1st International Conference on
Metrology for Archaeology
Benevento, Italy, October 22-23, 2015

Combination of Landsat 8 and Sentinel 1 data for the characterization of a site of interest. A Case Study: the Royal Palace of Caserta

M. Focareta[1], S. Marcuccio[2], C. Votto[2], S.L. Ullo[3]

[1]*Mediterranean Agency for Remote Sensing and Environmental Control (MARSec), via Perlingieri 1, I-82100 Benevento, marianofocareta@gmail.com*
[2]*Università di Pisa, Engineering Department,via Girolamo Caruso 8, I-56122 Pisa, salvo.marcuccio@unipi.it, claudio.votto@gmail.com*
[3]*Università degli Studi del Sannio, Engineering Department, Piazza Roma 21, I-82100 Benevento, ullo@unisannio.it*

Abstract – **In this paper a very recent application of remote sensing techniques to the investigation of archeological sites is discussed. In the last two decades non-invasive techniques have been preferred to old and less modern operations like excavations and corings that have appeared to be risky, expensive, too invasive and very time-consuming. At this end, objective of this paper is to present new added-value tools by the integration of different satellite platforms: data from NASA Landsat-8 and ESA Sentinel-1 have been used and combined. Since the two systems are very different, their data combination provides useful and interesting results. Data from optical/multispectral sensors and data from SAR are processed and integrated to monitor and identify not only the cultural heritage monuments but also the surrounding vegetation, and the green areas and parks inside. Satellite images can put in evidence boundaries modifications, vegetation state, their degradation, and other phenomena, such as changes in the territories due both to natural and to anthropogenic causes. The Royal Palace of Caserta has been chosen as case study: the site in fact by presenting besides the central building a huge extension of parks and fountains has appeared to be suitable to our aims.**

I. INTRODUCTION

In the past, capturing images of our planet Earth from space has fascinated people, and it still does. In these days images of the earth are continuously detected and acquired and scientific communities use them to better understand and improve the management of the land itself and its environment [1]. These images allow us to see the world through a wide frame, to witness large scale phenomena, with an accuracy and completeness that human efforts on the ground could barely reach [2]. This becomes extremely beneficial for acquiring data in the world of areas too remote or otherwise inaccessible. The applications range in a wide circle of study subjects, such as geology (i.e. topography or production of DEMs, Digital Elevation Models of the terrains), agriculture (i.e. classification of crops, soil moisture), forestry (i.e. tree biomass, height, species, plantation, deforestation, or forest monitoring and fire detection), cities (i.e. urban structure and density, control for the detection of unauthorized urban construction), natural disaster management (i.e. earthquake monitoring, identification of landslides, damage monitoring and classification), oceanography (i.e. waves, wind, ship detection), man-caused disasters management (oil spills and monitoring of patches), to name a few [3]. In very recent years scientists have realized how remote sensing can find a new application by providing accurate, inexpensive, and timely information related to artistic heritage, either natural (parks, landscapes, etc.) or cultural (monuments, archaeological sites, and so on) [4]. The action of man, pollution, corrosion due to rain, cold, harsh weather conditions, solar radiation and thermal stress, can damage the artistic heritage. In addition, operations like excavations and corings have appeared to be risky, expensive and invasive techniques. On the other side, remote sensing techniques present many advantages: a global vision of the artistic and cultural sites, included the surrounding area; a periodic monitoring of the events, with quite fast intervention in case anomalies or dangers are detected; the identification of certain sites in the world, that present special characteristics such that they can be classified and associated, for instance, as part of World Heritage; besides the possibility to locate buried, not yet excavated sites. Another consideration is that environmental changes and their actions are very slow and the resulting damages appear only after a very long time. Remote sensing can help also in this sense, because of its ability to discriminate even small changes. We underline in this work the peculiarity of remote sensing to provide information not only on the cultural heritage but also on the surrounding vegetation or parks inside. This aspect is more recent, because more extensive research has been performed in the field of artefacts and manufacts, less instead in the field of archeological parks and green areas related to them.

At this end, objective of this paper is to present new added-value tools by the integration of different satellite platforms: data from NASA Landsat-8 and ESA Sentinel-1 have been used, combined and compared.
The paper is organized as follows: in the Section II Landsat-8 and Sentinel-1 main characteristics are presented and some anticipations on our work given; in the Section III characteristics of Landsat-8 and Sentinel-1 selected data are discussed for the area of interest; in the Section IV first results are provided; different Landsat-8 data bands are combined and Sentinel-1 signals processed; in the last Section, NDVI and CTest1 are compared and some conclusions derived.

II. LANDSAT 8 AND SENTINEL 1

A. *Landsat 8*

The Landsat-8 (official name LDCM - Landsat Data Continuity Mission) is the last of the historic Landsat series designed by NASA, one of the first missions of Earth observation and by far the most long-lived with decades of experience from the first satellite in 1972. Launched in February 2013, just a month later the satellite became operational providing shots with a time of 16 days. The improved image quality, compared to the previous Landsat-7, the introduction of new spectral channels and the availability of constant acquisitions make Landsat-8 a useful tool for monitoring and analysing the territory. It mounts aboard the optical sensor OLI (Operational Land Imager) and the thermal sensor TIRS (Thermal InfraRed Sensor). Thanks to their different spectral bands (11 in total) and their characteristics, it's possible to get satellite maps consolidated as Real Color Maps, Infrared Maps, Change Detection, Vegetation Indexes, Multiband Fusion with the Panchromatic channel. In addition with the availability of two new bands of the thermal sensor it is possible to obtain maps of temperature with limited noise pollution and production of maps of gravity on land routes from fires. Moreover, the IR (infrared) band 9 allows clouds monitoring in the atmospheric field, while the new Deep Blue band (Band 1) is ideal for the study of coastal zones and phenomena related to aerosol pollution. The mission Landsat-8 is guaranteed up to 2018 and beyond, thus ensuring stability and comparison in analysis for many decades, with the coaching in the coming years of comparable ESA Sentinel missions. More detailed information can be found at [5].

B. *Sentinel 1*

Sentinel-1 constitutes the first series of operational satellites responding to the Earth Observation needs of the EU-ESA Global Monitoring for Environment and Security (GMES) programme. Its design has been driven by the need for continuity of ERS/Envisat class data provision ([6], [7], [8]). The two-satellite Sentinel-1 constellation carries on a Synthetic Aperture Radar (SAR) instrument at C-band and has been designed to address medium and high resolution applications. The SAR operates at a center frequency of 5.405 GHz and has the ability to scan the area with double polarization, that is with support for HH-HV and VV-VH simultaneous co- and cross-polarization receive channels. Sentinel-1A was expected to be launched in 2013 and its sister Sentinel-1B 18 months later. Actually, the launch of the first satellite, Sentinel-1A, happened on 3rd of April 2014 and the launch for the second is scheduled by 2016. Four operational modes are supported in terms of resolution and swath width: Strip Map mode (SMM); Interferometric Wide Swath (IWS); Extra-Wide Swath Mode (EWSM) and Wave-Mode (WM). See ([9], [10], [11]) for more details.

A Sentinel-1 toolbox is distributed with free license by ESA and available at [10]. In the Figure 1 a Window of

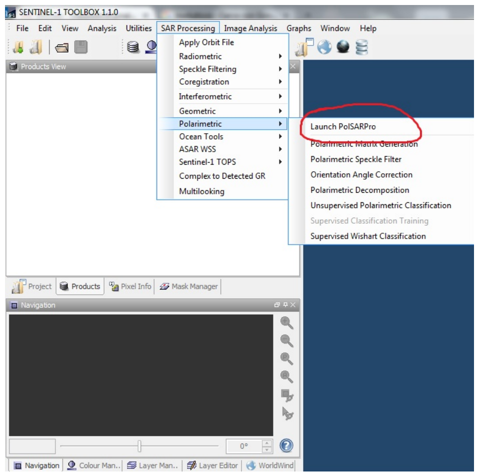

Fig. 1. A window of Sentinel-1 toolbox - version 1.1.0

Sentinel-1 toolbox is shown, with the different processing that can be launched, as an example. In particular, for the polarimetric elaboration the available PolSARPro package has been used. It is a universal program for the management of satellite SAR data, a valuable tool used for any satellite platform. The drawback is that it has many modules and their functionality is wide. Therefore the analysis and processing of the Sentinel-1 SAR data has been a daunting task to get to know all products this software could generate. Another issue has been that SAR data in order to be compared with other data need to be georeferenced. In effect, both the Sentinel-1 toolbox and the PolSARPro software have the georeferencing function. The problem with PolSARPro was that by dealing only with bursts couldn't process the whole image. Therefore we made the necessary coordinate transformation through a specific QGIS program module. After that, a classification algorithm was used. There are some algorithms for SAR images classification. We used the Unsupervised Wishart classification, provided by PolSARPro. More precisely on the basis of a SAR image, we generated a Wishart Supervised classification after an automatic pre-setting with a Wishart Unsupervised.

III. AREA OF INTEREST AND SELECTED DATA

The chosen test site was the province of Caserta and included the city of Caserta and the surrounding area for an extension of about 300 square kilometers. The site has been selected by taking into account a number of particular characteristics that could favor the process of combination between SAR and optical/multispectral data. In particular, we found a little accentuated morphology that could facilitate the observations within the SAR scope, well-defined alternating between urban and predominantly agricultural areas, mountainous areas distinguishable as the different ground covers. These conditions typical of some areas of the Apennines can be optimal for defining parameters and methods of analysis that can then be extended to other areas of interest. Given the wide coverage area of single acquisitions by Landsat-8 and Sentinel-1 satellites, a single (90×20)Km-size Burst has been selected for the Sentinel-1, the Burst n.9 of the second Swath, and the corresponding area chosen from Landsat-8 image. The covered area is still broad enough to encompass various types of territory: mountain, hilly, urbanized areas, cultivated fields, hedges and wooded grasslands.

To conduct our study we have used Landsat-8 data downloaded from [12] and Sentinel-1 data downloaded from [13] after registration.

In Table 1 all the characteristics for the selected data are summarized.

Table 1. Characteristics for Landsat8 and Sentinel 1

Characteristic	Landsat 8	Sentinel 1
Acquisition date	25dec 2014	01nov 2014
Product Type	L1T	L1SLC
Acquisition Mode	OLI/TIRS	Ascendent-IWS
Information	All bands	Amplitude and phase

In the Figure 2 we can see for the area of interest, the image from Sentinel-1 (related only to Burst n.9) overlaid to a portion of Landsat-8 (georeferenced through QGIS).

The two regions are not completely overlapping, in fact at the left bottom corner there is a small portion not covered. This however has not been a problem because the territory of our interest is all within the selected area.

Moreover, we will concentrate our analysis and finalize our conclusions to an artistic and cultural site of big interest, the Royal Palace of Caserta [14].

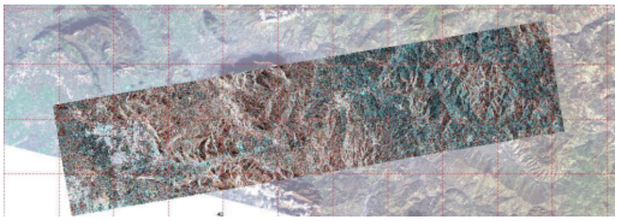

Fig. 2. Overlay of Sentinel-1 (only Burst n.9) and georeferenced Landsat-8 (QGIS image)

In the Figure 3 an aerial photo of the site is shown.

Fig. 3. Aerial photo of the Royal Palace of Caserta-nov.2014

As we can see from the picture, the Royal Palace is adorned with a vast grassland in front and behind the main building. The choice fell on this site right because of the presence and the huge extension of parks and fountains that have appeared to be suitable to our aims.

IV. RESULTS FOR THE SELECTED AREA

A. *Area analysis with Landsat-8 bands combination The NDVI index.*

Landsat-8 offers eleven bands, some with the OLI sensor, some with TIRS, and Band5 with both. By their combination different images can be plot and several conclusions derived. For sake of simplicity, we will refer to the different combination just with the corresponding band numbers. In the Figure 4 many QGIS images are presented in sequence. The band combination number appears in the bottom corner on the left. From the area of interest a portion including the Royal Palace of Caserta has been selected. In effect, the Royal Palace shape appears in the middle oh each image, on the right side.

The different bands have been combined in the three-channel RGB (Red, Green, Blue), so as to obtain different unique images in false or true colors, that bring into showing properties of the territory.For instance, the 543 combi-

nation corresponds to the image in RGB where in Red is the band 5, in Green the band 4 and in Blue the band 3.
Combination 543 is the standard image in "false colors". The vegetation appears in shades of red, urban areas are cyan and soil varies from dark to light brown. Conifers appear dark red for hardwoods. This combination is useful for studies of vegetation, monitoring of the drainage, terrain models and control of different stages of crop growth. In general, deep shades of red indicate wide leaf and / or healthy vegetation, while the light red tones mean grasslands or sparsely vegetated areas. Urban areas appear in blue. We can see that the Royal Palace appears in blue and all the parks behind and in front of the main central building appear red; it's also possible to see the wooded area in a deep shade of red, surrounding the park on the top. **Combination 432** is the image in "true colors". The ground features appear in colors similar to their natural look. Healthy vegetation is green, unhealthy vegetation is brown and yellow; the streets are gray and shorelines are white. Sparsely vegetated or disposed areas are not as easily detected as in 562 or 543 combinations. Moreover also the types of vegetation are not easily distinguishable as in the 562 combination. Shallow waters are not as well distinguished from the soil as in 764 combination. About the Royal Palace, the parks appear in a green color and the building is light brown. The presence of tanks and fountains is here more evident than in 543. **Combination 753** provides a "natural-like" yeld. The healthy vegetation appears bright green, grasslands appear green, pink areas represent sterile soil. The orange and brown are for sparsely vegetated areas. Dried vegetation appears orange and the water of blue color. Sand, soil and minerals are highlighted in a multitude of colors. This band combination provides amazing pictures for the desert regions. It is useful for geological studies, agricultural and wetlands. Urban areas appear in shades of magenta. Grasslands appear bright green and points of green light inside the city indicate a grassy cover, i.e. parks, cemeteries or golf courses. Here the parks of the Royal Palace are very evident with a very bright green color. In **Combination 562** healthy vegetation appears in shades of red, brown, orange and yellow. The deep waters appear to be very dark. Soils can be green and brown; urban characteristics are white, cyan and gray; bright blue areas represent land recently working and reddish areas show new growth of vegetation or grassland probably scattered. For studies of vegetation, the sensitivity to detect various stages of plants growth or stress is increased. In this combination it's possible to differentiate the yellow parks of the Royal Palace from the wooded area surrounding them, that appears very red testifying a wooded area.

Also the **Combination 764** provides a "natural-like" yeld and also penetrates the weather particles, smoke and haze. The vegetation appears in shades of dark green and bright green during the growth season. Urban characteristics are white, gray, cyan or purple; sand, soil and minerals appear in a variety of colors. Water sources are well highlighted in the image. Flooded areas appear blue or very dark black, much better than the 432 combination where the non-deep flooded regions appear gray and are difficult to distinguish. **Combination 654** as the 562 provides the user with a large amount of information and contrasts. Healthy vegetation is bright green and soils are mauve. While the 753 combination contains geological information, the 654 contains information of a more agricultural nature. This combination is useful for the study of the vegetation and is widely used in the fields of the wood management and pest infestation. **Combination 765** can be used to study the characteristics of soil weaving and moisture. The vegetation appears blue so if green is preferred this combination should be replaced. This band combination is also useful for geological studies. **Combination 642** showcases the topographical features of the land, while replacing the band 7 to 6, then with the combination 742, the differences between the types of rocks can be display.

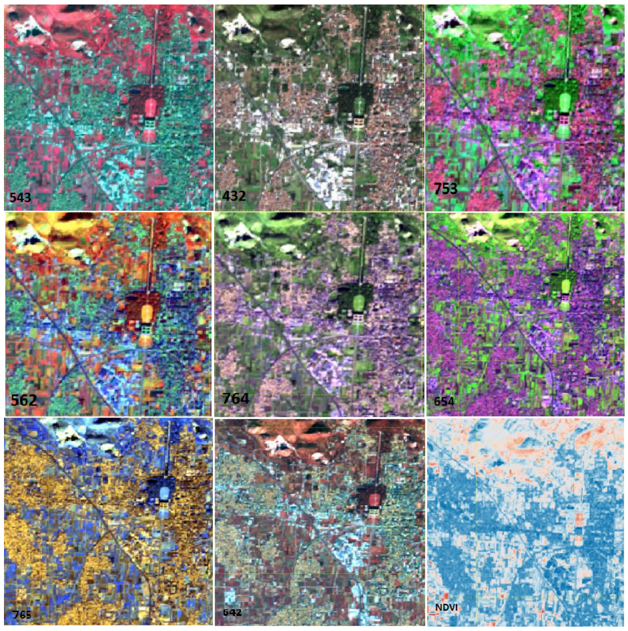

Fig. 4. Combinations of Landsat-8 bands-QGIS Images

The last image refers to the NDVI index. It was generated by combining the near infrared and the visible bands for Landsat-8, in order to obtain information on the type of vegetation present on the scene. The index is given by the following equation 1

$$NDVI = (B_5 - B_4)/(B_5 + B_4) \qquad (1)$$

The NDVI index gives all the information about the status of the crop which are mainly related to the density of biomass produced. For immediate display a scale of color representation has been chosen, which combines the minimal values to deep blue and the maximum to deep red. Thus the blue color indicates areas where vegetation is virtually absent, as buildings, infrastructure and bare lands. Very light blue colors indicate areas where the vegetation is mostly absent or dry. Red colors indicate areas with a certain type of vegetation, that can be poor (very light red) or thick (deep red). Where red is deep, it indicates that the vigor of the vegetation is very high, so it can indicate a plantation in growth or a healthy grassy. Thus the information that is derived concerns mainly the presence of vegetation cover.

B. Area analysis with Sentinel 1. The CTest1 index

After its launch, Sentinel-1A has shown all its great potentiality in terrain observation and high resolution retrievals for getting information on land surface and soil moisture ([6],[15]). A Sentinel-1 SAR image of the area of interest, after a Wishart Supervised Classification, and the image of the same area, processed with the algorithm of Pauli are presented in the Figure 5 on the left and on the right respectively.

You may notice that when Wishart is applied,the urbanized area is represented by the red color while the natural areas are green-yellow. Infrastructures such as roads and railways, and rivers are shown in blue. Furthermore, also the forested areas or in general surfaces with a mainly volumetric geometry are represented in blue. When the same area is processed with the algorithm of Pauli, the image appears a bit different. The polarimetric interferometry module has been used trough a Pauli decomposition. The Pauli coherent decomposition provides interpretation of a full polarimetric SLC (Single Look Complex) data set in terms of elementary scattering mechanism. See ([11], [16]) for a full description of algorithm overview. Trough a RGB combination according to the rule of Pauli, the SAR image presents the urbanized area in â light blue color, whitish for more reflective infrastructures. The land and cultivated fields appear with a color that ranges from light brown to dark blue, depending on their surface geometry. Mainly flat lands (eg. gravel) are represented by a dark brown. The waterways (rivers) are represented by the black color. Mountain areas are shown with the side facing the incident direction of the radar and appear very bright (white) and with the other side in the shade (dark brown).

Similarly to Landsat-8, instead of NDVI we have calculated the CTest1 index for Sentinel-1. This index has been obtained by data of Sentinel-1 according to the formula 2

$$CTest1 = (S_{VV} - S_{VH})/(S_{VV} + S_{VH}) \qquad (2)$$

that represents the amount of signal received back by the radar respectively in the two directions: vertically and horizontally polarized. The term S_{VV} is representative of the acquisition mode VV, while the term S_{VH} is representative of the VH acquisition mode. The same colored scale used for the NDVI, has been used also in this case, to facilitate the viewing and comparison of information. The values range from blue color (minimum) to red (maximum). Compared to the same target, the minimum values indicate a predominance of the VH mechanism reflection compared to VV: in reception mode with horizontal polarization, the signal component that is received from the satellite is very high. This means that the sent signal (vertically polarized) once hit the target, it is reflected almost totally with a horizontal polarization. As a consequence, in the reception mode with vertical polarization, the satellite will receive from the same target a reflected signal component very low. This experimental index, therefore, is essentially linked to the geometric characteristics of the territory surfaces. Depending on how the signal is received after been reflected from a target, it is possible to understand the type of geometry that has changed the signal reflection. Since the signal is transmitted by the SAR with vertical polarization, the geometry of a target capable of returning a signal of this type, it must be mainly vertical or close up. As regards the vegetated areas, targets associated to this type of geometry are "high" covers, such as vineyards, wheat crops, crops of corn, reeds, etc. In areas where blue is predominant, the index Ctest1 indicates that the radar signal has encountered obstacles that have reflected the sent signal as a almost totally horizontally polarized signal. Targets based on this signal have a geometry predominantly "flat", that are surfaces which dissipate most of the signal sent from the satellite. The targets associated to this type of response coverages are "low", such as grassy fields, joke grounds, available plantations, etc..

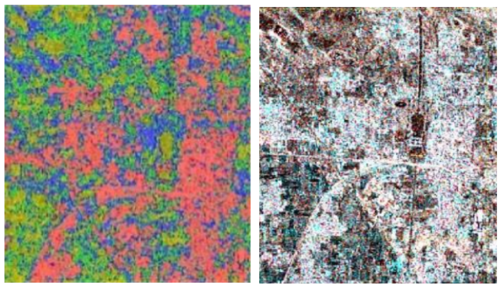

Fig. 5. Sentinel-1 SAR images after Supervised Wishart classification (left) and after Pauli rule application (right).

V. RESULTS COMPARISON AND CONCLUSIONS

To define and classify the type of coverage present on the ground and show the results of our analysis, we have compared the information obtained from the NDVI index with those obtained from the CTest1. We have further restricted the area of interest by taking into consideration just a part of the zone around the Royal Palace of Caserta.

As shown in the Figure 6 the NDVI is on the left and

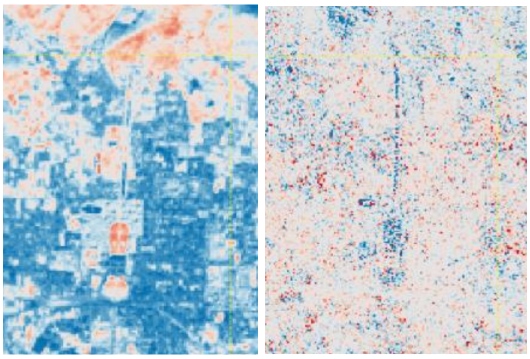

Fig. 6. Comparison between Landsat-8 NDVI and Sentinel-1 CTest1 indexes

identifies the central building with a deep blue color, while grassland appear in red. The index gives also information about the vigor of the vegetation, that is high, but does not provide other information for instance on the type of coverage. Through the index Ctest1, on the right, the building is identified with a light pink color and the ground grass with a deep blue color. This indicates that from the building the signal is sent back to the radar trough a double bounce, thus the horizontal and vertical components of the signal are almost equal, typical response of buildings; while the response on grasslands highlights how the signal sent back to the radar disperses almost completely and the satellite can capture back only a horizontal component sent from the reflection on the ground. This is clearly indicative of the fact that the target has a predominantly flat geometry.

If we put together this information to that given by NDVI (vegetation of high vigor) we can conclude that the place corresponds to a healthy grassy field, just as the picture of the Royal Palace confirmes. Moreover, we can observe that the thin strip of water formed by the tanks in the garden of the Palace appears blue both with the NDVI index and with the Ctest1. This means that the area is flat and without vegetation, i.e. a water mirror. In practice, the NDVI index can tell us how vegetation is: dry or healthy; and the CTest1 index tells more about geometry: flat or rugged profiles, presence of high or small targets. In the case of The Royal Palace the two indexes together say: "grasslands healthy, well maintained".
Our study on different combinations of Landsat-8 bands, on Sentinel-1 SAR images, and on the NDVI and CTest1 indexes, wants to represent a suggestion and a starting point to use remote sensing techniques in order to develop tools suitable to monitor and observe areas of interest, and above all not only the artistic and cultural heritage, but also the vegetated parts inside them or surrounding them. In fact always more and more interest is paid not only by scientists but also by international organizations concerned with the protection of the artistic heritage, such as UNESCO [17].

REFERENCES

[1] Lillesand, T. and Kiefer R.W. and Chipman J. "Remote Sensing and Image Interpretation", Wiley and Sons, 2014, 7th Edition.

[2] Elachi, C. and vanZyl, J. "Introduction to the physics and techniques of remote sensing", Wiley and Sons, 2006, 2th Edition.

[3] Schott, J. R. " Remote Sensing. The Image Chain Approach", 2007, Oxford University Press

[4] Masini, N. and Soldovieri, F. "Integrated non-invasive sensing techniques and geophysical methods for the study and conservation of architectural, archaeological and artistic heritage", Journal of Geophysics and Engineering, Vol.8, 2011.

[5] http://landsat.gsfc.nasa.gov/landsat8

[6] F. De Zan,F. and Monti Guarnieri, A.M. "TOPSAR: Terrain Observation by Progressive Scans", IEEE Transactions on Geoscience and Remote Sensing, Vol.44, Issue 9, Sept.2006, Page(s):2352-2360.

[7] Attema, E. "Mission Requirements Document for the European Radar Observatory Sentinel-1", ES-RS-ESA-SY-0007, Issue 1.4, 11 July 2005

[8] Snoeij, P. and Attema, E. and Davidson, M. and Duesmann, B. and Floury, N. and Levrini, G. and Rommen, B. and Rosich, B. "The Sentinel-1 Radar Mission: Status and Performance, IEEE International Radar Conference-Surveillance for a Safer World, 12-16 Oct. 2009, Bordeaux, Page(s) 1-6

[9] Snoeij, P. and Attema, E. and Davidson, M. and Duesmann, B. and Floury, N. and Levrini, G. and Rommen, B. and Rosich, B. "The Sentinel-1 radar mission: status and performance", Proceedings of Radar Conference - Surveillance for a Safer World, Oct. 2009, Page(s):1-6.

[10] https://earth.esa.int/web/guest/missions/esa-operational-eo-missions/sentinel-1.

[11] http://sarmap.ch.

[12] http://earthexplorer.usgs.gov/

[13] https://scihub.esa.int/

[14] http://www.realcasadiborbone.it/en/history-documents/palaces-residences/the-royal-palace-of-caserta/

[15] Hornacek, M. and Wagner, W. and Sabel, D. and Hong-Linh Truong and Snoeij, P. and Hahmann, T. and Diedrich, E. and Doubkova, M. "Potential for High Resolution Systematic Global Surface Soil Moisture Retrieval via Change Detection Using Sentinel-1", IEEE Journal of Selected Topics in Applied Earth Observations and Remote Sensing, Vol.5, n.4, Aug. 2012, Page(s):1303-1311.

[16] https://sentinel.esa.int/web/sentinel/sentinel-1-sar-wiki/-/wiki/Sentinel One/Algorithm+Overview.

[17] whc.unesco.org/en/list/549