Comparing soil moisture from the SMOS mission and GLDAS over two MOROCCAN stations

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Abstract
Soil moisture has been used in several environmental studies. Recent technologies have shown that soil moisture can be measured by a variety of remote sensing techniques; each method has its advantages and disadvantages. In this article we compared the soil moisture data from SMOS and GLDAS in two stations with different climate (SIDI SILIMANE station in northern Morocco and SMARA station in the south). At these two stations we analyzed the effect of precipitation on soil moisture. During year 2012, the results of this study show a correlation between GLDAS (0-10 cm), GLDAS (10-40 cm) and SMOS data at the SIDI SILIMANE station. The results show that at the SIDI SILIMANE station the correlation exists between the precipitation data of the month preceding the soil moisture measurements of GLDAS (0-10 cm), GLDAS (10-40 cm) and SMOS. At SMARA station we find a correlation only between GLDAS (10-40 cm) and the previous month of precipitation measurement.

Keywords: Soil moisture, SMOS, GLDAS, Morocco

1. Introduction
Soil moisture is an important variable for monitoring land surface, it can be used in several studies related to: drought, flood, agriculture, climate change, Water, irrigation planning, crop forecasting, etc. [1–7]. Soil moisture was defined in 2010 by the global climate observing System (GCOS) as one of the essential climate variables (ECV) [8–11]. Soil moisture is one of the most used hydrological variables, it regulates the exchange of energy between the earth and the atmosphere [12]. There are generally three ways to obtain the soil moisture data: (1) Instruments directly on the ground. (2) Using microwave remote sensing data. (3) Modeling or simulation.

For a long time the soil moisture has been measured with instruments on the ground, but also with the remote sensing [13]. This technique with remote sensing made possible to measuring soil moisture
globally at a high speed and low cost [14]. The soil moisture estimated from remote sensing technique was introduced in the 1970 using optical, thermal and microwave [15]. SMOS (Soil Moisture and Ocean Salinity Satellite) is one of the new missions of measuring soil moisture; it is based on microwave antennas using the L band (21 cm, 1.4 GHz). This mission measures three variables: soil moisture (SM), salinity of the oceans and depth of vegetation. The SMOS mission is led by the ESA (European Space Agency) with the CNES (National Center for Space Studies, France) and CDTI (Center for the Development of Industrial Technology, Spain) contributions [16,17]. Several studies have been achieved to evaluate the SMOS soil moisture: In the world [9,18], in the United States [19–21], in Europe [22,23], in Australia [24], in Spain [25], in Africa [5,26]. Another type for estimating soil moisture with remote sensing technique is the Global Land Data Assimilation System (GLDAS) [27], this system was developed by NASA, GSFC, NCEP and NOAA organizations, It was generated from four surface models (CLM, Mosaic, Noah and VIC). The GLDAS combines ground and satellite observations to provide real-time data [28].

We have proposed this study with the following objectives: (1) Compare soil moisture data from SMOS and GLDAS in two different climate stations (the SIDI SLIMANE station in northern Morocco and the SMARA station in the south). (2) Analyze the effect of rainfall on soil moisture. (3) Investigate the use of remote sensing data to estimate soil moisture.

2. Materials and methods

2.1. Study area

This study was achieved in two Moroccan stations; the first is located in the north with humid climate and the second in the south with dry climate. The position of these stations is shown in the figure 1.

2.2. Data Used

To reach our goal we have use two types of data: The first is provided from remote sensing techniques (Table 1), more detail for this data is presented below:

- SMOS mission (Soil Moisture Ocean Salinity) [16] is developed with the collaboration of European Space Agency (ESA), French Space Agency (CENS) and Spanish National Agency for Technological Development (CDTI). It was launched on November 2, 2009. The MIRAS instrument installed in the SMOS satellite allows the detection of radiation in L-band (1.42 GHz, 21 cm), this frequency is used to detect the change in soil moisture, ocean salinity and vegetation covers. Soil moisture data (SMOS-MIRAS) used in this study covers the year 2012, they are characterized by a spatial resolution of 30 to 50 m and a temporal resolution of 1-3 days. (Download link: ftp://smos-diss.eo.esa.int).

- GLDAS (Global Land Data Assimilation System) [27] is a global data simulation for surface, this system combines ground-based and satellite observations to provide near-real-time results. The GLDAS was developed by NASA, GSFC, NCEP and NOAA. In the current study, two types of GLDAS-NOAH data are used, the first one present moisture between 0 to 10 cm and the second simulates soil moisture in soil depth (10 to 40 cm). The data covers the year 2012,
they are produced with 0.25° of spatial resolution and 3 hours of temporal resolution. (Download link: ftp://hydro1.sci.gsfc.nasa.gov/).

**Table 1**: Characteristics of SMOS and GLDAS data

<table>
<thead>
<tr>
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<th>SMOS</th>
<th>GLDAS</th>
</tr>
</thead>
<tbody>
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<td>SMOS.MIRAS.MIR_SMUDP2</td>
<td>GLDAS_NOAH025SUBP_3H</td>
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<tr>
<td>Long name</td>
<td>SMOS MIRAS L2 Soil Moisture Output Product</td>
<td>GLDAS Noah Land Surface Model L4 3 Hourly 0.25 x 0.25 degree Subsetted V001</td>
</tr>
<tr>
<td>Version</td>
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<td>001</td>
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<td>Data Resolution Spatial</td>
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<td>0.25 degree x 0.25 degree</td>
</tr>
<tr>
<td>Spatial Coverage</td>
<td>-90 to 90; -180 to 180</td>
<td>-60 to 90 ; -180 to 180</td>
</tr>
<tr>
<td>Temporal</td>
<td>1-3 days</td>
<td>3 hours</td>
</tr>
</tbody>
</table>

**Figure 1**: Position of the stations. The SIDI SLIMANE station is located in the north (Latitude = 34.22, Longitude = -6.05), and the SMARA station is in the south (Lat = 26.73, Long = -11.68).
The second type of data is the daily meteorological data for the year 2012 (Rainfall, minimum temperature and maximum temperature), this data are available from the National Meteorological Direction. (Figure 2).

![Figure 2](image1)

**Figure 2:** Monthly evolution during year 2012 for mean precipitation, minimum temperature and maximum temperature. (a): SIDI SLIMANE station, (b): SMARA station.

### 2.3. Preparing data

After downloading the SMOS and GLDAS data, we proceeded to: (1) Converting data to TIFF formats, (2) Calculate the monthly mean data, (3) Identify for each station (SIDI SLIMANE and SMARA) the soil moisture values from the GLDAS (0-10cm), GLDAS (10-40cm) and SMOS data. We present in Figure 3 the monthly evolution of the mean soil moisture values for the two stations: SIDI SLIMANE and SMARA.

![Figure 3](image2)

**Figure 3:** Monthly evolution during year 2012 for mean soil moisture, these measurements are measured by GLDAS and SMOS. (a): SIDI SLIMANE station, (b): SMARA station.

### 2.4. Method

We use the coefficient of determination \((R^2)\) to validate the correlation between all variables. The \(R^2\) coefficient is a measure of the variability; it is explained by the linear regression model.

\[
R^2 = 1 - \frac{\sum_{i=1}^{n}(y_i - \hat{y}_i)^2}{\sum_{i=1}^{n}(y_i - \bar{y})^2} \quad (1)
\]
\( y_i \) is the values of the measurements, \( \hat{y}_i \) is the real values and \( \bar{y} \) is the average of the measurements. In this study, the \( R^2 \) test the link between quantitative measurements of the SMOS, GLDAS (0-10 cm), GLDAS (10-40 cm) and precipitation variables.

3. Results

The results of our study show in the SIDI SLIMANE station high correlation between SMOS and GLDAS (0 - 10 cm) data with the coefficient of determination \( R^2 = 0.9453 \) (Figure 4-a). For SMOS and GLDAS (10-40 cm) we have \( R^2 = 0.8153 \). At SMARA station (Figure 4-b) we find low correlation between SMOS and GLDAS (0-10 cm) data with a coefficient of determination \( R^2 = 0.2344 \) and \( R^2 = 0.0211 \) for SMOS and GLDAS (10-40 cm).

![Figure 4: Correlation between SMOS, GLDAS (0-10cm) and GLDAS (10-40cm) soil moisture data (a: SIDI SLIMANE station, b: SMARA station).](image)

The soil moisture is impacted by precipitation, in this study we want to verify for two different regions if there is any relation between the soil moisture and precipitation data. For the SIDI SLIMANE station, the results show the existence of the correlation between soil moisture data and precipitation of the previous month, the coefficients of determination are: \( R^2 = 0.8041 \) for GLDAS (0-10cm), \( R^2 = 0.81 \) for GLDAS (10-40cm) and \( R^2 = 0.7003 \) for SMOS (Figure 5).
Figure 5: Correlation between the same and previous month of precipitation measurement and the soil moisture data at the SID SLIMANE station, (a): is the correlation with soil moisture and same month of precipitation. (b): is the correlation with soil moisture and previous month of precipitation.

At the SMARA station, the correlation was identified just between GLDAS (10-40 cm) soil moisture data and precipitation of the previous month, the coefficient of determination is $R^2 = 0.5607$ (Figure 6).
Figure 6: Correlation between the same and previous month of precipitation measurement and the soil moisture data at the SMARA station, (a): is the correlation with soil moisture and same month of precipitation. (b): is the correlation with soil moisture and previous month of precipitation.

4. Discussion and conclusion
In this study we have used SMOS and GLDAS soil moisture data for Moroccan case. The estimate of soil moisture in Morocco has a specificity because in this country the climate is not homogeneous, it is very different between the regions [29]. The northern areas are characterized by a humid climate, but in the south we find a dry climate. The difference between the north and the south is not limited to the climate but also in the topography, vegetation and soil types.

We presented in Figures 4 the correlation between SMOS and GLDAS soil moisture (The correlation in SIDI SLIMANE is high but in SMARA is low), these results are justified by the difference in the effects of climate, topography, vegetation and soil types in all region of Morocco.

Many studies show that there is a high correlation between precipitation and soil moisture data [4,30], but in arid and semi-arid regions we can have also positive correlations between the precipitation and the deep soil moisture [31].In this study, SMOS, GLDAS (0-10cm) and GLDAS (10-40cm) soil moisture measured at SIDI SLIMANE station are correlated with the previous month of precipitation (Figure 5). But in the SMARA station just GLDAS (10-40cm) soil moisture depths is correlated with the previous month of precipitation (Figure 6). All of the results can be justified by: (1) the climate differences between the Morocco’s north and south. (2) The types of soil prevailing in southern
Morocco helps the rains to infiltrate, (3) The SMOS mission is based on microwave radiation (L-band), this band is backscattered and influenced by the effects of water content, surface roughness, topography and vegetation structure [32]. In the other hand the GLDAS simulation is based on combined ground and satellite observations [28].

The measurements of soil moisture directly in the ground are accurate, but this method is punctual and very costly. While remote sensing technology produces periodic observations with a larger surfaces (Zawadzki et al., 2016).Remote sensing techniques are an essential tool for recovering soil moisture data on a large scale with a very high temporary resolution. But the microwave instruments are influenced by several factors such as precipitation, soil characteristics, topography, geographical location and weather conditions. More research is needed to find the appropriate methods to estimate the soil moisture data in the arid zones.

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6. References


