ANALYSIS OF THE THERMAL AND DEFORMATIVE SUPERFICIAL FIELDS OVER SOUTHERN ITALY VIA THE EXPLOITATION OF LONG-TERM MODIS LST AND SAR DATA TIME SERIES

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ABSTRACT

Along the coast of the Tyrrhenian Sea there is an Italian region, extending from Tuscany to Campania, characterised by significant geothermal gradients and volcanic activity. In the framework of the 'Geothermal Atlas' project funded by the National Research Council, CNR-IREA used 2002-2010 time series of Land Surface Temperature (LST) from NASA-MODIS to identify thermal anomalies, and SAR data from ESA ENVISAT sensor to apply the SBAS-DInSAR approach to map ground deformation field. Although the presented results are preliminary, they show on one side that land surface temperature can vary significantly with time, land cover and topography, and on the other side that the detected deforming areas are located in correspondence of the regions characterized by anomalous values of heat flow.

INTRODUCTION

The geothermal energy is a form of thermal energy released and stored in the Earth; it propagates through the rocks and the fractures reaching the Earth surface. Although geothermal energy is generally dispersed, it can be found concentrated in some region where geological conditions are favourable (local thermal anomalies). In Italy, the Apennines separate the peninsula into two regions with very different geothermal capacity of which the western one, running from Tuscany to Campania along the Tyrrhenian Sea, is characterised by a high geothermal and volcanic activities.

The project 'Geothermal Atlas' funded by the Italian National research Council (CNR) aims to evaluate over Southern Italy the geothermal potential and, in particular, over a study area in the Campania region. Accordingly, we acquired and processed both optical and radar data to characterize land surface temperature (LST) and deformative superficial field, both over time and space.

In particular, we used MODIS (Moderate Resolution Imaging Spectroradiometer) time series between 2002 and 2010 to analyse intra- and inter-annual variability of LST and the influence of both the land cover and topography. We found very few works in the literature concerning this topic and they are mainly focus an areas of tectonic and/or volcanic activity[1,2]. Our work can contribute to the 'Geothermal Atlas' project by providing information on surface thermal fields at the regional scale, which can be carried out only with satellite data[3].

In the same time interval, we acquired ESA (European Space Agency) ENVISAT SAR data to detect ground deformation and follow their temporal evolution, by generating mean deformation velocity maps and corresponding time series at low spatial resolution scale (100m x 100m) via the Small BAseline Subset (SBAS) technique[4]. Results provide significant information for the characterization of the dynamics of the study region and they are in good agreement with the heat flow distribution map of the Italian territory[5,6], thus suggesting that the thermo-rheological conditions of the upper crust have an active role within the driving forces that control the observed dynamics.

DATA AND METHODS

Multi-temporal analysis of the MOD11A2 product

We used the NASA-MODIS MOD11A2 product which provides estimates of day (10.30 am) and night (10.30 pm) LST, emissivity and Quality Control (QC) flags at 1km spatial resolution every 8 days. LST values are retrieved based on the *Split Window* algorithm[7]; more details on the algorithm can be found in the *Collection-5 MODIS Land Surface Temperature Products, Users' Guide* (https://lpdaac.usgs.gov/products/modis_products_table). Data available over tile h19v04 (1100 km x 1100 km) were downloaded from the USGS Glovis web site (http://glovis.usgs.gov/) to total 457 files over the period 2002 to 2010. HDF (Hierarchical Data Format) files of 8-day LST were stacked for each year and a subset over the study area (Fig. 1) was extracted from tile h19v04. Spatial and temporal syntheses in order to describe LST intra- and inter-annual variability.

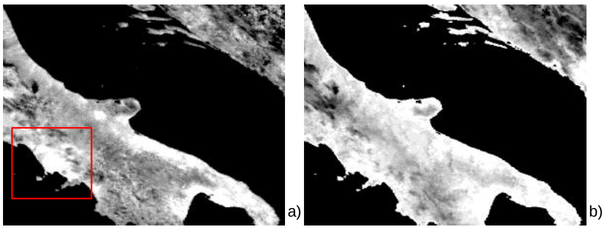

Figure 1: Examples of day (a) and night (b) LST over the study area (red rectangle) from the MOD11A2 product in sinusoidal projection. Digital Numbers (DNs) are shown as grey shades from black (0-no data) to white.

We downloaded the UMD (University of Maryland) land cover (LC) map from the MODIS MCD12Q1 product that provides LC distribution at 1 km spatial resolution (Table 1). The UMD LC map was used for masking (i.e. water) and for analysing LST for different cover classes. Finally, we used a Digital Elevation Model (DEM) (1 km Globe DEM, http://www.ngdc.noaa.gov/mgg/topo/globe.html) to quantify the relationship between LST and elevation with a regression analysis. Before applying the regression analysis, the MODIS product has been re-projected to geographic coordinates, WGS84.

Table 1: Classes of the UMD LC map (MODIS MCD12Q1 product) at 1 km resolution.

Class code	Class name	Class code	Class name
0	Water	7	Open shrublands
1	Evergreen needleaf forest	8	Woody savannas
2	Evergreen broadleaf forest	9	Savannas
3	Deciduous needleleaf forest	10	Grasslands
4	Deciduous broadleaf forest	12	Croplands
5	Mixed forest	13	Urban and built-up
6	Closed shrublands	16	Barren or sparsely vegetated

Deformation time series generation from SAR data

We focused on the basic Small BAseline Subset (SBAS) approach[4], a well-established DInSAR (Differential Synthetic Aperture Radar Interferometry) technique that has been originally developed to investigate large spatial scale displacements (100km x 100km) with low resolution (100m x 100m) by using low-pass filtered (multilook) DInSAR interferograms. In particular, the SBAS technique relies on the use of interferograms characterized by "small" spatial and temporal separation (baseline) between the acquisition orbits, and provides an estimate of the radar line of sight (LOS) projection of the occurred displacements. The SBAS approach allows to produce mean deformation velocity maps and deformation time series for each coherent pixel of the investigated area (i.e., for each pixel whose phase measurement is considered reliable) with an accuracy of about 1-2 mm/year and 5-10 mm, respectively[8]. In this work we exploited a set of 60 SAR data (track 36, frame 2781) acquired by the ENVISAT satellite from descending tracks, spanning the 2002 – 2010 time interval. Starting from this data-set we selected 178 interferograms (with perpendicular and temporal baseline values smaller than 400 m and 4 years, respectively) that we inverted via the SBAS-DInSAR approach.

RESULTS

LST from MODIS data

Figure 2 shows three example profiles of 8-day MODIS day and night LST [K] for different classes of the UMD LC map. Profiles show both the inter- and intra-annual seasonality of LST. The yearly cycle is due to changes in solar radiation whereas changes from year to year are the response to climatic variability. As an example, 2003 shows the highest values although differences among the land covers can be appreciated: the mixed forest class (green line) shows a lower increase from previous years probably due to a greater thermal inertia of the vegetation compared to agricultural lands and urban areas. A different behaviour is observed for the night-time LST where the three land cover classes are characterised by a narrower range of variability. The contribution of the land cover is therefore an important factor to take into account when looking for surface thermal anomalies.

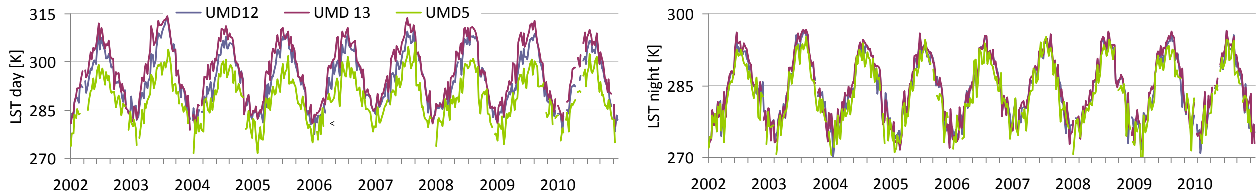

Figure 2: Profiles of 8-day MODIS LST (day and night) [K] over the period 2002-2010 in correspondence of area of 3x3 pixels over three land cover classes (UMD12: agricultural lands, UMD13: urban and built up, UMD5: mixed forest).

The monthly average daytime LST is shown in Figures 3 where also the spatial variability can be observed. Since land cover and topography are two factors that can influence LST spatial distribution, we analysed the relationship between average monthly day-time and night-time LST and elevation (Table 2) and the land cover classes (Fig. 4).

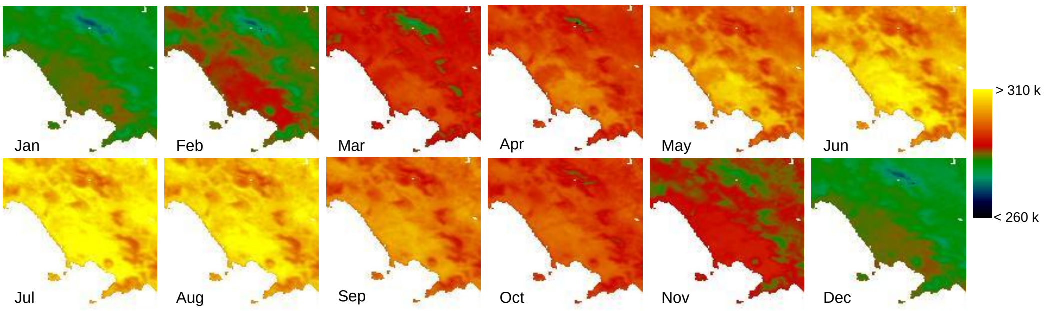

Figure 3: Monthly average daytime LST over the study area in southern Italy as derived from the 2002-2010 time series of the MOD11A2 product.

Results highlight that i) there is a significant linear relationship between topography and surface temperature, ii) correlation is higher during winter months in the case of day-time LST, the opposite occurs in the case of night-time LST and iii) the range of r values is narrower for night-time LST.

Table 2: The Pearson r correlation coefficient derived by regressing pixel by pixel average day-time and night-time MODIS LST against elevation [m asl] given by the Globe DEM.

Month	Day-time r	Night-time r	Month	Day-time r	Night-time r
January	-0.92	-0.81	July	-0.69	-0.90
February	-0.94	-0.86	August	-0.70	-0.91
March	-0.86	-0.89	September	-0.79	-0.90
April	-0.78	-0.89	October	-0.82	-0.84
May	-0.78	-0.89	November	-0.90	-0.82
June	-0.77	-0.90	December	-0.92	-0.81

Finally, box plot graphs shown in Figure 4 highlight that i) winter months are characterised by a narrower range for both day-time and night-time LST across all land covers, ii) some of the land cover classes can be grouped together with respect to the range of variability of LST and iii) outliers could point at locations where LST is different than the expected LST given the land cover characteristics.

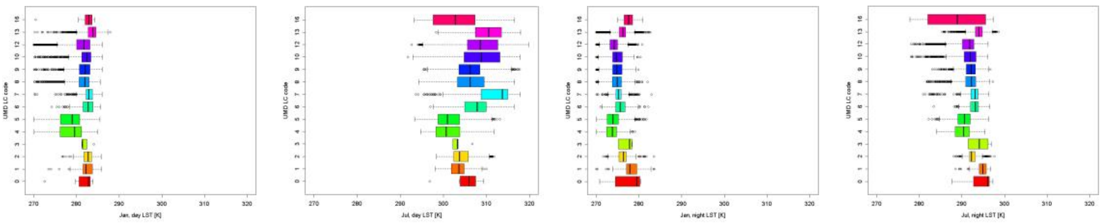

Figure 4: Box plots of the example average monthly day and night LST across the UMD land cover classes (on the y-axis, see Table 1).

Deformation time series from ENVISAT data

Figure 5a shows the estimated LOS mean deformation velocity, geocoded and superimposed on an optical image of the area. Note that the velocity map has been computed with respect to a reference pixel located in the zone of the Napoli Harbor (pixel marked as RF in Figure 5a); moreover, the noisy areas (non-coherent zones) with low accuracy measurements have been excluded. We observe that significant LOS displacements are visible on several coherent areas which can be easily identified: the Campi Flegrei caldera, various deforming zones within the city of Napoli, other displacements occurring on the top and around the base of the Vesuvio Volcano as well as in the Ischia Island and in the areas of Mondragone and Volturno Plain.

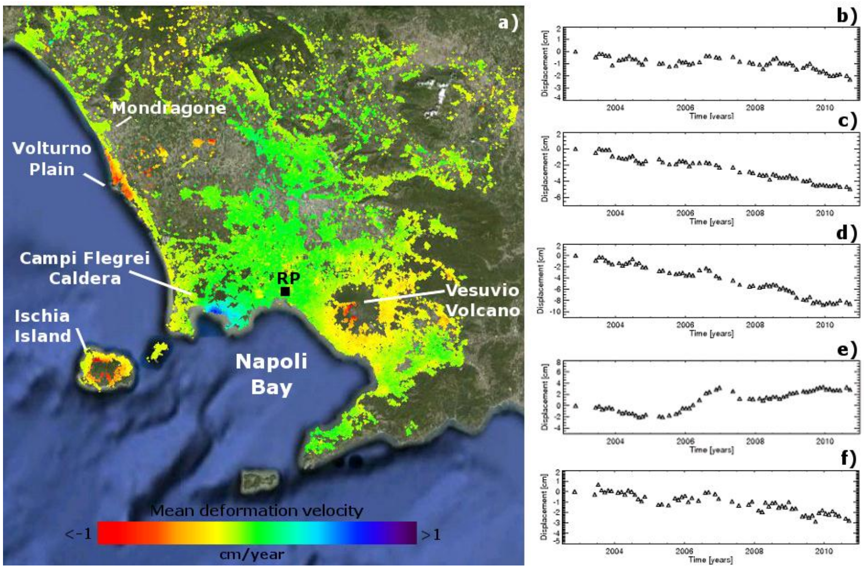

Figure 5: (a) LOS mean deformation velocity map, geocoded and superimposed on an optical image. Red and blue colours correspond to an increase and decrease of the sensor-target distance, respectively; the reference pixel for all the DInSAR measurements (RP) is identified by the black square. (b-f) Deformation time series for five pixels identified as Mondragone (b), Volturno Plain (c), Ischia Island (d), Campi Flegrei caldera (e) and Vesuvio Volcano (f).

Figures 5b-f show the displacement time series (computed with respect to the RF pixel) of five coherent pixels relevant to Mondragone, Volturno River, Ischia Island, Campi Flegrei caldera and Vesuvio Volcano, respectively. The deformation time series provide crucial information to study the temporal evolution of the retrieved displacements. . In the following we report some comments on the five identified zones for which displacement time series are shown.

The Mondragone area, located in the North-Western sector of Campanian Plain, is characterized by a well spatial correlated subsidence pattern (see Figures 5a and 5b) that is related to the terrigene sediment compaction process. This behaviour is more evident along and in the delta region of Volturno River (Figure 5c), where velocity values of about 0.6 cm/year are measured. In particular, the detected subsidence velocity values are similar to the ones computed in the Campanian Plain via geo-morphological approaches.

The Ischia Island represents the emerged part of a volcanic complex. As revealed by the displacement time series of the coherent pixels of the area (see Figures 5a and 5d), the volcano is characterized by a linear subsidence trend with a maximum LOS velocity value of about 1.4 cm/year; this behaviour is influenced by tectonic and volcano-tectonic structures as well as by hydrothermal processes[9].

The Campi Flegrei is a resurgent caldera that has experienced in the last twenty years a substantial long-term subsidence process, which followed the 1982-1984 unrest phenomenon. The SBAS-DInSAR analysis shows the very complex deformation behaviour of the caldera during the 2002-2010 time interval. In particular, deformation time series show (Figure 5e) that: (i) the 2002-2005 period is characterized by a residual subsidence after the 1982-1984 unrest phenomenon; (ii) the 2005-2010 time interval reveals a new phase of background slow rate uplift which begins with a small crisis episode in 2006-2007. Results suggest that the caldera stress release post 1982-1984 unrest episode has extinguished and a new phase of accumulation stress has begun as also witnessed by a renewed seismic activity.

The Somma-Vesuvio volcanic complex shows a general subsidence pattern (Figure 5f), whose spatial distribution is not bounded by the Somma caldera structures (Figure 5a). Mean velocity values range from 0.6 cm/year in the summit area to zero along the coast. Moreover, a further subsidence pattern is clearly visible in the volcanic apron region in the Northern-North-Western sector of the volcano. These two subsidence patterns have different origins: the first one is associated to the active gravity-driven tectonic phenomenon as the spreading process of the volcanic edifice beneath the ductile sediment basement[10]; the latter is the effect of the regional subsidence of Campanian Plain related to the extensional processes that govern the tectonic dislocation of Mesozoic structures of the area (Campanian Apennines).

CONCLUSIONS

In this work we present preliminary results of the use of time series (2002-2010) of optical and radar data for the analysis of the thermal (LST) and deformative fields over the Campania Region (Southern Italy). The MODIS LST product highlighted the spatial and temporal variability of the surface temperature also as a function of topography and the land cover distribution. Since these results are very preliminary, future research will further investigate this topic by using vegetation indices as a proxy of vegetation seasonality and conditions. The ENVISAT SAR data analysis revealed the presence of a number of deforming areas and provided significant information to characterize their dynamic in both space and time.

Moreover, all the studied areas, according to the heat flow distribution map of the Italian territory[5,6], are characterized by anomalous values of heat flow that range from 200 mW/sqm (4 HFU) for the Ischia-Campi Flegrei district to 70-80 mW/sqm (2 HFU) for the areas of Vesuvio Volcano and Volturno plain. The SBAS-DInSAR analysis reveals that all these areas are characterized by active ground deformation processes. Accordingly, we hypothesize an active role of thermo-rheological conditions of the upper crust within the driving forces which control the observed dynamics.

ACKNOWLEDGEMENTS

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