Remote sensing of soil moisture and wetland dynamics using SMOS data. Application in the Mediterranean basin.

Charou E.[1], Papadopoulou Th.D.[1], Stefouli M.[2], Gyftakis S.[1], Stathopoulos N.[3], Vasileiou E.[3]

[1]NCSR Demokritos, Institute of Informatics & Telecommunications
15310 Agia Paraskevi, Greece email: exarou@iit.demokritos.gr
[2]Institute of Geology and Mineral Exploration Studies - IGME
Department .of Geology and Geological Mapping email: stefouli99@gmail.com
Olympic Village, Entrance C, ACHARNAE 13677, GREECE
[3] National Technical University of Athens, School of Mining Engineering & Metallurgy, Department of Geological Sciences, Laboratory of Engineering Geology & Hydrogeology, Iroon Poltechneiou 9, Zografou, Greece, email: nstath@metal.ntua.gr, elvas@metal.ntua.gr

Abstract
In this study, Soil Moisture from SMOS satellite data is used for regional and local detection of soil moisture and wetlands dynamics. SMOS soil moisture data delivered from the Level 2 algorithm are used to map and estimate wetlands and soil moisture seasonal variability in regional scale. For the Mediterranean basin, a qualitative as well as a quantitative analysis is performed. A more detailed analysis is also presented for Evros transnational river basin where the SMOS Soil Moisture estimations were synergistically used with MERIS based GlobCover. SMOS observations turn to be the most promising for further analysis, in order to achieve a better estimation of Soil Moisture and quantification of wetlands and their distribution in space and time.

Key words: Remote sensing, SMOS, soil moisture, Mediterranean, Evros basin, wetland seasonal variability.

Introduction
Soil moisture (SM) is an important parameter in climatologic and atmospheric models in hydrology for water resources management, hazard analysis (flooding, channel erosion) and wetlands extend and dynamics. As the field measurements of the entire's earth SM is extremely time and labor intensive, a great effort has been made in using satellite measurements. Visible and infrared wavelengths have shown certain constraints as they are limited to cloud-free areas, and cannot detect SM below vegetation although they have high spatial resolution. Active microwave observations with Synthetic Aperture Radars (SAR) can provide information even under clouds with high spatial resolution (100m), although these observations are not often available for a given location. A lot of studies have concluded to the possibility of detecting SM using passive microwaves, (Sippel *et al*. 1998; Vinnikov *et al*. 1999; Mialon *et al*. 2005). The first global estimate of wetland extent and dynamics over a decade was presented by Prigent *et al.* (2007) using multi-satellite observations. That method combines visible, infrared, active and passive microwave observations. In this direction, it is possible to combine all the advantage of each wavelength range and to detect the wetlands for all environments, nevertheless this method is complicated to establish and a better methodology should be developed for estimation of wetlands at global scale.

Soil Moisture and Ocean Salinity (SMOS) microwave measurements at 1.4 GHz (L band) are available since ESA launched the SMOS satellite in 2009. Using longer microwave wavelengths than those used before, sensor on board SMOS satellite (MIRAS) minimizes disturbances due to weather, atmosphere (almost transparent) or vegetation (semi-transparent) coverage above the surface. These advantages combined with MIRAS high sensitivity to the presence of open water at the surface enable efficient detection of soil moisture in global and regional scale. Currently, low spatial resolution (50 km) and RFI are critical parameters that limit the quality of data (Daganzo-Eusebio, 2013).
This paper presents a preliminary study on the low resolution SMOS SM satellite data usage in the Mediterranean and particularly, in Evros transnational river basin. Additionally, other

key geospatial data sources and technologies are exploited. It focuses on observing and analyzing the seasonality of wetlands regionally and locally, in the Mediterranean and Evros basins. The surface area of the Mediterranean area of study is 10778159 km^2, Figure 1. Evros river basin is a trans-boundary basin which extends in three countries: Bulgaria, Greece and Turkey. The whole basin area is about 53000 km^2; 66% of this basin area belongs to Bulgaria, 28% to Turkey and 6% to Greece. Evros river length in Bulgaria (Maritsa River) is about 321 km, in Greece about 218 km, while 203 km of that length are the natural borders between Greece and Turkey, Figure 2.

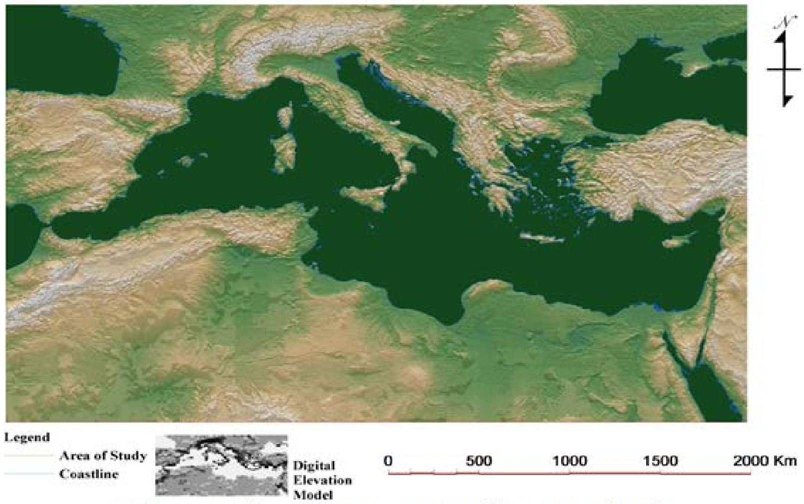


Figure 1. Pilot project area - Mediterranean basin

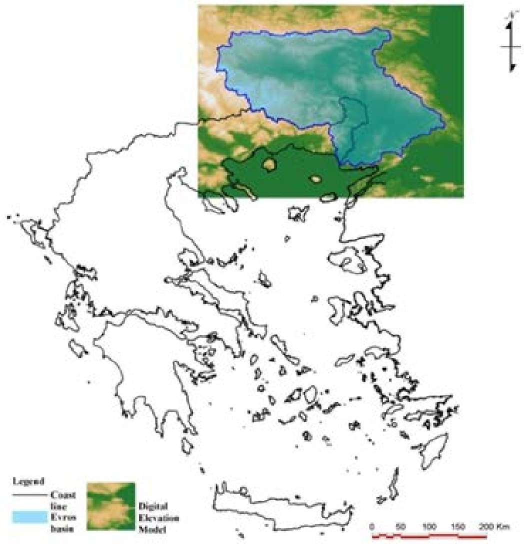


Figure 2. Pilot project area - Evros river basin

The study focuses on:

- Detection, qualitative/ quantitative assessment of the seasonal variability of important wetlands based on SM measurements obtained by SMOS in the Mediterranean basin.
- Evaluation of SM observations obtained by SMOS in a complex terrain environment like the Evros river basin.
- Estimation of monthly/seasonal SM variability.
- Evaluation of the potential of integrating readily available datasets from various sources.
- Analysis of the significance of land cover/high resolution topographic data for supporting interpretation of the measurements obtained by SMOS.

Data and Methods

The main datasets used for the Mediterranean (regionally) and the Evros basin (locally), are SMOS SM Level2 (L2) estimations from July 2013 to June 2014. The L2 SM product contains not only the SM retrieved, but also a series of ancillary data derived from the processing (nadir optical thickness, surface temperature, roughness parameter, dielectric constant and brightness temperature retrieved at top of atmosphere and on the surface) with the corresponding uncertainties. The product is geolocated on the Icosahedron Snyder Equal Area-ISEA 4H9 grid with a spatial resolution of 43 km. SMOS SM L2 data were acquired from the EOLI-SA platform, in the framework of ESA Cat-1 Project 14575 "Soil Moisture Atlas for Greece". The particular data are retrieved from the L2 algorithm presented by Kerr *et al.* (2012). The retrieval algorithm delivers global soil moisture maps with 0.04 m^3/m^3 accuracy. The SMOS SM data have been validated and proven (**anafora**) Having available both morning and afternoon measurements, only the afternoon passes were taken into consideration, as they present less RFI and morning soil moisture was avoided as well (Calla *et al*. 2013). The ESA's BEAM-VISAT open-source visualization and analysis toolbox was used for the mapping of geolocalized SMOS SM L2 data.

Various types of ancillary geodata were used for the interpretation such as the free datasets provided by MicroImages (www.microimages.com) software developers i.e. various global data in vector format referring to the coastline, elevation contours (300 m interval), elevation points, hydrologic data, main river system, general purpose land cover like forest cover, grasslands, croplands, urban areas, and other data in 1:1,000,000 scale and the low resolution DEM of 695x925 meters. The watershed process of TNT Mips GIS and Image Processing software and was used to compute the local directions of flow and the gradual accumulation of water moving down slope across the landscape. Next, from these intermediate results the stream network and the boundaries between the watershed and the areas drained by particular stream systems was computed. Attribute information is created (classification according to Horton (1945); Strahler (1957); Shreve (1966)) and saved with the flow paths and watersheds. These data sets have been used for determining the Evros river watershed boundary and extracting the study area from SMOS SM L2 data and other datasets. The global land cover map GlobCover 2009 was also used. The GlobCover 2009 is derived by an automatic and regionally-tuned classification of a time series of global MERIS FR mosaics for the year 2009. It counts 22 land cover classes defined with the United Nations (UN) Land Cover Classification System (LCCS), (ESA GlobCover 2009 Project). The resolution is 230x308 meters cell size – pixel. The GlobCover 2009 map covers the needs of the current study, in Figure 3. The newly acquired DEM provided by the GMES RDA project (EU-DEM, resolution 25m) - version 1, Oct. 2013 has been used for estimating the parameters of Slope, Aspect and Shading relief (Figure 4).

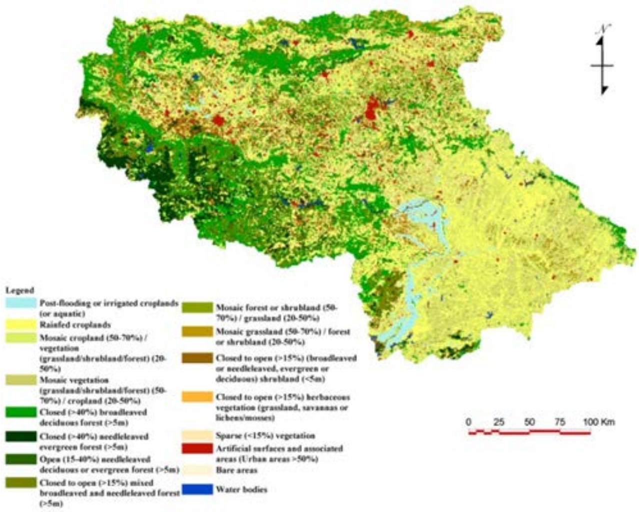


Figure 3. Land cover map of the Evros basin

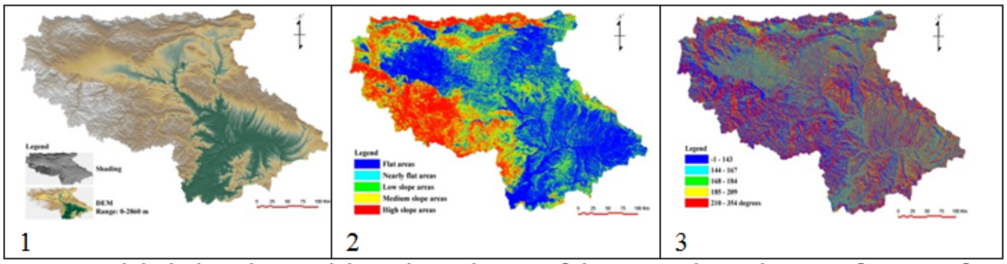


Figure 4. 1. Digital Elevation model, 2. Thematic map of slopes, 3. Thematic map of aspect of Evros river basin

Results and Discussion

a) SMOS soil moisture of the Mediterranean Basin

For the Mediteranean basin, both a qualitative (visual) and a quantitative analysis was held.

I. Qualitative analysis

SMOS soil moisture maps are presented in four months each one representing one season. In the specific study area for each pixel, all available soil moisture values (within a month) were taken into consideration, and Figures 5, 6, 7, 8, represent monthly averages of each pixel, for February, April, July and October, respectively. All four figures visualise the seasonal variability in the Mediterranean wetlands, especially in February and July. Important wetlands and their variability in space and time are captured:

- Guadalquivir river in southern Spain
- Evros transnational basin
- Rhone delta in France
- Lake Maggiore in northern Italy
- Chott Ech Chergui, Chott el Hodna, Chott Felrhir and Melrhir and Chott el Djerid in northern Africa

Wetlands along the Guadalquivir river in southern Spain are detected in February. In April and October these regions have moist soil and some inundations, but they are not completely inundated and during July neither the river line nor the wetlands can be detected. The Evros basin appears flooded and the surrounding areas wet to inundated in February, but in July this phenomenon disappears. The response of Rhone delta and wetlands in southern France are stronger in February,intermediate during the spring (snow melt) and lighter during the other months. Lake Maggiore in northern Italy has the same responses, but because of its standing water it appears wet also during July. In contrast, its surrounding environment is inundated during winter and quite dry in the summer. In northern Africa, five saline lakes are captured in all four seasons. The explanation relies on the fact that SMOS satellite detects also salinity and in this case, soil moisture values might be contaminated by the strong response of salt. Besides that, the wetlands around the five major chotts(Chott Ech Chergui, Chott el Hodna, Chott Felrhir and Melrhir and Chott el Djerid) appear to be inundated in February and slighly moist to dry in July.

Detecting the sites mentioned above, SMOS SM L2 products enable us the further research of a smaller area that of the Evros river basin, in the northeastern part of Greece.

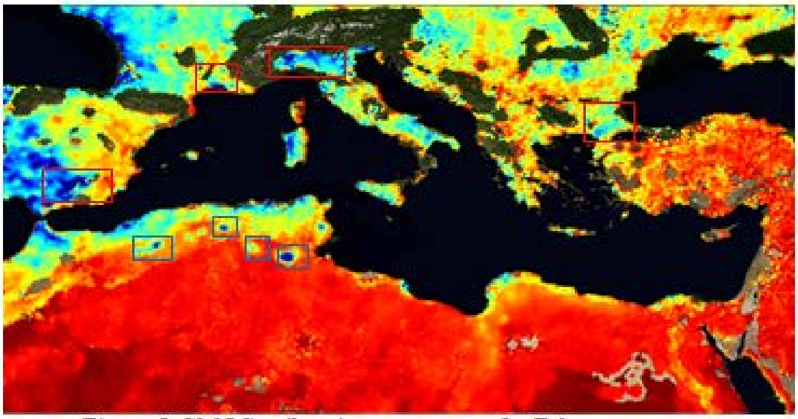


Figure 5. SMOS soil moisture averages for February

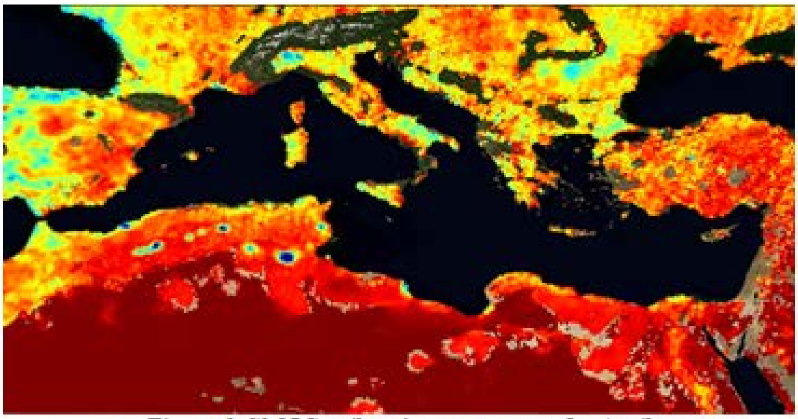
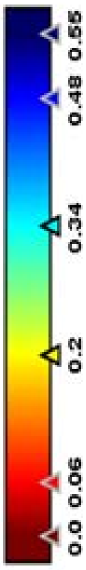


Figure 6. SMOS soil moisture averages for April



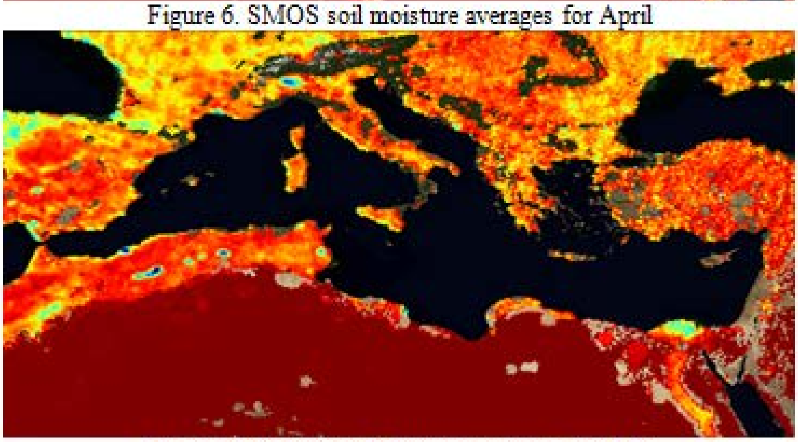


Figure 7. SMOS soil moisture averages for July

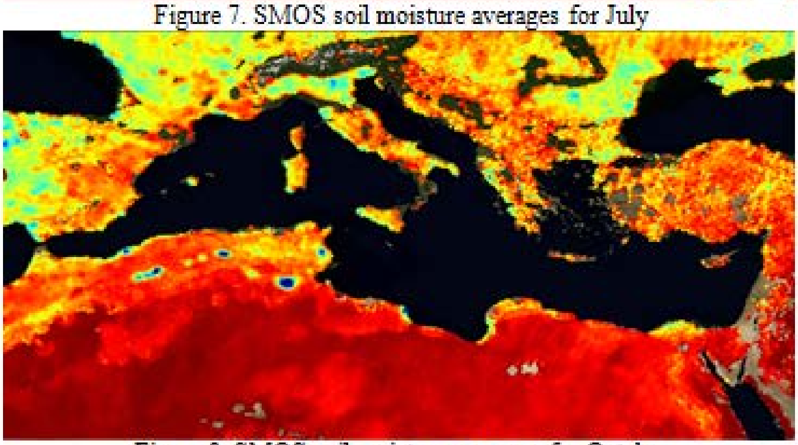


Figure 8. SMOS soil moisture averages for October

II. Quantitative analysis

The qualitative analysis described above for five important wetlands of the Mediterranean basin is also validated quantitatively. For each studied wetland the soil moisture changes from one season to another have been calculated and presented in Figure 9.

Furthermore, for each month available, SMOS SM pixels were distinguished in four classes according to their soil moisture level; flooded for soil moisture values more than 0.4 m^3/m^3, very wet soil from 0.25 m^3/m^3 to 0.4 m^3/m^3, wet soil from 0.05 m^3/m^3 to 0.25 m^3/m^3 and dry for soil moisture values less than 0.05 m^3/m^3. Table 1 below shows the relative number of pixels (in percentage) that belongs in each of these classes for each month (season). As it is expected the most flooded pixels are observed in February with 2.64%. In the Mediterranean region, February (representing winter) is the season with the most precipitations. Most of the pixels of February (79.93%) belong to wet and very wet soils and hence dry pixels represent the smallest percentage (17.43%) compared to the other three months. Another mentionable point observed in Table 1 is that flooded pixels in July (summer) are only 0.08% of the total pixels, and almost 99% correspond to dry and wet.

In Table 2, the seasonal variability of the Mediterranean from summer (July) to winter (February) shows that the majority of pixels have a very low soil moisture change (36.45% for less than 0.05 and 60.14% from 0.05 m^3/m^3 to 0.25 m^3/m^3).

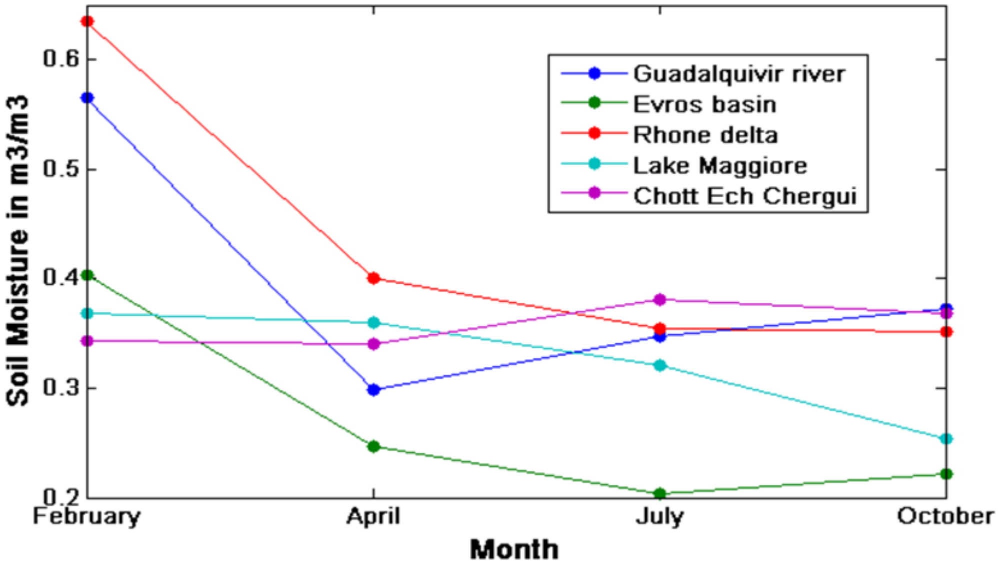


Figure 9. Soil moisture dynamic variability from each studied Mediterranean wetland

Soil Moisture	**>0.4 (flooded)**	**0.25 - 0.4 (very wet)**	**0.05 - 0.25 (wet)**	**<0.05 (dry)**
FEBRUARY	2.64%	14.24%	65.69%	17.43%
APRIL	0.14%	3.91%	54.61%	41.34%
JULY	0.08%	1.14%	49.70%	49.08%
OCTOBER	0.14%	4.23%	56.55%	39.08%

Table 1. Pixel percentages for high, medium, low and close to zero soil moisture values, in four months

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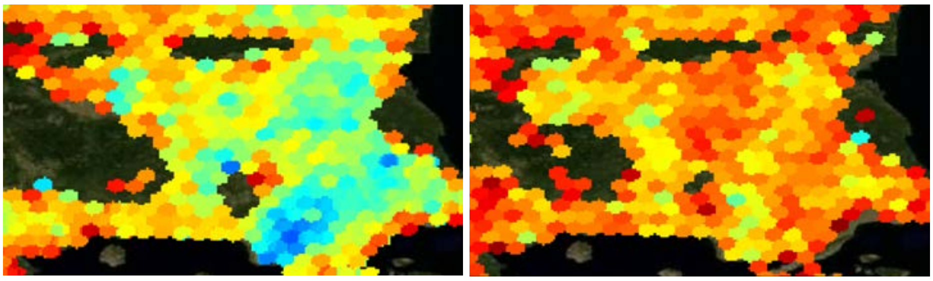
Soil Moisture Change	**>0.4**	**0.25 - 0.4**	**0.05 - 0.25**	**<0.05**
FEB-JUL	0.18%	3.23%	60.14%	36.45%

Table 2. Pixel percentages for high, medium, low and close to zero soil moisture change from winter (February) to summer (July).

b) SMOS soil moisture of Evros basin

After analysing the available data, February and July data appeared to be more appropriate, in order to visualize the largest variability differences in soil moisture values. Taking into consideration the monthly precipitation levels in the Evros basin, it is expected to have higher soil moisture values in February, than in July that is a very dry month. Figure 10 represents SMOS SM measurements in February where, a lot of pixels with high soil moisture values are displayed following the Evros river line, especially near the Delta of Evros. In the contrary, in Figure 11, displaying measurements in July, SMOS values seem not to follow the Evros river line. This discrepancy happens due to the very low spatial resolution of SMOS, as within a 43km×43km pixel it is difficult to monitor soil moisture values, which vary in cm.
In Figure 12, the seasonal variability of SMOS SM measurements shows that most of the pixels correspond to a positive change in soil moisture. This change is expected from July to February, as this region passes from a very dry season to a season full of precipitations. Furthermore, high soil moisture change is noted around the Evros river line and delta.



Figures 10 &11. SMOS soil moisture over Evros basin in February and July respectively (same colorbar as Mediterranean basin)

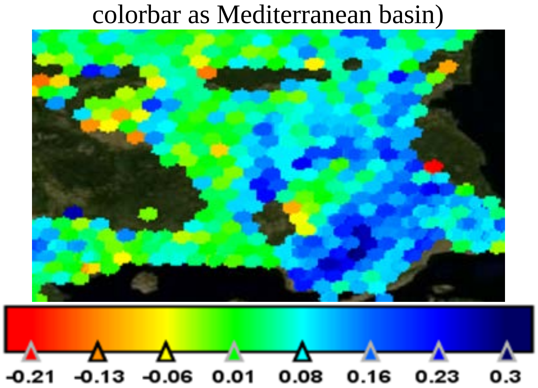


Figure 12. SMOS seasonal soil moisture variability in m3/m3 between July 2013 and February 2014

c) Soil moisture and Land Cover of Evros basin

Land cover has been studied with SM values obtained by SMOS. The Glob Cover classes have been grouped and intersected with SMOS SM maps in order to analyze spatial and seasonal variability in Evros basin. The main land cover groups, shown as detailed polygons in Figure 13, are the following:
<u>Bare lands</u>: They cover a small percentage of the total basin area and they show very low moisture values with no spatial or seasonal variability.
<u>Forest areas</u>: (includes: Closed to open (>15%) broadleaved evergreen or semi-deciduous forest (>5m), Closed (>40%) broadleaved deciduous forest (>5m), Open (15-40%) broadleaved deciduous forest/woodland (>5m), Closed (>40%) needle-leaved evergreen forest (>5m) Glob Cov classes. They cover a large percentage of the total Evros basin area with spatial distribution mainly on the periphery of the basin and they show both spatial and seasonal variability. They have lower moisture values in relation to the other classes.
<u>Crop lands</u>: (includes: Rainfed croplands, Mosaic cropland (50-70%) / vegetation (grassland/shrubland/forest) (20-50%), Mosaic vegetation (grassland/ shrubland /forest) (50-

70%) / cropland (20-50%)) Glob Cov classes. They cover a large part of Evros basin and they show a high degree of fragmentation with very high spatial and seasonal variability. Soil moisture values range from wet and dry in the summer to very wet and almost flooded during winter (compared to Tab. 1 of the Mediterranean basin).
Post-flooding or irrigated croplands (or aquatic): They show high seasonal variability while it covers the outflow area of Evros River. Near the Evros delta, in February floods are detected.
The percentage coverage of each class in relation to the total of Evros basin is shown in Figure 13.

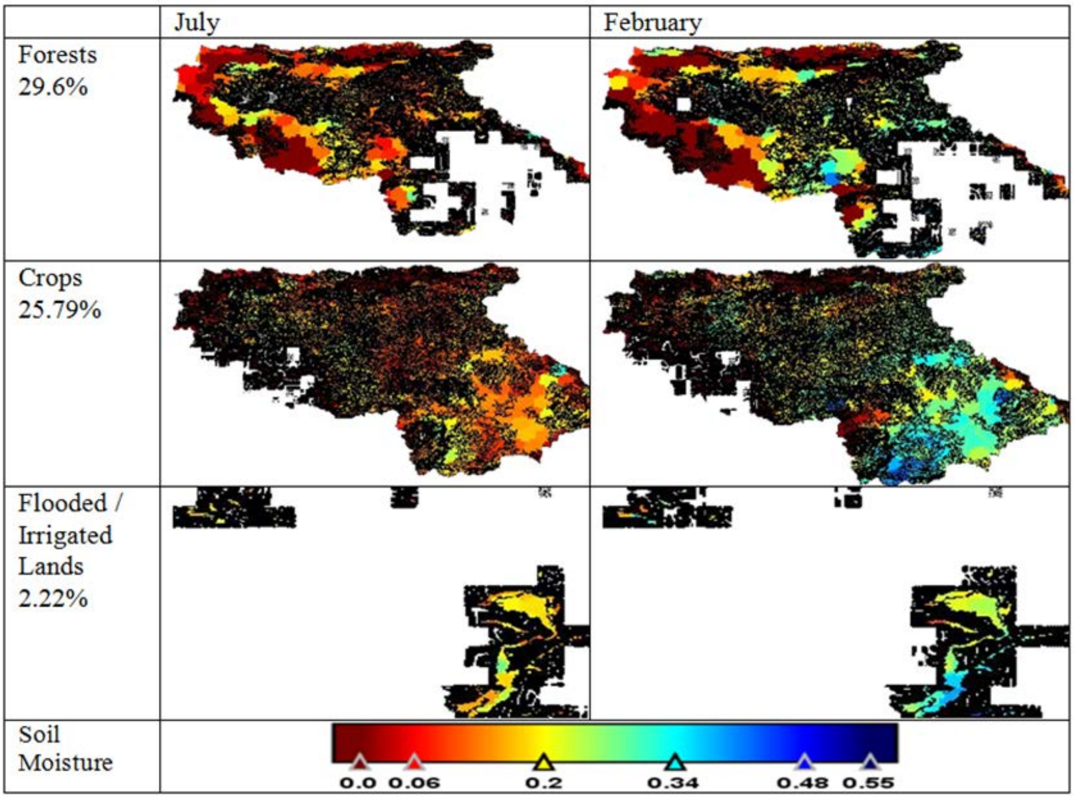


Figure 13. Spatial variation of soil moisture in relation to main land cover GlobCover classes.

Conclusion

SMOS soil moisture multi-temporal maps in regional scale for the Mediterranean basin and in local scale for the Evros river basin and surrounding wetlands have been constructed. From the interpretation of the maps it is shown that wetlands are successfully following a clear seasonal variation. High soil moisture and presence of open water is detected in February, while lower or zero soil moisture values are detected in July. A further quantitative analysis in the Mediterranean basin show less number of flooded pixels during the summer (0.08%) and most of flooded pixels during winter (2.64%). In a local scale the synergistic use and interpretation of SMOS soil moisture measurements and GlobCover data have been carried out enabling as to drawestimations for the variations and changes of soil moisture values in different land cover classes. In general, the various qualitative and quantitative assessments that were drawn based on SMOS SM L2 data indicates the possibilities of this data set as well as the need for further investigation and exploitation in order to formulate an enhanced methodology related to soil moisture datasets that can be used for supporting management decisions regarding surface/groundwater systems. The provided analysis of SMOS SM data deliversvital information for better understanding of the variability of the wetlands in space and time, suitable estimations for the amounts of fresh water storage and protection of the rich ecosystems of the Mediterranean.

Acknowledgments

This ongoing study is being carried out in NCSR "D" under the framework of the coordinated Cat-1 Project 14575 titled "Soil Moisture Atlas for Greece" of ESA that is acknowledged.

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