HIGH RESOLUTION SOIL MOISTURE CONTENT FROM SENTINEL-1 DATA


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https://exploit-s-1.ba.issia.cnr.it/
Objectives

- Further **development**, implementation and test of **high resolution near surface soil moisture (SSM)** retrieval methods using **Sentinel-1 (S-1) IWS** data.

- **Validation** based on independent in-situ soil moisture information from a number of test sites & on analysis of large scale SSM patterns.

- Assessment of the potential for **pre-operational high resolution SSM products** and services at large scale

**Investigate the link between S-1 & SMAP & SMOS & ASCAT SSM**

- extend the study work to include comparison between S-1 & SMAP & SMOS & ASCAT SSM data over various cal/val sites

- develop and validate **SSM algorithms complementary, consistent and harmonised with respect to the low-resolution products** from passive L-band and scatterometer missions

- formulate key mission requirements for soil moisture information for future S–1 missions
Outline

• Overview of the Short Term Change Detection (STCD) algorithm for SAR SSM retrieval

• Validation strategy and initial results at low & high spatial resolution
  – the effect of SSM-measurement error on the SSM retrieval at high resolution

• Summary
A short term change detection (STCD) retrieval algorithm

Approximations:

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

SAR response dominated by soil attenuated scattering

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

Backscatter temporal change depends solely on SSM: the shorter the revisit the better the approximation

Segmentation of areas dominated by surface scattering (Satalino et al., RSL, 2014)

Retrieval algorithm:
N-1 measurements → N unknowns (Balenzano et al., JSTAR, 2011 & EuJRS, 2013)

Soil Moisture retrieval from multi-temporal SAR data (SMOSAR)

Pre-processing: calibration, coregistration, multilooking, geocoding

N-masked VV images

Retrieving block

Time series of N-SSM products

Soil texture map

Time series of S-1 IW

Land cover
Validation plan: local scale

- S-1 SSM time series retrieved vs *in situ* measured over multiple-sites

<table>
<thead>
<tr>
<th>Site</th>
<th>Lat., Lon (centre)</th>
<th>Climate zone (Köppen-Geiger climate classification)</th>
<th>Land cover (International Geosphere-Biosphere Program)</th>
<th>Hydrological network (extension and number of stations)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Apulian Tavoliere (Italy)</td>
<td>41°22'13&quot;N 15°29'23&quot;E</td>
<td>Csa (warm temperature, summer dry, hot summer)</td>
<td>croplands</td>
<td>4km², 12 stations</td>
</tr>
<tr>
<td>Biebrza (Poland)</td>
<td>53°37'12&quot;N 22°55'48&quot;E</td>
<td>Dfb (snow, fully humid, warm summer, warm summer)</td>
<td>marshlands grasslands</td>
<td>0.25 km², 9 stations 0.13 km², 9 stations</td>
</tr>
<tr>
<td>Yanco (Australia)</td>
<td>34°50'39&quot;S 146°07'13&quot;E</td>
<td>BSk (arid, steppe, cold arid)</td>
<td>croplands grasslands</td>
<td>3600km² 13 permanent (oznet network) and 24 semi-permanent (SMAP network) 625km², 20 stations</td>
</tr>
<tr>
<td>Little Washita (USA, Oklahoma)</td>
<td>34°53'53&quot;N 98°04'44&quot;W</td>
<td>Cfa (warm temperature, fully humid, hot summer)</td>
<td>grasslands</td>
<td>1300km², 40 stations</td>
</tr>
<tr>
<td>TxSON (USA, Texas)</td>
<td>30°18'26&quot;N 98°46'13&quot;W</td>
<td>Cfa (warm temperature, fully humid, hot summer)</td>
<td>grasslands</td>
<td>1200km² 20 permanent (USDA &amp; NASA &amp; University of Iowa) and 40 temporary (SMAPVEx16 network)</td>
</tr>
<tr>
<td>South Fork (USA, Iowa)</td>
<td>42°27'20&quot;N 93°23'25&quot;W</td>
<td>Dfa (Snow, fully humid, hot summer)</td>
<td>croplands</td>
<td>300 km², 9 stations</td>
</tr>
</tbody>
</table>

**Additional test sites:**
- Wallerfing test site (Germany), ground campaign April-Sep 2016
- REMEDHUS network (Spain), 20 stations located within an area of 1225 km²
- The Hydrological Observatory (HOBE) in Denmark, 30 stations located in one SMOS pixel
SSM retrieved vs observed at low resolution (site scale)

Obs. SSM: average among all stations
Retr. S-1 SSM: average among pixels closest to each station

**TxSON**

<table>
<thead>
<tr>
<th></th>
<th>S-1</th>
<th>SMAP</th>
<th>SMOS</th>
<th>ASCAT</th>
</tr>
</thead>
<tbody>
<tr>
<td># dates</td>
<td>34</td>
<td>29</td>
<td>29</td>
<td>13</td>
</tr>
<tr>
<td>Correlation (R)</td>
<td>0.46</td>
<td>0.92</td>
<td>0.77</td>
<td>0.45</td>
</tr>
<tr>
<td>rmse % [v/v]</td>
<td>6.45</td>
<td>3.85</td>
<td>6.25</td>
<td>6.25</td>
</tr>
<tr>
<td>ubrmse % [v/v]</td>
<td>6.44</td>
<td>2.99</td>
<td>5.29</td>
<td>6.25</td>
</tr>
<tr>
<td>Mean-(x) (&lt;x&gt;) % [v/v]</td>
<td>18.90</td>
<td>17.98</td>
<td>18.04</td>
<td>16.52</td>
</tr>
<tr>
<td>Mean-(y) (&lt;y&gt;) % [v/v]</td>
<td>19.27</td>
<td>15.56</td>
<td>21.38</td>
<td>16.47</td>
</tr>
</tbody>
</table>

**Yanco & Apulian Tavoliere**

<table>
<thead>
<tr>
<th></th>
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<th>SMAP</th>
<th>SMOS</th>
<th>ASCAT</th>
</tr>
</thead>
<tbody>
<tr>
<td># dates</td>
<td>107</td>
<td>78</td>
<td>78</td>
<td>38</td>
</tr>
<tr>
<td>Correlation (R)</td>
<td>0.72</td>
<td>0.77</td>
<td>0.77</td>
<td>0.84</td>
</tr>
<tr>
<td>rmse % [v/v]</td>
<td>7.12</td>
<td>7.39</td>
<td>7.92</td>
<td>6.45</td>
</tr>
<tr>
<td>ubrmse % [v/v]</td>
<td>7.00</td>
<td>6.79</td>
<td>7.91</td>
<td>5.9</td>
</tr>
<tr>
<td>Mean-(x) (&lt;x&gt;) % [v/v]</td>
<td>21.41</td>
<td>21.68</td>
<td>21.68</td>
<td>19.39</td>
</tr>
<tr>
<td>Mean-(y) (&lt;y&gt;) % [v/v]</td>
<td>20.13</td>
<td>18.76</td>
<td>21.98</td>
<td>21.98</td>
</tr>
</tbody>
</table>
rmse & ubrmse per station (250m res)

single pixel SSM & no outlier analysis

**Yanco**
- 35 stations
- 20 rmse < 8 v/v %
- 23 ubrmse < 8 v/v %

**Apulian Tavoliere**
- 11 stations
- 6 rmse < 8 v/v %
- 8 ubrmse < 8 v/v %
Time series of obs & retr SSM over Yanco (250m res)

46 dates: from Dec 2014 to Feb 2017

Retr vs Obs SSM over Yanco & Apulian Tavoliere (250m res)

- # points: 1860
- # outliers: 55
- Correlation (R): 0.7
- rmse % [v/v]: 7.8
- ubrmse % [v/v]: 7.8
- Mean-x (<x>) % [v/v]: 18.66
- Mean-y (<y>) % [v/v]: 18.25
- Y=A+Bx
  - A=8.46 & B=0.52
SSM sampling error & its impact on linear regression

\[ n = \left( z_{\alpha/2} \frac{\sigma}{e} \right)^2 \]

Jacobs et al., RSE, 2004

error=±4% at 95% C.I.

error=±12% at 95% C.I.

12 SSM observations over an area of \( \sim 9 \times 9 \text{ km}^2 \)

SSM\text{\(_{\text{retr}}\)} = \alpha + \beta \text{SSM}_{\text{obs}} + \epsilon

\text{SSM}_{\text{obs}} = \text{SSM}_{\text{obs}} + \delta

E(\delta) = 0 \text{ and } \text{cov}(\epsilon, \delta) = 0

\text{std}(\delta) = 8 \%\]

\[ \text{mean obs/ret} \quad 21.02 / 20.28 \]

R

\[ \text{rmse/urmse} \quad 8.9 / 8.9 \]

A=6.69

\[ y=A+Bx \quad B=0.65 \]
Summary

- An initial validation of the STCD algorithm at **250 m resolution** indicates:
  - over the croplands & grazing sites of Yanco & Apulian Tavoliere an overall rmse/ubrmse $\sim 8$ v/v % & $R \sim 0.7$ (107 S-1 images from late 2014 to early 2017 & in situ SSM data gathered from 46 ground stations);
  - the **SSM measurement error** (related to the poor representativeness of a single measurement for a resolution cell of 250m x 250m) **significantly biases the performance of SSM retrieval at high resolution** → important to obtain reliable estimates of the SSM meas. err. at high resolution

- At low resolution (site scale) SMAP, SMOS performed better than S-1 SSM & ASCAT over the TXSON site, whereas ASCAT performed best over the Yanco & Apulian Tavoliere site
**TxSON**

- 29 Descending (PM) SMOS Level-3 product (daily map), release 300, from Centre Aval Traitement des Donnes (CADTS) - 25 km, EASE Grid Ver. 2.0 global projection
- 29 Ascending (PM) SMAP Level-3 product (daily map), release 4.010- 36km, EASE Grid ver 2.0 global projection
- 13 Ascending (PM) ASCAT H109/H110 product- 12.5km discrete global grid (DGG)
- SMOS / SMAP and ASCAT products closest to S-1 acquisitions (max 3-day difference) from mid April to December 2016 and from mid April to July 2016

**Yanco**

- 34 Ascending (AM) SMOS Level-3 product (daily map), release 300, from CADTS - 25 km, EASE Grid Ver. 2.0 global projection
- 34 Descending (AM) SMAP Level-3 product (daily map), release 4.010- 36km, EASE Grid ver 2.0 global projection
- 38 Descending (AM) ASCAT H109/H110 product- 12.5km discrete global grid (DGG)
- SMOS / SMAP and ASCAT products closest to S-1 acquisitions (max 3-day difference) from May 2015 to December 2016 and from January 2015 to July 2016.

**Apulian Tavoliere**

- 44 Descending (PM) SMOS Level-3 product (daily map), release 300, from CADTS - 25 km, EASE Grid Ver. 2.0 global projection
- 44 Ascending (PM) SMAP Level-3 product (daily map), release 4.010- 36km, EASE Grid ver 2.0 global projection
- 34 Ascending (PM) ASCAT H109/H110 product- 12.5 km discrete global grid (DGG)
- SMOS / SMAP and ASCAT products closest to S-1 acquisitions (max 2-day difference) from May 2015 to December 2016 and from January 2015 to July 2016.
ASCAT H109/H110: The soil moisture product represents the water content in the upper soil layer in relative units between totally dry conditions (0%) and total water capacity (100%). The time series are available on a discrete global grid (DGG) with a spatial resolution of 25 km (grid spacing 12.5 km).

ASCAT linear scaling:

$$ASCAT' = \frac{ASCAT}{100} \times (MAX_{obs} - MIN_{obs}) + MIN_{obs}$$

ASCAT resampling: The ASCAT maps were resampled to the EASE-2 12.5 km.

Resampling SSM estimates from the original grid into the EASE-2 grid was performed using a two-dimensional Hamming window function centered at every grid node. For each grid cell, the final resampled SSM estimate is obtained by means of a weighted average of SSM estimates in direct vicinity of the respective grid node. The weights are defined with the spatial distance.

When resampling, also the uncertainties associated with each SSM estimate located in the vicinity of the target EASE-2 grid cell were considered. So that SSM estimates associated with larger uncertainty were given less weight.