MAPPING URBAN AREAS FROM SPACE CONFERENCE
4-5 November 2015 | ESA-Esrin | Frascati, Rome (Italy)

Mapping the Land Surface Temperature over Urban Areas from Space: a Downscaling Approach

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INTRODUCTION

The land surface temperature (LST) is a parameter widely considered in the urban area mapping from space. LST has been often retrieved and mapped to evaluate the surface urban heat island (SUHI) using different spaceborne platforms, such as AATSR, ASTER, MODIS and Landsat. But the satellite sensor spatial resolution may be a limiting factor in detailing the fine scale spatial variability in a urban texture, especially in the presence of impervious surfaces and sharp transitions (e.g., buildings, roads, parking lots, riverside, restricted vegetated zones). The growing demand of remote sensing maps with finer and finer spatial resolution to successfully monitor the SUHI effects at district level and to avoid temperature underestimation stimulates the development of downscaling techniques when the actual sensor measurements do not meet the spatial detail requirements. In this work we perform the downscaling of coarse resolution LST maps from MODIS and Landsat to finer resolutions with the aim to increase the information content of the original maps, using summer satellite images over Milan and Florence, Italy.

DOWNSCALING APPROACH

The downscaling is the enhancement of the spatial resolution of the original pixel data using ancillary information at higher spatial resolution. Different physical and statistical downscaling approaches have been proposed in literature: in this work, a statistical LST downscaling approach using different spectral indices (SI) over heterogeneous urban landscape is proposed. This analysis allows to select the spectral indices and their combinations providing the best results in the LST image sharpening. The technique fits a ordinary least-squares regression function between each index *SI(i)* (the predictors) and the LST (the predictand) derived from the satellite image at coarse resolution (subscript CR):

$$LST_{CR}=a_0+a_1\cdot SI(1)_{CR}+a_2\cdot SI(2)_{CR}\ldots+a_n\cdot SI(n)_{CR}$$

Then, each pixel within the finer resolution (FR) image is estimated by:

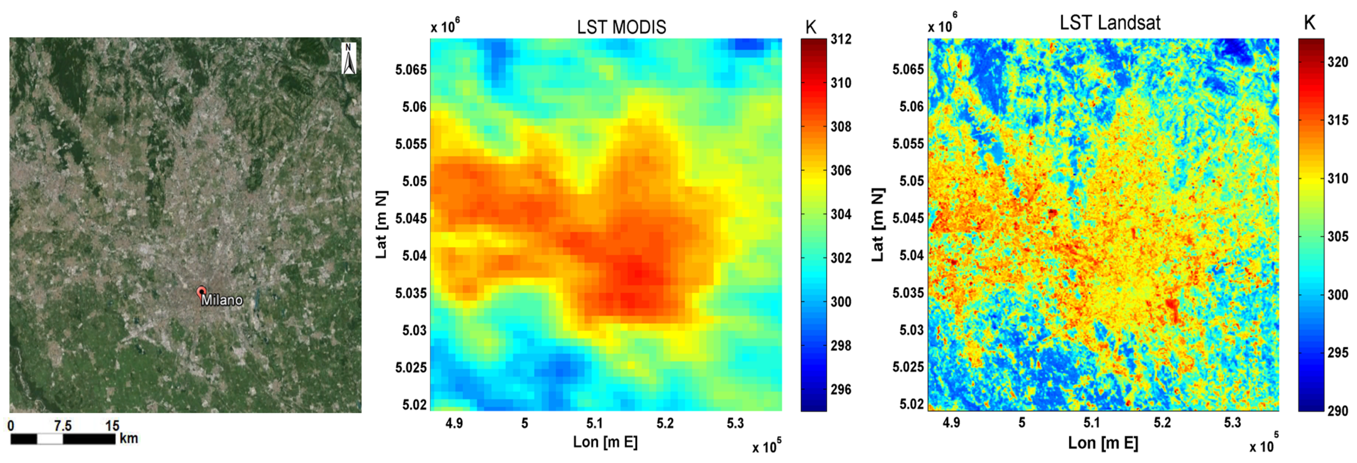
$$LST_{FR}=a_0+a_1\cdot SI(1)_{FR}+a_2\cdot SI(2)_{FR}\ldots+a_n\cdot SI(n)_{FR}+\Delta T_{CR}$$

where ΔT_{CR} is the difference between the model estimation (LST_{CR}) and the correspondent observed LST (LST_{REF}) [1]:

$$\Delta T_{CR}=LST_{REF}-LST_{CR}$$

DOWNSCALING OVER MILAN AREA

Processing of MODIS and Landsat 5 TM images acquired over Milan during summer passages.



Left: Study area (50 km x 50 km) around the Milan city centre (from Google Earth). Centre: LST [K] from MODIS, August 28, 2011, h.11:35, pixel 960 m. Right: LST [K] from Landsat, August 28, 2011, h.11:59, pixel 120 m. Lat/Lon are in UTM [m].

1) Downscaling using the Landsat TM data only (120 m spatial resolution image as reference). LST images at different resolutions were generated at growing pixel sizes (240 m, 480 m and 960 m) and the aggregated coarser resolution at 960 m was downscaled and validated.

RMS error for LST [K] between the downscaled image at the finer resolution 120 m, 240 m, 480 m and the reference one. In brackets the correlation coefficient (R) is reported.

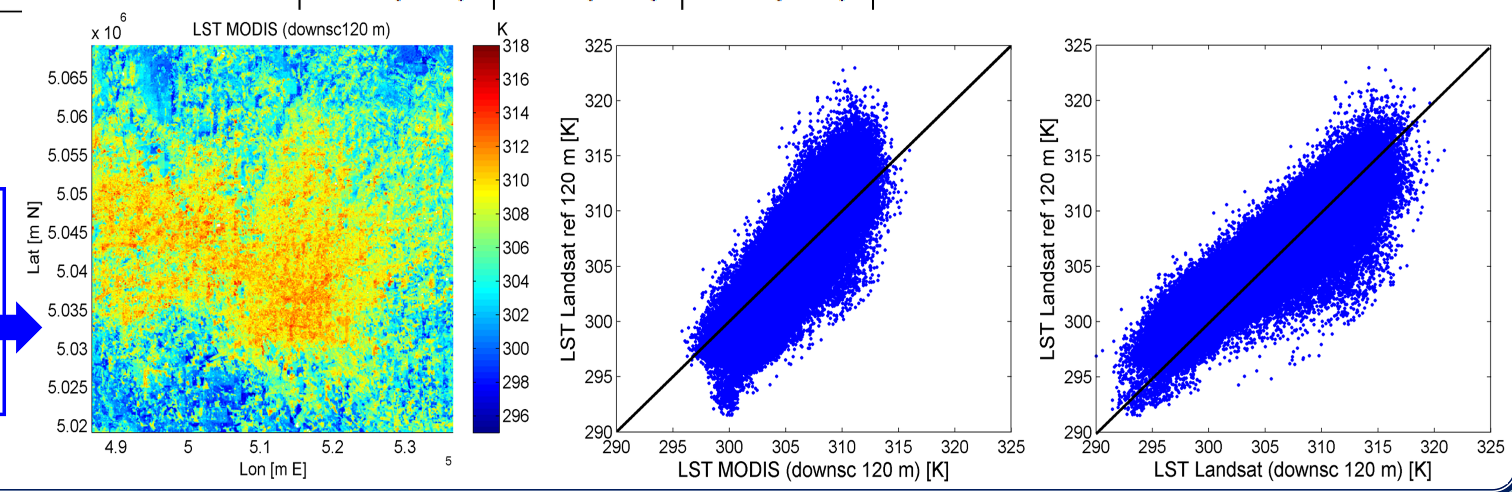
Regression	RMS K (R) 120 m	RMS K (R) 240 m	RMS K (R) 480 m
a+bNDBI+cNDVI^2	2.11 (0.92)	1.54 (0.95)	1.05 (0.97)
a+bNDBI+cNDVI^2+dBI^2	2.12 (0.92)	1.55 (0.95)	1.05 (0.97)
a+bGRVI+cNDBI+dBI^2+eNDVI^2	2.11 (0.92)	1.53 (0.95)	1.03 (0.97)

Acronym	Description	Formulation
NDVI	Normalized Difference Vegetation Index	$\frac{TM4-TM3}{TM4+TM3}$
GRVI	Green Ratio Vegetation Index	$\frac{TM4}{TM2}$
NDBI	Normalized Difference Built-up Index	$\frac{TM5-TM4}{TM5+TM4}$
BI	Bare soil Index	$\frac{(TM5+TM3)-(TM4+TM1)}{(TM5+TM3)+(TM4+TM1)}$

2) The same downscaling regressive schemes were applied on the contemporary coarse resolution LST MODIS image (960 m) and verified with the reference LST Landsat map.

Regression	RMS K (R) 120 m	RMS K (R) 240 m	RMS K (R) 480 m
a+bNDBI+cNDVI^2	2.55 (0.88)	2.38 (0.89)	2.15 (0.90)
a+bBI+cNDVI^2	2.55 (0.88)	2.38 (0.89)	2.15 (0.90)

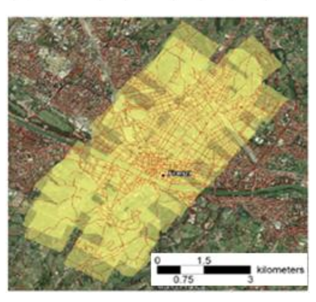
Left: LST [K] map from MODIS downscaled at 120 m by transfer function a+bNDBI+cNDVI^2. Centre: LST [K] from MODIS downscaled at 120 m and comparison with the reference Landsat image at 120 m. Right: LST [K] from Landsat downscaled at 120 m by transfer function a+bNDBI+cNDVI^2 and comparison with the reference Landsat image at 120 m



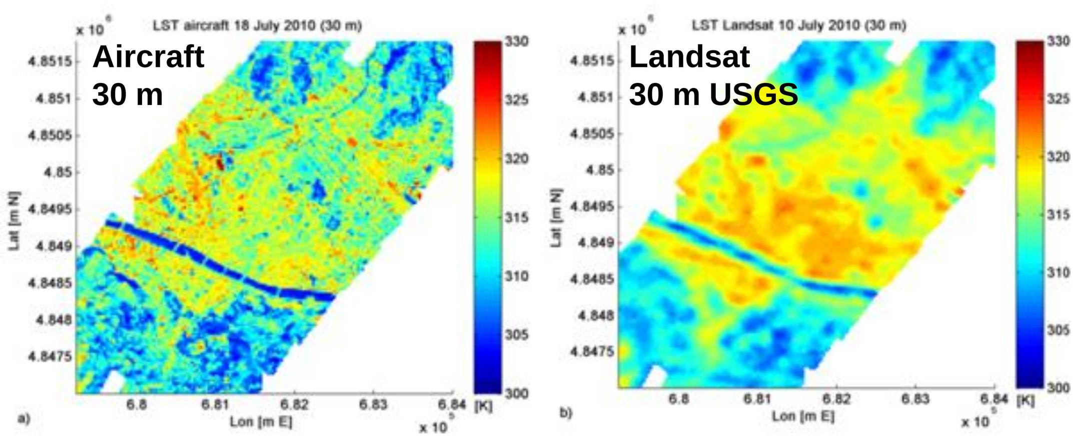
DOWNSCALING OVER FLORENCE AREA

LST retrieval from Landsat 5 TM over Florence, Italy, and comparison with a high-resolution (1 m) thermal image provided by an airborne survey carried out on July 18, 2010.

The yellow zone is the area covered by the aircraft flight (6 km x 2.5 km)



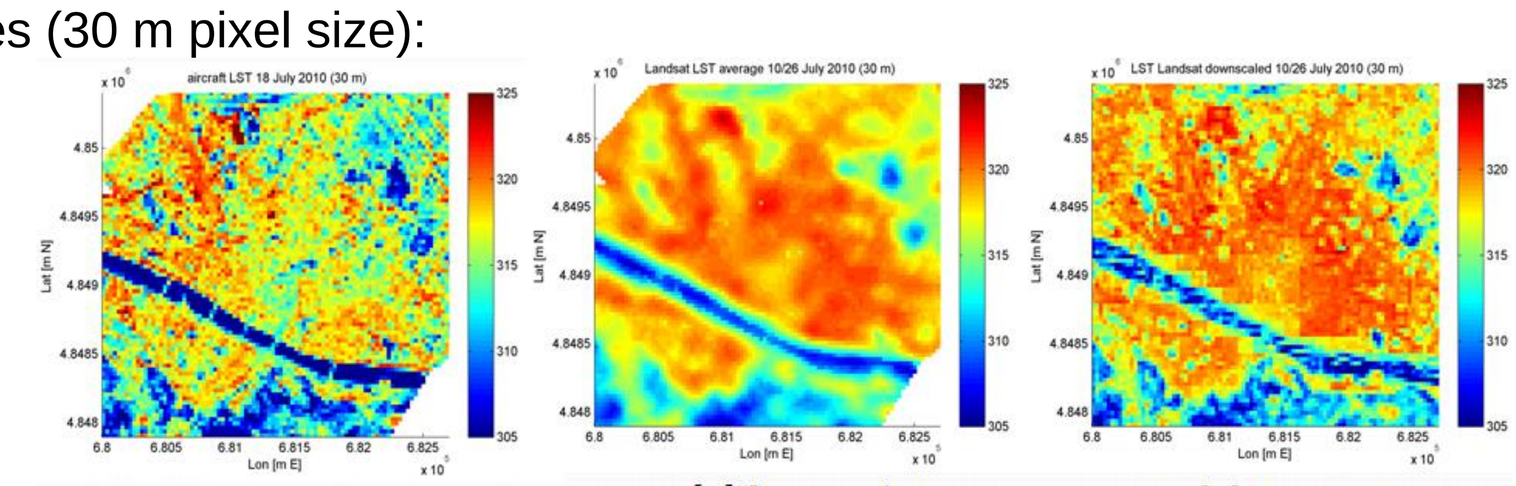
Landsat thermal channel has a native 120 m spatial resolution also delivered at 30 m, resampled with a cubic convolution, by the US Geological Survey (USGS) Center



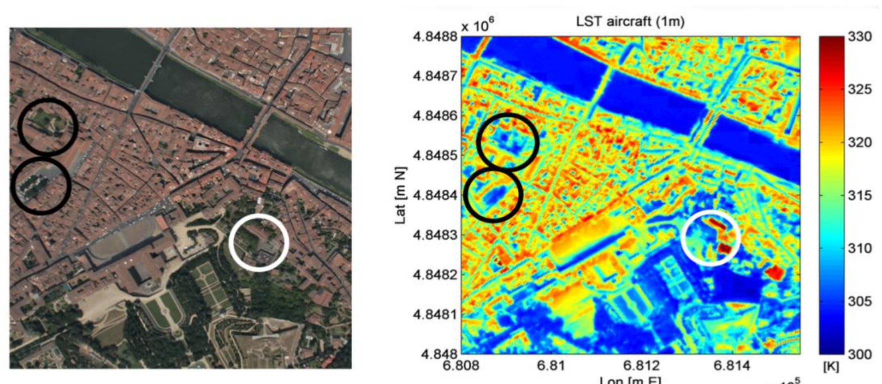
Evaluation of the impact of the Landsat TM thermal channel resolution (120 m) on the LST urban mapping applying a downscaling at 30 m with a statistical algorithm using a regression on different spectral indices.
The best performance was obtained by:

$$LST_{30}=a_0+a_1\cdot NDVI+a_2\cdot NDBI+a_3\cdot NDBI^2+\Delta T_{120}$$

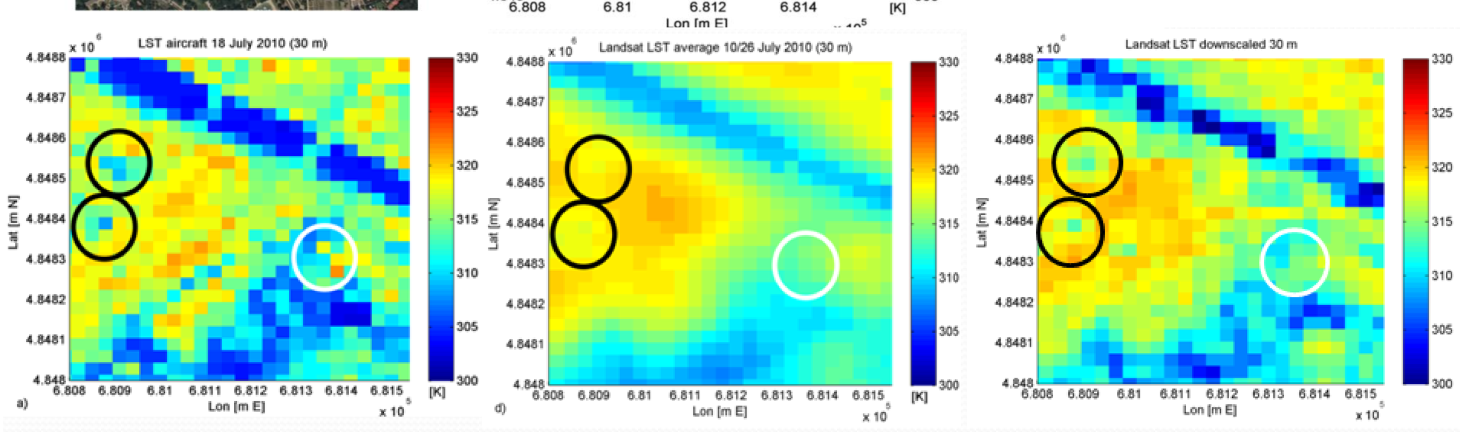
Comparison among airborne, Landsat USGS and Landsat downscaled images (30 m pixel size):



LST [K] from airborne data with 30 m averaged pixels | LST [K] from Landsat resampled by USGS at 30 m | LST [K] from Landsat downscaled at 30 m



Sub-area (750 x 800 m). *Left*: visible image from the aircraft. *Right*: LST from airborne thermal data with 1 m resolution:
– white circle: strong heating of a roof among the vegetation
– black circles: vegetated/shadowed cold zones among the built-up area



LST [K] from airborne data with 30 m averaged pixels | LST [K] from Landsat resampled by USGS at 30 m | LST [K] from Landsat downscaled at 30 m

[1] W. P. Kustas, J. M. Norman, M. C. Anderson, and A. N. French, "Estimating subpixel surface temperatures and energy fluxes from the vegetation index-radiometric temperature relationship," *Remote Sens. Environ.*, vol. 85, no. 4, pp. 429–440, 2003