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LAND SURFACE TEMPERATURE OF URBAN AREAS USING THERMAL REMOTE SENSING DATA: STATE OF THE ART, PROBLEMS AND PERSPECTIVES

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Abstract: *In the present study is attempted a comprehensive overview of the applications of land surface temperature (LST) as a parameter for analysis and evaluation in urban areas. Were examined state of the problem through a keyword search in the bibliographic database Scopus. Presented are various applications of thermal infrared remote sensing (TIR RS) data as a whole and in particular data on surface temperature in the urban environment. A brief overview of the most commonly used TIR RS sensors is made. Mentioned are some of the main problems and obstacles in the use of thermal remote sensing data in urban areas. Finally are presented the possibilities for future development of TIR RS.*

ТЕМПЕРАТУРА НА ЗЕМНАТА ПОВЪРХНОСТ В УРБАНИЗИРАНИ ТЕРИТОРИИ ЧРЕЗ ИЗПОЛЗВАНЕ НА ТЕРМАЛНИ ДИСТАНЦИОННИ ДАННИ: СЪСТОЯНИЕ НА ПРОБЛЕМА, ПРОБЛЕМИ И ПЕРСПЕКТИВИ

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Ключови думи: *Температура на земната повърхност, LST, Градски топлинни острови, UHI, SUHI, Термални дистанционни изследвания, TIR RS*

Резюме: *В настоящото проучване е направен опит за цялостен обзор на приложенията на температурата на земната повърхност, като параметър за анализ и оценка, в градски територии. Изследвани са състоянието на проблема посредством търсене по ключови думи в библиографската база данни Scopus. Представени са различни приложения на термалните данни от дистанционни изследвания като цяло и в частност на данните за температура на земната повърхност в градска среда. Направен е кратък обзор на най-често използваните термални сензори към момента. Споменати са някои от основните проблеми и препятствия при използването на термални данни от дистанционни изследвания в урбанизирани територии. В заключение са представени възможностите за бъдещото развитие на термалните дистанционни изследвания.*

Introduction

Remote sensors measures the temperature of surface, directly exposed to the satellite sensor's field of view. Land surface temperature (LST) is defined as a skin temperature of the surface (roofs, roads, trees, grass, water) (Qin and Karnieli, 1999; Klok et al, 2012). Therefore, main products of a thermal sensor observation are LST and sea surface temperature (SST). They are a base for further analysis in many different topics although thermal infrared (TIR) remote sensing (RS) is not as popular as other RS application areas (optical, microwave). In the Fuegosat Synthesis Study, a project funded by the European Space Agency (ESA), the TIR RS applications are classified in different topics and subtopics including 39 different applications (Sobrino et al, 2013).

LST have been widely used to analyze surface urban heat island (SUHI) which refers to the relative warmth of the surface, because the variable to be analyzed is the surface temperature, but not the air temperature (Voogt and Oke, 2003). LST is an important parameter used in many disciplines such as: climatology, including urban climatology, heat island and heat sink detection; hydrology, water temperature pattern, water mixing, freeze-thaw processes; agriculture, vegetation monitoring, volcano monitoring, geothermal analysis, fires and burned area detection, pipeline monitoring, soil moisture data, industrial areas observation (Zhan et al, 2013; Kuenzer et al, 2013).

Obtaining LSTs over extensive terrains was impractical until the advancement of satellite thermal sensors (Zhan et al, 2013). Today there are many different TIR sensors and although they have better spatial resolution, from earliest thermal satellite data (7-8 km per pixel), it does not meet the users requirements yet. Currently the highest spatial resolution of civilian RS satellites has Landsat's ETM+ sensor with 60 m in the thermal band. It is applicable for many different topics and though this is the most used data there is still a necessity of better spatial and temporal resolution.

Land surface temperature of urban areas: state of the art

Nowadays, a great attention has been paid to the thermal environment due to greenhouse effect and global warning. It not only refers to the air temperatures, but also the land surface temperatures (LSTs) (Zhang et al, 2006, Falahatkar et al, 2011). Human settlements and especially, large urban areas significantly modify the environment (Pongracz et al, 2010). The most documented and unquestioned urban climatic effect is the urban influence on the surface temperature exemplified by the urban heat island (Atwater, 1975). Urbanization process leads to two essential changes: the changes of materials that cover the earth's surface affecting the absorption of solar energy and the changes of the shapes of the earth's surface affecting the air flow (Omija, 1991).

Concerning privately the urban areas remotely sensed surface temperature is very useful for mapping and estimating surface heat islands (SHI), often named surface urban heat islands (SUHI), or urban heat islands (UHI). LST and emissivity data are used in urban areas mainly for analyzing LST patterns and its relationship with surface characteristics and for assessing urban heat island (UHI) (Quattrochi and Luvall, 1999; Weng, 2009). Other typical applications of retrieving LST over the cities are: vegetation mapping; Land Cover Land Use (LCLU) changes; building information including 3D mapping, energy leaks in buildings, cooling/heating degree day estimation; analyze the urbanization process; urban climatology (urban microclimate dynamic, urban surface-atmosphere exchange).

In our study we analyzed all the articles in the Scopus database that correspond to the following search criteria: "thermal remote sensing urban" AND "LST" OR "land surface temperature" (Fig. 1)

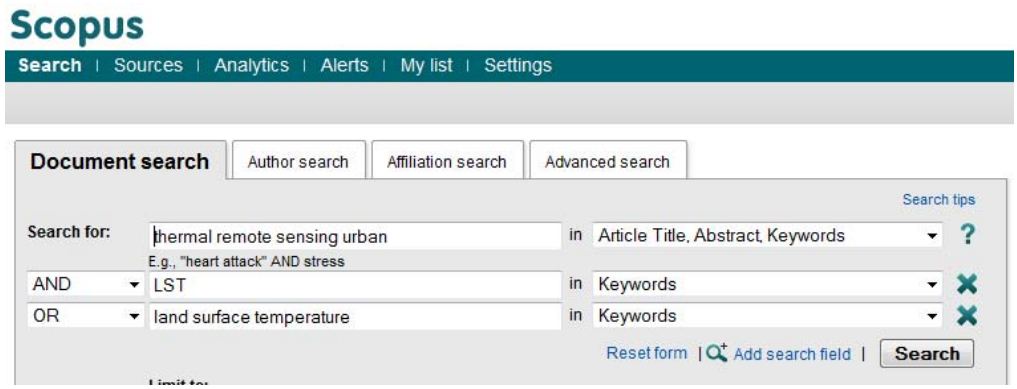

Fig. 1. Used search criteria in Scopus database

TIR RS research and applications have gained momentum in the last decade. And while in the earlier years of TIR RS investigations there have been several articles per year today they are several dozen every year. The LST trade line follows this represented from the TIR documents (Fig. 2)

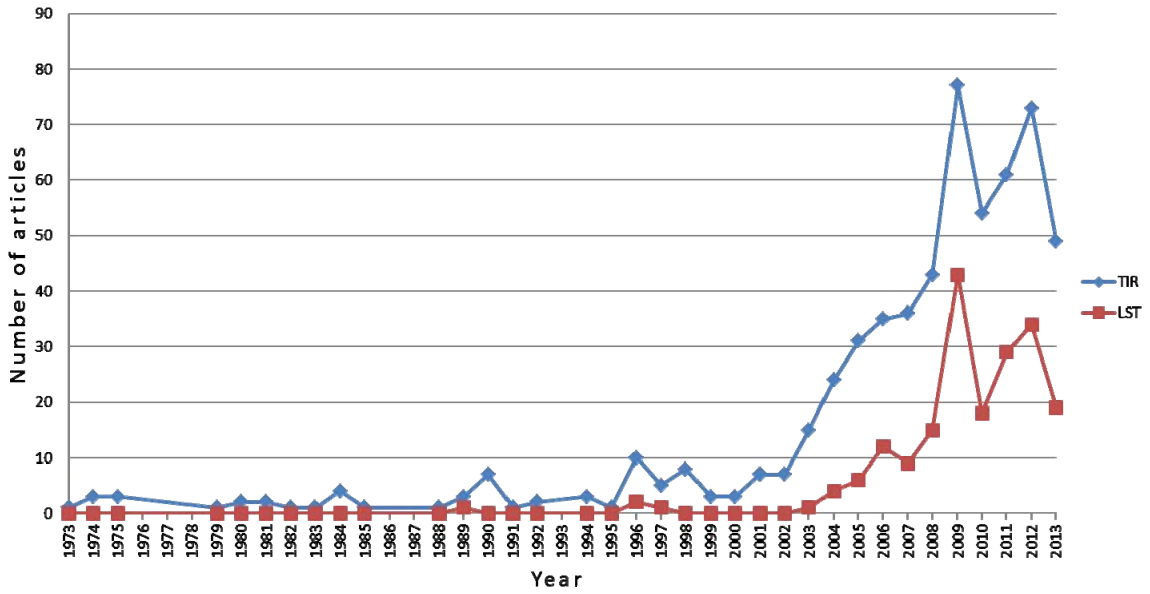

Fig. 2. Number of articles by year for LST and TIR

LST and UHI/SHI are the most investigated area in TIR RS of urban areas. In the Scopus citation database 55 % from the articles, related to the search phrase “Thermal remote sensing urban”, contain at least one of these words/phrases “LST, land surface temperature, UHI, urban heat island” in there keywords section. There are total of 194 documents related to the defined search. The majority of the documents relate to the UHI/SUHI including: 1) Mapping of LST and UHI; 2) Impact of urbanization/urban growth on the LST/UHI; 3) LU/LC changes; 4) Impact of one surface type (green areas, impervious surfaces) on the thermal environment

A few documents relate to LST retrieval methods plus downscaling LST data. There is also several “review” documents and few documents relating to LST dynamic. The total number of documents related to a given topic is represented in (Fig. 3)

LST applications	Number of documents
UHI/SUHI	87
LULC	68
LST retrieval	14
Vegetation maps	8
Landscape metrics	4
Air quality	2
Soil moisture	2
Growing degree day	1
Epidemiology	1
LST accuracy	1
Water management	1

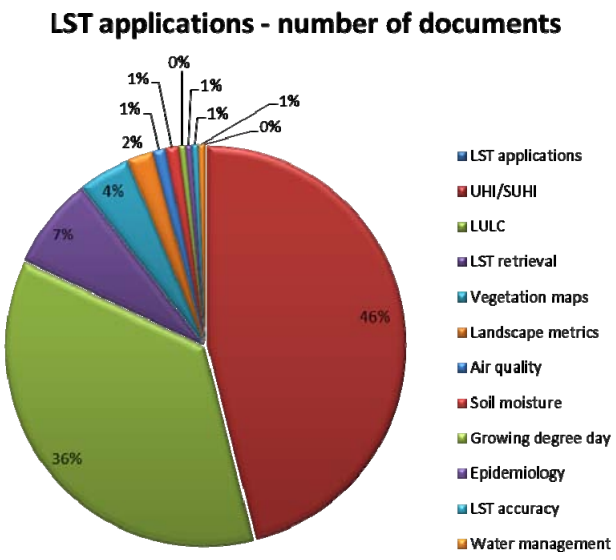

Fig. 3. Total number of documents related to a given topic

A large variety of instruments acquiring data in the TIR part of the electromagnetic spectrum exist. They vary from low spatial resolution (SR) (tens to one kilometer pixel) sensors with daily to hourly temporal resolution (MODIS, AVHRR) to medium SR sensors (~60 m) and with time revisit rates enabling only one to two observations per month (ETM+, ASTER). The most common sensors used for LST retrieval are presented on (Fig. 4). Data investigated by Kuenzer et al., (2013) based on remote sensing SCI journals from the past decade.

Sensor	SR	Revisit	Platform/Satellit	Agency
MSG-	1-3 km	<1 d	Meteosat-8, 9, 19	ESA/EUMETSAT
AVHRR	1.1 km	< d	NOAA	NOAA,
MODIS	1 km	4 per	TERRA, AQUA	NASA
AATSR	1 km	35 d	Envisat	ESA, UKSA
InfraredCam	300 m	31 d	HJ-1B	CRESDA, CAST,
MERSI MVISR IVISSR	250 m 1.1 km 5 km	1 d 3-4 d 1 d	FengYun	NRSCC, CAST, NSM, CMA
IRMSS	160 m	26 d	CBERS-2	CRESDA, INPE
TM	120 m	16 d	Landsat 5	USGS, NASA
ETM+	60 m	16 d	Landsat-7	USGS, NASA
ASTER	90 m	16 d	Terra	NASA

Fig. 4. Most common sensors used for LST retrieval (Kuenzer et al., 2013)

In the Scopus analyzed documents the most used sensors are these with the highest spatial resolution. Therefore, the Landsat's sensors are "the leader" followed by ASTER and MODIS. Of course it strongly depends on the scale of the study. For instance, for large scale investigations coarse spatial resolution is not an obstacle so the most used sensors here are MODIS and NOAA AVHRR. The following figure represents the TIR sensors used in the Scopus articles (Fig. 5)

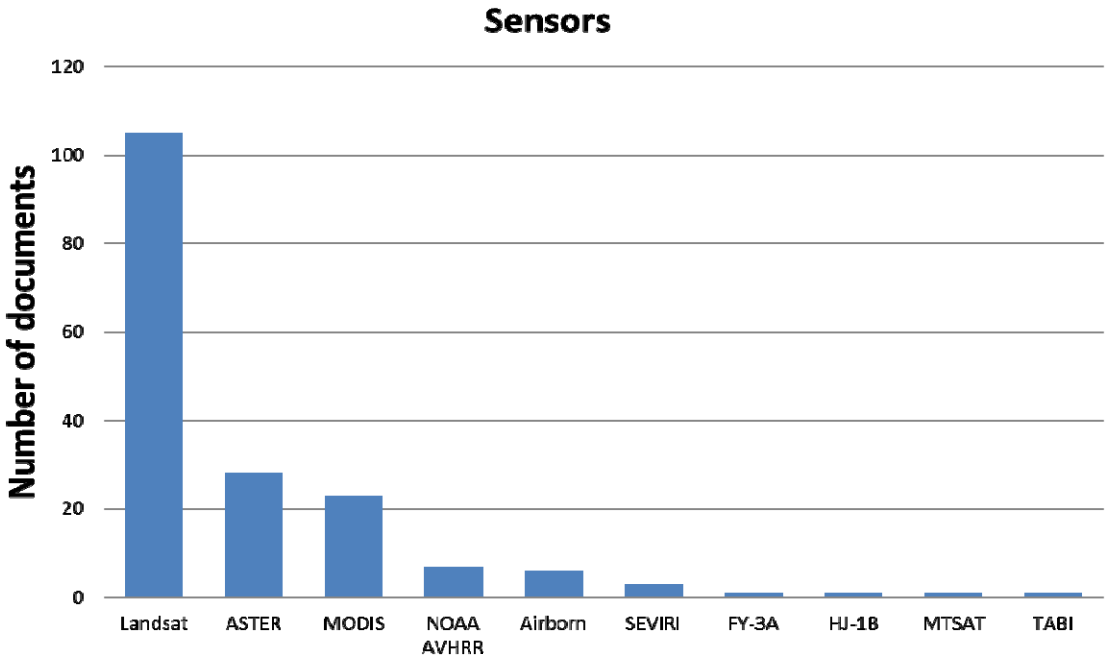

Fig. 5. The most used TIR sensors in the Scopus articles query

Problems

The main problem of TIR RS is the spatial resolution (SR). The TIR SR of currently operating civilian satellites is not high enough, especially when studying urban areas where the land cover is very variable. The lack of common SR leads to the use of different "downscaling" resolution algorithms (Zakšek and Oštir, 2012; Stathopoulou and Cartalis, 2009; Zhiwei et al. 2009, Cao et al. 2012).

The temporal resolution (TR) is another problem especially when it comes to study dynamic processes. It is difficult for example to investigate the diurnal LST dynamic in the cities. The TIR instruments with “high” SR take one to two observations per month. Generally, the better SR the worse TR and vice versa.

Another thing that we have to have in mind is urbane surface area and instantaneous field of view (IFOV). For retrieving LST in urban area we need a remote sensing instrument that “sees” the Earth surface in nadir. This is another limiting factor when we choose scenes for a particular study area.

Perspectives

Concerning spatial and temporal resolution of RS data, the TIR RS community needs a satellite mission with high SR and nearly daily revisit time. Currently there are several projects which are trying to meet the TIR users expectations. The MicroSatellite for Thermal Infrared Ground Surface Imaging (MISTIGRI) project is cooperation between France (CNES) and Spain (Univ. Valencia). It is currently completed Phase-A. TIREX (Thermal infrared explorer) is a proposal presented in a recent (2010) ESA’s call for Earth Explorer Opportunity Missions, although it was finally rejected for Phase-A (Sobrino et al., 2013). Both missions are expected to have spatial resolution approximately 50 m and revisit time 1 or 2 days. The Hyperspectral Infrared Imager (HyspIRI) mission is a work of NASA/JPL (Jet Propulsion Laboratory, California Institute of Technology) and it is going to produce TIR data with 60 m SR and 5 days revisit time. The mission is currently at the study stage.

Further research in the other fields of LST applications required. Aforementioned, TIR RS has large variety of applications but a very dense concentration in narrow range topics. This is a good perspective to combine the TIR building analysis, energy leaks in buildings, cooling/heating degree day estimation, with the possibilities of the newest 3D modeling products. Another niche for extensive research are the dynamic processes in the urban microclimate, especially LST dynamics.

In the sense of some of the disadvantages of currently available TIR RS data a good decision are Unmanned Aerial Vehicles (UAVs). They are very cost effective for small to medium scale projects, they have much better (compared to spaceborn and ground based observations) spatial resolution which depends on the flight height and the desired area can be investigated – also repeatedly - in a relatively short amount of time (Vasterling and Meyer, 2013). Also UAVs are capable to collect data from inaccessible and risk prone areas.

Conclusion

The TIR RS data, and LST parameter in particular, have a lot of applications in many different disciplines. Although the LST parameter is used mainly in heat islands studies as well as impact of urbanization on the LST and respectively on UHI, LU/LC changes, impact of one surface type on the thermal environment. With the advent of new technologies and wider use of UAVs, it is needed to address and develop new algorithms and technologies for studying LST dynamics, internal building thermal environment and energy losses, human comfort and health as a result of thermal pollution as well as the other application areas mentioned above.

In conclusion the observed increase of TIR RS investigations and articles will continue with a greater pace in the near future, due to the fact that TIR is a relatively new to RS and its application areas and scientific domains become more technologically and scientifically oriented in a climate of more and stronger links between the industry and academia.

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