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Correlation between remote sensing data and ground based measurements for solar reflectance retrieving

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ABSTRACT

Surface and atmospheric modifications due to urbanization generally lead to the urban heat island effect (UHI). This phenomenon is an issue of growing interest and has long been studied by ground based observation. With the advent of remote sensing technologies, observation of UHIs became possible with airborne and spaceborne sensors. Remote sensing data allow urban surfaces characterization to study UHI mitigation methodologies such as the application of cool roofs and cool colors.

In this study remote sensing data have been used first to identify urban surfaces and then to retrieve the solar reflectance value of these surfaces.

The first area of interest is the city of Modena in the Emilia Romagna region (Italy). On this area orthorectified images by an airborne sensor are used. Available images do not allow to directly obtain the solar reflectance value. Therefore it has been investigated a correlation between satellite remote sensing data and ground based measurements.

The solar reflectance was obtained for all urban surfaces of interest such as roofs and pavements. In this way it was possible to assess the real situation and to hypothesize achievable improvements in the solar reflectance of several urban surfaces aimed at improving thermal comfort and energy efficiency of buildings.

1. Introduction

The phenomenon of urban heat island (UHI) is probably one of the most obvious examples of climate change caused by human activities. The process of urbanization has changed the nature of surfaces, determining a significant differences between urban and rural areas such as a major increase in both surface and air temperature in cities than in the surroundings. Currently, this phenomenon affects not only large metropolitan areas, but also smaller cities. The size and the shape of the UHI vary in time and space depending on the meteorological and morphological characteristics of the considered area [1–3].

There are several strategies to mitigate UHIs, one of the most important and most frequently used is to increase the solar reflectance of urban surfaces [4–8]. Solar reflectance, or albedo, is the hemispherical reflection of solar radiation integrated over the solar spectrum from 0.3 to 2.5 μm.

Remote sensing data in the thermal infrared spectral region (TIR region, from 7.0 to 20 μm) are commonly used to study UHIs [9,10]. Remote sensing is also a useful tool for urban surfaces characterization since it allows for near real time monitoring of large areas. Remote sensing data are used in urban planning to gain information on the type of coverage of natural and human-made surfaces. Several satellite sensors, such as ASTER (Advanced Spaceborne Thermal Emission and Reflection Radiometer), allow the direct estimate of the albedo value from sensor acquisition bands [11]. However, spatial resolution of these sensors is not sufficient to study small surfaces as building roofs. In Europe in particular, land cover in urban centers shows a large variability and sharp transitions between different types of materials, requiring images with high spatial resolution (i.e. less than 1 m) in order to successfully investigate them.

In this work airborne remote sensing images with a spatial resolution of 50 cm have been used. The first area of interest is the city of Modena in the Emilia Romagna region (Italy). These images were used to compute the surface brightness *B*, which represents a linear combination of the sensor acquisition in the visible and in the near infrared spectral regions [12].

Thereafter, the surface brightness has been correlated with the ground measurements of solar reflectance of urban surfaces. This correlation allows the estimation of the albedo over large areas in order to assess the current typology of cover materials and to plan

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actions for UHI mitigation by increasing the albedo of urban surfaces in specific areas. Ground measurements of solar reflectance have been made by means of a Solar Spectrum Reflectometer considering the Air Mass 1 Global Horizontal (AM1GH) irradiance spectrum [13,14] according to ASTM Standard Test Method C1549 [15].

Other studies in the scientific literature have already correlated ground based measurements with satellite data [16,17]. This study is the first comparing surface brightness to ground measured solar reflectance. In particular, this work focuses on human-made surfaces such as roofs of residential and industrial buildings, and urban pavements. On these surfaces, it is possible to apply coverings such as cool roofs, cool colors and cool pavements [18,19] to increase their albedo and consequently mitigate the UHI.

Several studies indeed correlate albedo to the UHI reduction in terms of decrease in atmospheric temperature and in CO_2 emissions [7]. Human-made surfaces with high solar reflectance can also decrease cooling energy use in air conditioned buildings, increase comfort in unconditioned buildings and improve outdoor air quality [8,20].

There are also several models that quantify direct benefits brought by the application of cool roofs and cool pavements in urban settings [7,21,22]. For example Xu et al. [22] quantified that the annual energy savings from roofs whitening of previously black roofs ranged from 20 to 22 kWh/m^2 of roof area in the metropolitan Hyderabad region (India), corresponding to an estimated CO_2 reduction of 11–12 kg CO_2/m^2 of flat roof area. Akbari, Matthews, and Seto [7] showed that increasing albedo for a 1-m^2 surface by 0.01 would have the same effect on global temperature as decreasing emissions by 6.5–7.5 kg of CO_2. Cotana et al. [21] show that the surface area with high solar reflectance (equal to an albedo of 0.9) required to offset the effect of atmospheric emissions of one ton of CO_2 is $S = 19\ \text{m}^2/\text{tCO}_2$. These models are suitable for the hot and temperate regions of the world.

Finally this work fits perfectly in the environmental policies of the European Union, since most recent EU requirements provide the reduction of CO_2 emissions by 20% by 2020 [23].

In particular the first study area, the city of Modena, recently adopted a voluntary plan of action for sustainable energy (SEAP) in order to reduce by more than 20% its greenhouse gas emissions through local policies improving energy efficiency of buildings, increasing the use of renewable energy sources and promoting energy saving and rational use of energy [24].

2. Data set, materials and methods

2.1. Remote sensing data

In this work, orthophotos acquired over the city of Modena in the Emilia Romagna region have been used. Four images were acquired by an airborne sensor on August 10, 2008 and have a spatial resolution of 50 cm. These orthophotos were provided by the cartographic archive of the Emilia Romagna region.

The images are composed by four bands described in Table 1. Three bands are in the Visible spectral region (VIS), while the last band is in the Near Infrared spectral region (NIR).

Fig. 1 shows the first study area.

Table 1
Bands of the airborne sensor.

Band	Spectral region		Wavelength (μm)	Spatial resolution (cm)
1	VIS	Red	0.62–0.75	50
2		Green	0.49–0.55	50
3		Blue	0.43–0.47	50
4	NIR		0.75–1.50	50

The images were mosaicked and the area of interest was then cropped. Atmospheric effects may influence significanlty remote sensing measurements and they should be removed. Nevertheless, this study deals with a first analysis and atmospheric corrections were not applied. The effects of this assumption is discussed in the next sections.

2.2. Samples gathering

Referring to remote sensing images, different kinds of building materials representative of the study area have been chosen. In particular, chosen materials are:

- Asphalt shingle (**G**), typical coverage of industrial buildings roofs or of other roofs;
- Bare zincalume steel (**L**), typical coverage of some old buildings;
- Concrete pavement tiles (**C**), typical coverage of several flat roofs but also of parking lots and sidewalks;
- Dolomite (**P**), used as pavement stone for squares and pedestrian streets;
- Asphalt (**A**), used for streets and roads;
- Interlock paving blocks (**B**), typical pavement recently used for parking and sidewalks;
- Different type of clay roof tiles (**T**), typical roofs of residential buildings.

In Fig. 1 the two red boxes indicate the areas where the measurements has been done. Fig. 2 shows a detail of ground based measurement points marked with a letter that identifies the sampled material.

Samples gathered are all related to human-made surfaces, whose solar reflectance can be increased. For some of these materials, the potential increase in albedo is limited, yet not negligible: for example, the asphalt used for road surfaces must maintain a dark enough color not to be dazzling for the human eye. Other materials allow for a larger increase in albedo. For example, cool roofs materials can be applied on flat roofs of industrial, residential and tertiary buildings to increase the albedo up to 70% [7,25].

2.3. Instrument description

For each chosen material, the solar reflectance has been measured with a Solar Spectrum Reflectometer (SSR) V6.0 made by Devices & Services (Dallas, TX, USA). This instrument is a hemispherical reflectometer designed to measure near normal-hemispherical solar reflectance. This reflectometer is based on the principle that the diffuse-directional spectral reflectance of a surface is equal to its directional-hemispherical spectral reflectance [26]. In this way it is possible to indirectly measure near normal-hemispherical reflectance by illuminating a surface with diffuse light and sensing light reflected at near-normal incidence [27].

In the SSR, the diffuse light source is a white chamber illuminated by a tungsten lamp. The surface to be characterized is placed at a 2.5 cm diameter aperture in the chamber wall where it is shielded from the lamp by a baffle. Four separate detectors view light reflected from the surface through a shared collimating tube angled 20° from the surface's normal. The four detectors are named L1 (IR), L2 (Red), L3 (Blue), and L4 (UV), where each parenthetical description roughly locates the peak of the detector's spectral response [27,28].

Solar reflectance is thus measured in the wavelength range from 0.35 μm to 2.0 μm (from the Ultraviolet to Medium Infrared spectral regions).

The solar reflectance metric chosen by this instrument is the "AM1GH", acronym of Air Mass 1 Global Horizontal according to