Sentinel-1 Soil Moisture Product At 1 km Resolution Over The Mediterranean Basin
ACKNOWLEDGEMENTS:

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The Mediterranean basin is a fragile “eco-region”

- North-South economic and social tensions, increasing anthropogenic pressure, highly variability of the hydrologic cycle and strong climate change threat (IPCC, 2014 & 2018).

- Important challenges in terms of water scarcity and hydro-meteorological extremes, e.g., floods and droughts.


Climate zone (Köppen-Geiger climate classification), Csa= warm temperature, summer dry, hot summer (Kottek et al, 2006).
Soil moisture plays a key role in the **interactions between water, energy and biochemical fluxes**; forecasting of meteorological and hydrological events; crop yield prediction, etc.

Earth Observation products of near surface soil moisture (SSM) content at low resolution are operationally delivered (e.g. **ESA SMOS, EUMETSAT ASCAT and NASA SMAP**)

Mediterranean region: **small to medium size watersheds (e.g. from 500 km² to 5000 km²)** → spatial resolution is a key factor to resolve processes at basin scale.
Objectives & Outline

Objectives

- Illustrate a pre-operational near surface soil moisture (SSM) product derived from Sentinel-1 (S-1) data over the Mediterranean basin
- Present examples of prospective applications

Outline

- Sentinel-1 (S-1) SSM product at 1km
- Evolution: S-1 & S-2 SSM product at “field scale”
- Examples of high resolution SSM product exploitation for Numerical Whether forecast, hydrological, and agricultural applications
- Conclusions & perspectives
Soil moisture retrieval from multi-temporal SAR data (SMOSAR) prototype is based on a Short Term Change Detection Retrieval Model.

Physical approximations:

\[ \sigma_0 \approx \tau^2 \cdot \sigma^{soil}_0 \approx \tau^2 \cdot \left| \alpha_{pp}(\theta, \epsilon) \right|^2 \cdot F(\Omega, \theta, \lambda) \]

SAR response dominated by soil attenuated scattering:

\[ \frac{(\sigma_0)_{DoY(i+1)}}{(\sigma_0)_{DoY(i)}} \approx \frac{\left| \alpha_{pp}(\theta, \epsilon) \right|_{DoY(i+1)}^2}{\left| \alpha_{pp}(\theta, \epsilon) \right|_{DoY(i)}^2} \approx \frac{SSM_{DoY(i+1)}}{SSM_{DoY(i)}} \]

Backscatter temporal change depends solely on SSM:

Pre-processing: calibration, coregistration, multilooking, geocoding

Retrieving block

Low pass filter

Time series of VV&VH S-1 IW (40m pixel)

CCI Land cover

ISRIC Soil texture map

Masking block

N-masked VV images

Time series of N-SSM maps at 1km spatial resolution

https://exploit-s-1.ba.issia.cnr.it
S-1 SMOSAR SSM map composite @1km resolution

Dates 15/12/2017 - 20/12/2017

Tracks From E to W
D125 D052 D154 D081 D008 D110 D037 D139 D066 D168 D095 D022 D124 D051 D153 D080 D007 D109 D036 D138 D065 D167 D094 D021
SatDoY
S1B0 S1A1 S1B2 S1A3 S1B4 S1A5 S1A0 S1B1 S1A2 S1B3 S1A4 S1B5 S1B0 S1A1 S1B2 S1A3 S1B4 S1A5 S1A0 S1B1 S1A2 S1B3 S1A4 S1B5

SSM Mean

0.05 m³/m³ 0.5

river basins
(JRC CCM v2.1
UNU WaterBase databases)
SMOSAR SSM map composite @1km resolution

Date 20/12/2017

Tracks From E to W

SatDoY    D110     D022     D109     D021
          S1A5      S1B5      S1A5      S1B5

0.05 m³/m²  0.5
SMOSAR SSM map composite @1km resolution

Dates 08/01/2018 - 13/01/2018

Tracks From E to W
D125 D052 D154 D081 D008 D110 D037 D139 D066 D168 D095 D022 D124 D051 D153 D080 D007 D109 D036 D138 D065 D167 D094 D021
SatDoY
S1B0 S1A1 S1B2 S1A3 S1B4 S1A5 S1A0 S1B1 S1A2 S1B3 S1A4 S1B5 S1B0 S1A1 S1B2 S1A3 S1B4 S1A5 S1A0 S1B1 S1A2 S1B3 S1A4 S1B5

0.05 m³/m² 0.5
S-1 SMOSAR SSM standard deviation map composite @1km resolution

Dates 15/12/2017 - 20/12/2017
SSM changes resolved at basin scale (e.g. soil texture, topography, land cover/use, etc.)

Area ≈ 150 km x 110 km

Date 17/12/2017
Status of S-1 SSM product validation over seven cal/val experimental sites

Retrieved vs observed SSM [m$^3$/m$^3$] at site scale

Comparison at site scale between S-1, SMAP L3 36km, SMOS L3 25km, ASCAT L2 25km and *in situ* measurements

<table>
<thead>
<tr>
<th></th>
<th>S-1</th>
<th>SMAP</th>
<th>SMOS</th>
<th>ASCAT</th>
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<tbody>
<tr>
<td># dates</td>
<td>475</td>
<td>333</td>
<td>313</td>
<td>138</td>
</tr>
<tr>
<td>Correlation (R)</td>
<td>0.64</td>
<td>0.78</td>
<td>0.72</td>
<td>0.77</td>
</tr>
<tr>
<td>rmse [m$^3$/m$^3$]</td>
<td>0.065</td>
<td>0.061</td>
<td>0.07</td>
<td>0.061</td>
</tr>
<tr>
<td>ubrmse [m$^3$/m$^3$]</td>
<td>0.064</td>
<td>0.054</td>
<td>0.068</td>
<td>0.061</td>
</tr>
<tr>
<td>Mean-x (&lt;x&gt;) [m$^3$/m$^3$]</td>
<td>0.2080</td>
<td>0.206</td>
<td>0.209</td>
<td>0.179</td>
</tr>
<tr>
<td>Mean-y (&lt;y&gt;) [m$^3$/m$^3$]</td>
<td>0.2198</td>
<td>0.177</td>
<td>0.191</td>
<td>0.186</td>
</tr>
</tbody>
</table>
Dense hydrological network for S-1 SSM product validation

- Agricultural areas (CORINE)

11 stations in Segezia site, approx. 2*2km² (spacing between stations ~500 m)

- at 1 km resolution, the impact of representative error for N=1 station cannot be disregarded -> a validation strategy for S-1 SSM product(s) is required

Retrieved vs observed SSM at 2*2km²

\[
\text{rmse} = 0.06 \text{ m}^3/\text{m}^3
\]

\[y=0.72 \times + 0.07, \ R=0.61 \ (WLS)\]
Examples of S-1 SSM exploitation in land applications

To estimate the root zone soil moisture

*Example of SMAR application on S-1 SSM (rmse=0.02)*

Segezia farm

0.4m

0.05m

SMAR

Manfreda et al., 2014 HESS

To estimate the accumulative rainfall

SM2RAIN

Brocca et al., 2014 JGR

Ingestion in a high resolution Numerical Weather Prediction

ESA STEAM project

Tomorrow’s presentation

Manfreda et al., 2014 HESS
Sentinel-1 & Sentinel-2 SSM product at field scale

18/10/17 (Spain)

SSM

Std dev SSM

ensagri

- S-2 NDVI and parcel borders (Land Parcel Identification System) to provide SSM estimates at field scale

Area at north-west of Valladolid
Detection of irrigation events

Segmentation S-1/S-2 SSM at high resolution (e.g. ~100m) to discriminate irrigated from not-irrigated fields

SSM contrast depends on the balance between the amount of water supplied and the evapotranspiration rate

S-1/S-2 SSM may support irrigation scheduling and/or water management (i.e. improve estimate of water consumption)

<table>
<thead>
<tr>
<th>Timespan before the S1 passage</th>
<th>TP(%)</th>
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<tr>
<td>Within 1 day</td>
<td>90.0</td>
</tr>
<tr>
<td>Within 2 - 1 days</td>
<td>64.6</td>
</tr>
<tr>
<td>Within 3 - 2 days</td>
<td>56.8</td>
</tr>
</tbody>
</table>

OA 79.4% 
TPR 61.6% 
FPR 15.2%

True Positive (TP) 
False Positive (FP)
Consistent SSM & LAI products for yield forecast

SSM map on 15/04/17

LAI green map on 12/04/17

Coupled SMAR-AquaCrop

- Food security (production at regionale scale): support informed decision
Conclusions

- A S-1 SSM product at 1 km has been developed and validated at large scale: **case study Mediterranean basin**
  - applications, e.g., improvements of numerical weather prediction (NWP), early warning/monitoring hydrologic extremes, monitoring SSM-land-surface-temperature coupling at basin scale, etc.

- **Network of Mediterranean based EO validation sites needed**

- A follow-up product integrating S-1 & S-2 for SSM at "**field scale**" resolution for agriculture application, e.g., irrigation events & water consumption; yield forecast, etc.