the definition of city microclimate, together with the monitoring of their evolution. Satellite data fulfill the

V. Murino et al. (Eds.): ICIAP 2015 Workshops, LNCS 9281, pp. 95–102, 2015.
DOI: 10.1007/978-3-319-23222-5_12

requirements of wide territory covering and availability of information relative to different periods; on the other hand, the resolution for the bands necessary for thermal analyses is around 100 m. This circumstance opens the theme of the detailed recognition and classification of materials constituting the urban texture.

The paper proposes a comparison of satellite data with airborne infrared thermography images, characterized by a higher resolution (up to 1 m); the strengths and weaknesses of both methods are analyzed, and the correlation between the satellite retrieved surface albedo and the SUHI is finally investigated.

2 Description of Data Recovery

2.1 Landsat Data

The Landsat Thematic Mapper (TM) sensor is composed by seven bands, six of them (TM1-5, TM7) in the visible, near infrared (NIR) and short-wavelength infrared (SWIR), and one band (TM6) in the thermal infrared (TIR) region.

TM has a native spatial resolution of 30 m for the six reflective bands and 120 m for the thermal band. TM6 is also delivered at 30 m, resampled with a cubic convolution by the US Geological Survey (USGS) Center. In this study, observations of the TM instrument onboard Landsat-5 platform were used (16-day revisit interval), passing over Florence at 11:50 CEST (Central European Summer Time), projected in the Universal Transverse Mercator (UTM) WGS84 coordinate system (meter). Landsat TM data were processed and calibrated in order to convert digital number values to at-sensor spectral radiance values and then to at-sensor reflectances for the reflective bands [2]. Finally, an atmospheric correction was carried out to obtain at-surface reflectivities [3].

2.2 Airborne Data

The airborne measurements were carried out by a Sky Arrow 650 TCNS ERA research aircraft, with a FLIR A40-M thermal camera installed onboard, producing images of brightness temperature in the TIR region (7.5-13.0 μm), with a thermal resolution of 0.08° and an IFOV of 1.3 mrad. Visible images were also acquired during the aircraft flight by means of a Canon EOS-20D camera, allowing a direct comparison between the thermographic and the visible images.

The flight was carried out on July 18, 2010, at around 13:30 CEST, at an average altitude of 1370 m above sea level. Each thermal image has a resolution of 320 × 240 pixels with a nadir pixel size of about 1 m. The area covered by the aerial survey approximately corresponds to the yellow box shown in Fig. 1. The raw thermal images were analyzed by the ThermaCam Researcher Software and then geometrically corrected by Ground Control Points (GCP) and Digital Elevation Model (DEM) before applying the mosaicking tool of Geomatica PCI software.

2.3 LST Recovery from Landsat and Airborne

Land surface temperature (LST) can be obtained from the channel located in the thermal infrared region by inversion of the radiative transfer equation according to the following expression:

$$L_{sens,\lambda} = [\varepsilon_\lambda B_\lambda(T_s) + (1 - \varepsilon_\lambda) L_\lambda^{\downarrow}] \tau_\lambda + L_\lambda^{\uparrow} \quad (1)$$

Where $L_{sens,\lambda}$ is the at-sensor radiance, ε_λ is the surface emissivity, $B_\lambda(T_s)$ is the Planck's law where T_s is the LST, $L_\lambda^{\downarrow}$ is the downwelling atmospheric radiance, τ_λ is the total atmospheric transmissivity and $L_\lambda^{\uparrow}$ is the upwelling atmospheric radiance. The atmospheric parameters τ_λ, $L_\lambda^{\downarrow}$ and $L_\lambda^{\uparrow}$ can be calculated by a web-based tool [4] able to calculate these atmospheric-correction parameters for the thermal band for a given site and date.

The knowledge of land surface emissivity ε_λ is necessary for the inversion of Eq. (1): a method based on the Normalized Difference Vegetation Index (NDVI) using the at-surface reflectivity values was applied [5].

Fig. 1. Area covered by the aircraft flight for the infrared thermography measurements

3 Surface Urban Heat Island Assessment

Land surface temperature (LST) is a fundamental parameter controlling the surface energy balance of the Earth. In urban areas, LST allows the assessment of the SUHI effect [6]. The SUHI describes the changes in temperature at the urban surface and is strongly linked with the material type and orientation of the surface respect to the sun. Since decades, with the advent of earth observation satellites, remote sensing technology has been widely utilized to measure LST and SUHI: compared to the traditional meteorological observation methods measuring air temperature, spaceborne sensors have the advantages of providing information completely covering large areas at the same time, while conventional data registered *in situ* are typically un-evenly distributed in space.

The SUHI intensity is a parameter used to quantify the urban heating effects: it is defined as the difference in surface temperature between the urban pixels and the surrounding rural areas, used as an average reference, within a given time period:

$$SUHI = LST_{urban} - LST_{rural} \quad (2)$$

In order to have a rural reference taking into account all the possible scenarios (countryside or suburbs) of the areas surrounding Florence, T_{rural} has been computed as the average among the air temperatures measured by the three rural stations.

The retrieved SUHI images of Florence study area observed by the spaceborne and airborne sensors are shown in Fig. 2. For comparison purposes, the images are gridded with a resolution of 30 m. Beyond the two Landsat images acquired on 10th and 26th July 2010, it is also shown the image obtained averaging the two ones.

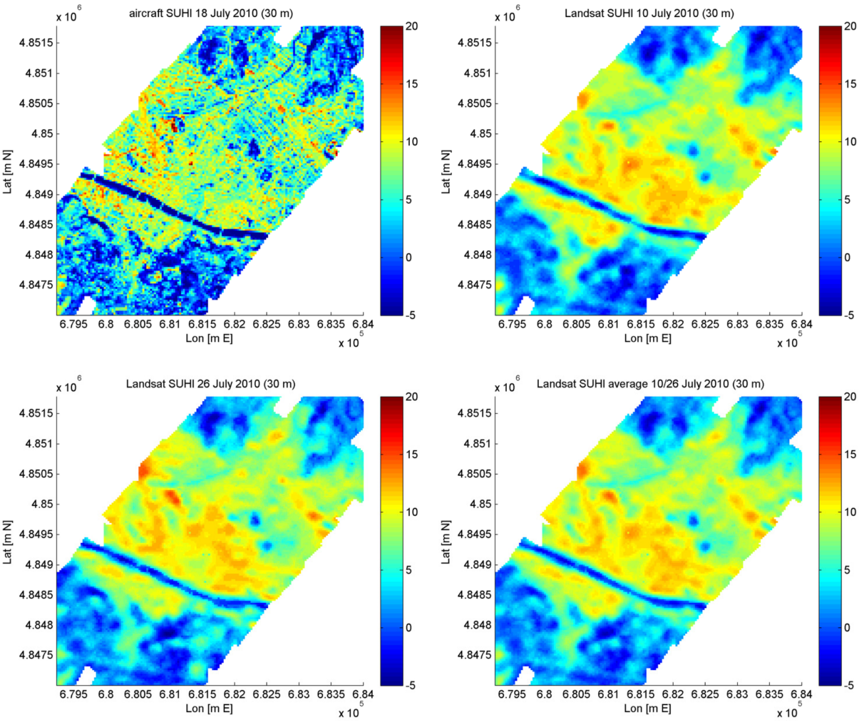

Fig. 2. From top to bottom: SUHI [°C] full image from airborne data (18th July 2010) with 30 m averaged pixels; SUHI [°C] from Landsat TM (10th July 2010); SUHI [°C] from Landsat TM (26th July, 2010); SUHI [°C] from Landsat TM (average of 10th and 26th July). Landsat TM pixels are 30 x 30 m (resampled from thermal observation at 120 m). Lat/lon are in UTM [m], 32 T zone

Despite the clear difference in detailing the spatial features, the trends of the surface urban heat island pattern result similar: negative SUHI values are registered in water bodies and vegetation areas, while higher values are located in the central urbanized areas, as expected. The SUHI, with values higher than 10 K, reaches the maximum impact on the urban in the early afternoon (the airborne flight was made on July 18, 2010, at around 13:30 CEST, while the Landsat passed over Florence on July 10 and July 26, 2010, both at 11:50 CEST).

However, clear differences emerge in the detailed definition due to the different spatial resolution of the Landsat TM and airborne sensor acquisitions, where the former (TM6) has a native 120 m spatial resolution resampled at 30 m by the USGS Center, while the latter is obtained by block-averaging at 30 m the original acquisition at 1 m.

These results suggest that LST from the Landsat TM thermal channel can be considered reliable to evaluate, for instance, the presence and the pattern of the SUHI over a wide urban area: however, it smoothes the heat discontinuities at a finer scale and it is not adequate to resolve details over a complex urban texture.

4 Albedo

Since the Landsat Thematic Mapper sensor provides data on seven bands, it is possible to use five of them (TM1: 0.452–0.518 μm, TM3: 0.626–0.693 μm, TM4: 0.776–0.904 μm, TM5: 1.567–1.784 μm, TM7: 2.097–2.349 μm) to retrieve the shortwave albedo, as described by Liang relation [7]:

$$\alpha = 0.356\alpha_1 + 0.130\alpha_3 + 0.373\alpha_4 + 0.085\alpha_5 + 0.072\alpha_7 - 0.0018 \tag{3}$$

All of the above mentioned bands have a spatial resolution of 30 m.

Surface albedo is defined as the ratio between the reflected flux density and the incident flux density (irradiance) at the surface level [8]. It represents one of the most influent input parameters in the regulation of the city environment thermal balance. As a matter of fact, the presence of wide surfaces characterized by a high level of solar radiation absorption (low albedo) within city textures, seems linked to the SUHI effect increase [9].

Hence, it results interesting to compare the maps of SUHI (both the Landsat and the airborne ones) with albedo maps, looking for eventual correlations.

Figure 3 reports the full albedo map, next to the SUHI full image from Landsat; since the focus is now directed on the artificial materials, the vegetation and water pixels were excluded from the albedo image, on the basis of two indices: the NDVI and the NDWI (Normalized Difference Water Index) [10].

The patterns result quite correlated (low albedo means higher temperature), confirming the influence of the albedo on SUHI, mainly because of the large presence in highly urbanized towns of absorptive roofs and impervious surfaces, such as asphalt parking lots, roads, squares and pavements.

If the spaceborne detected albedo map is compared with the high definition (1 m) airborne infrared thermography, it emerges that, despite the lower resolution of satellite data, the latter show an effective potential for the assessment of the albedo of single roofs or single streets, with an impressive level of accuracy. Figures 4 and 5 show the detail of two sub-areas of interest: one of the main road of the city (Viale Lavagnini), and the platform roof of Santa Maria Novella railway station.

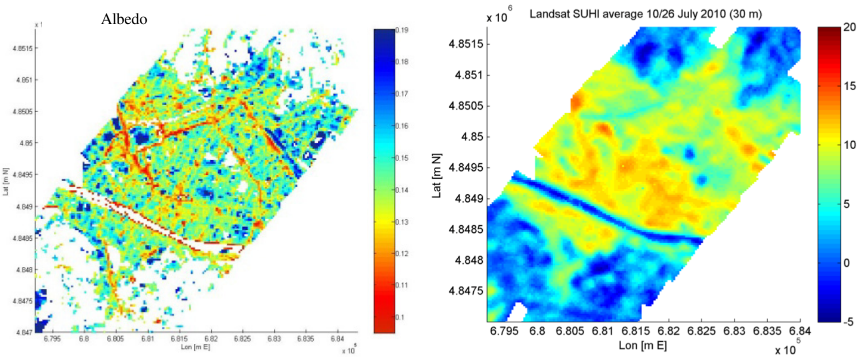

Fig. 3. Comparison between albedo and SUHI [°C] maps retrieved from satellite observations

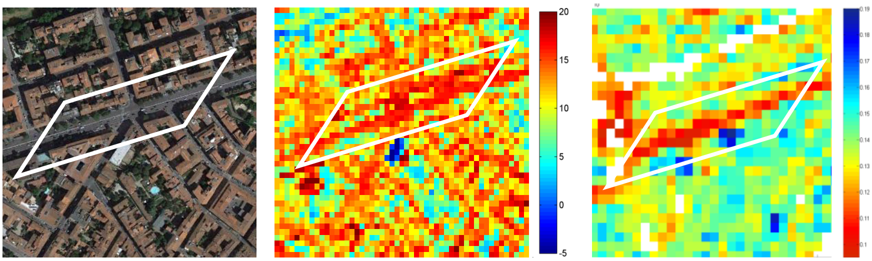

Fig. 4. Detail of an asphalt road: visible image, SUHI (°C) from airborne IR thermography (pixel 1 x 1 m) and Landsat TM albedo (pixel 30 x 30 m)

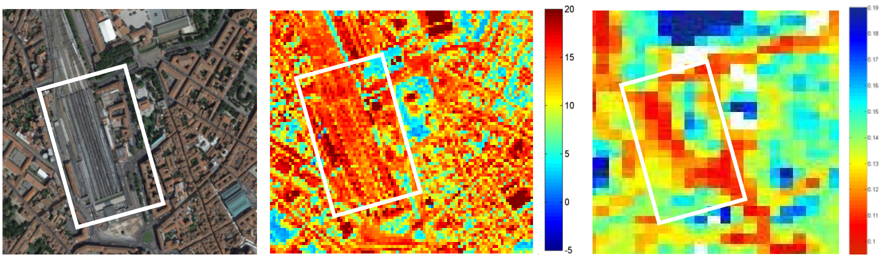

Fig. 5. Detail of the platform roof of Santa Maria Novella railway station: visible image, SUHI (°C) from airborne IR thermography (pixel 1 x 1 m) and Landsat TM albedo (pixel 30 x 30 m)

Figure 4 demonstrates how the low albedo of road asphalt turns into high temperature levels (when the road is not shadowed from the neighbouring buildings); Fig. 5 focuses on roofs with highly absorptive external surface, which produce again the effect of raising the temperature of the surrounding area.

It results interesting to note that the satellite albedo succeeds on detecting these noteworthy wide parts of the urban texture, as well as the high resolution IR thermography [11]. Overall, to recognize the thermal details within a urban environment the airborne image is obviously better than the Landsat one, even though the spaceborne detection has already proven as un useful tool to detect large scale SUHI. Also, the future availability of spaceborne observations with higher spatial resolution at the visible, NIR and SWIR bands would allow to perform albedo analysis at a finer spatial scale. It will be therefore possible to provide details that today are not distinguishable at the 30 m TM resolution, detailing up to the single roof.

5 Conclusions

The use of remote sensing instruments like onboard both satellite and aircraft platforms provide a global monitoring of extended areas and, using suitable recovery algorithms, an inspection of different surface properties: the analysis detail depends on the spatial resolution of the sensors. Peculiar surface properties, such as the surface temperature and albedo, occupy a key position in the material classification and recognition in a urban texture. In particular, this work points out the possibility to detect construction materials and building structures absorbing solar radiation (low albedo) and exposed to thermal effects highlighted by a SUHI increase. The availability of an airborne thermal image and of both thermal and reflective images from Landsat TM over Florence allowed to correlate the absorption and thermal characteristics of particular areas within a urban texture, and to analyze the role of the sensor spatial resolution. Examples of impervious surfaces characterized by low albedo producing the effect of raising their temperature were shown, and even if the current 30 m pixel size of the Landsat data seems to be suitable for the construction material classification, the hoped-for availability of observations with higher spatial resolution would allow to perform albedo recognition at a finer scale. In fact, although aircraft surveys ensure a pixel size of about 1 m, and in some cases provide both thermal and reflective data, they result sporadic, area-limited and expensive.

Acknowledgments. Authors wish to thank Beniamino Gioli and Piero Toscano (CNR IBIMET) for the airborne data processing, Roberta Anniballe for the software support, Claudio Belli for the flight coordination and airborne data acquisition provided by Terrasystem (www.terrasystem.it). Airborne surveys were made in the frame of the EC project BRIDGE (www.bridge-fp7.eu).

References

1. Tan, J., Zheng, Y., Tang, X., Guo, C., Li, L., Song, G., Zhen, X., Yuan, D., Kalkstein, A.J., Li, F., Chen, H.: The heat island and its impact on heat waves and human health in Shanghai. International Journal of Biometeorology **54**(1), 75–84 (2010)
2. Chander, G., Markham, B.L., Helder, D.L.: Summary of Current Radiometric Calibration Coefficients for Landsat MSS, TM, ETM+, and EO-1 ALI sensors. Remote Sensing of Environment **113**, 893–903 (2009)
3. Chavez, P.S.: Image-based atmospheric correction—revisited and improved. Photogrammetric Engineering and Remote Sensing **62**, 1025–1036 (1996)
4. National Aeronautics and Space Administration. http://atmcorr.gsfc.nasa.gov
5. Stathopoulou, M., Cartalis, C.: Downscaling AVHRR land surface temperatures for improved surface urban heat island intensity estimation. Remote Sens. Environ. **113**(15), 2592–2605 (2009)
6. Voogt, J.A.: Urban Heat Island: Hotter Cities - America Institute of Biological Sciences (2004). http://www.actionbioscience.org/environment/voogt.html
7. Liang, S.: Narrowband to broadband conversions of land surface albedo – I Algorithms. Remote Sens. Environ. **76**(2), 213–238 (2000)
8. Schaepman-Strub, G., Martonchik, J., Schaaf, C., Schaepman, M.: What's in a satellite albedo product? In: IGARSS 2006, pp. 2848–2851. IEEE Press, Denver (2006)
9. Santamouris, M., Synnefa, A., Karlessi, T.: Using advanced cool materials in the urban built environment to mitigate heat islands and improve thermal comfort conditions. Sol. Energy **85**(12), 3085–3102 (2011)
10. Xu, H.: Extraction of urban built-up land features from Landsat imagery using a thematic-oriented index combination technique. Photogrammetric Engineering & Remote Sensing **73**(12), 1381–1391 (2007)
11. Baldinelli, G., Bonafoni, S., Anniballe, R., Presciutti, A., Gioli, B., Magliulo, V.: Spaceborne detection of roof and impervious surface albedo: Potentialities and comparison with airborne thermography measurements. Solar Energy **113**, 281–294 (2015)