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Spaceborne detection of roof and impervious surface albedo: Potentialities and comparison with airborne thermography measurements

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Abstract

The albedo of urban roofs and impervious surfaces constitutes one of the key parameters in the energy balance of the city environment, and its detailed and accurate assessment represents an ambitious and challenging objective.

In this work, an analysis of Landsat Thematic Mapper (TM) data and airborne infrared (IR) thermography data over the city of Florence was performed to assess the satellite sensor capability to successfully detect the surface albedo with a high level of detail over a heterogeneous urban texture. The effect of the TM reflective bands spatial resolution (30 m) on the albedo retrieval of single roofs, squares or roads was investigated, comparing these data with the aircraft surface temperature measurements at 1 m spatial resolution, which are indirectly linked to the surface reflective properties. The detailed analysis of the albedo pattern from spaceborne observations provided reliable albedo values for dark and light roofs and for low albedo surfaces; different significant situations were investigated, and interesting results came up. The Landsat TM albedo succeeds on detecting dark and light roofs, as well as the high resolution IR thermography, but if the latter is averaged in a 30 m grid (the same of the albedo), the most significant information gets lost. Besides, in the presence of low albedo materials, occasionally cold surfaces appeared in the airborne image due to the shadow of buildings, a circumstance that could bring to wrong evaluations of the surface reflective properties, trusting only on thermal images. Moreover, it is shown how the different exposures to the sun of the same surface affected the thermography results, a circumstance not found on Landsat TM albedo pattern.

The paper demonstrates that satellite data show an effective potential for the assessment of the albedo of roofs and impervious surfaces, even when a high level of detail is required, providing information for improving urban planning efforts to dampen heating effects.

Keywords: Satellite observations; Albedo; Cool roofs; Airborne infrared thermography

1. Introduction

The albedo of urban roofs and impervious surfaces plays a fundamental role in regulating the surface energy balance and therefore the cooling energy demand during

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Nomenclature

B	spectral irradiance [W/(m^2 m)]
CEST	Central European Summer Time (–)
E	east (–)
f	fractional cover (–)
FOV	field of view (°)
h	heat transfer coefficient (W/m^2 K)
IFOV	instantaneous field of view (mrad)
IR	infrared (–)
L	radiance (W)
LST	land surface temperature (K)
N	north (–)
NDVI	Normalized Difference Vegetation Index (–)
NIR	near infrared (–)
SWIR	short-wavelength infrared (–)
T	temperature [K]
TIR	thermal infrared (–)
TM	Thematic Mapper (–)
U	thermal transmittance (W/m^2 K)
USGS	United States Geological Survey (–)
W	solar radiation (W/m^2)

Subscripts

a	air
c	urban area
e	external
max	maximum
min	minimum
s	surface
sens	sensor
short	shortwave
v	vegetation

Superscripts

$\downarrow$	downwelling
$\uparrow$	upwelling

Greek symbols

α	albedo (–)
ε	emissivity (–)
λ	wavelength (m)
τ	atmospheric transmissivity (–)

the summer season. Within the city texture, the large presence of surfaces characterized by a high level of solar radiation absorption brings to numerous unwanted effects:

- Increase of the temperature difference between the city area and the surrounding rural background (urban heat island), with consequent increment of electricity consumption for indoor environment cooling (Santamouris et al., 2011, 2012; Santamouris, 2014);
- buildings equipped with air conditioning plants suffer a higher solar load, derived from the radiation absorbed by the external surfaces (Synnefa et al., 2007);
- the electric energy demand for summer cooling increases also because of the lesser efficiency of compression refrigerators due to the exposure of the outdoor units (condensers) to hotter air temperatures;
- the progressive substitution of vegetation with inorganic materials cuts the cooling effect of evapotranspiration (Kolokotsa et al., 2013);
- the road pavement asphalt durability decreases with the enhancement of surface temperature;
- the average air temperature growth has the side effect of increasing the tropospheric ozone concentration.

Indeed, since many years the potential benefits of improving the surface solar-reflection properties in city areas has been widely investigated.

Akbari et al. (2001) focused on various large United Stated cities and on the Greater Toronto Area (Akbari and Konopacki, 2004), Dousset and Gourmelon, 2003 gave attention to the Paris microclimate, Stathopoulou et al. (2009) analyzed the metropolitan area of Athens, Boixo et al. (2012) concentrated their study of possible energy savings on all the provinces of Spain, Haixia et al. (2012) registered the variation of land surface albedo of Beijing during the years 1999–2010, Xu et al. (2012) evaluated the benefits of cool roofs by monitoring buildings in the metropolitan region of Hyderabad (India) and Dobrovolný (2013) focused his analysis on Brno urban heat island.

Other researchers examined the albedo effects at the global scale: Shi and Zhang (2011) simulated the effect of longwave emissivity and solar reflectance modification on 35 cities distributed all over the world; Menon et al. (2010) and Akbari et al. (2012) calculated the land surface temperature decrease and the emitted CO_2 reduction following a fixed increase of roof and pavement albedo in worldwide urban areas; Akbari et al. (2009) performed an economic analysis to assess the monetary value of urban albedo increase in terms of CO_2-equivalent negative emissions at a fixed greenhouse gas trading rate. Therefore, the strategic function of surface albedo calls for the definition and the application of precise and reliable methods for its measurement and retrieval.

One measurement technique consists of using spectrophotometers, normally equipped with an integrating sphere accessory for hemispheric reflectance measurements, allowing the material analysis in the entire wavelength spectrum