HIGH RESOLUTION SOIL MOISTURE CONTENT FROM SENTINEL-1 DATA

F. Mattia(1), A. Balenzano(1), G. Satalino(1), F. Lovergine(1), A. Loew (2), J. Peng(2&3), U. Wegmuller(4), M. Santoro(4), O. Cartus(4), K. Dabrowska-Zielinska(5), J. Musial(5) and M. W. J. Davidson(6)

(1) Consiglio Nazionale delle Ricerche (CNR), Ist. Studi sui Sist. Intell. per Aut. (ISSIA), Bari, Italy
(2) Ludwig-Maximilians Universität München (LMU) - Department of Geography, Germany
(3) Max Planck Institute for Meteorology, Hamburg, Germany
(4) Gamma Remote Sensing Research and Consulting AG (GAMMA), Gümligen, Switzerland
(5) Institute of Geodesy and Cartography (IGiK) - Remote Sensing Centre, Poland
(6) ESA, ESTEC, 2201, Noordwijk, The Netherlands

esa seom scientific exploitation of operational missions Exploit-S-1 Project

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:

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

SAR response dominated by soil attenuated scattering

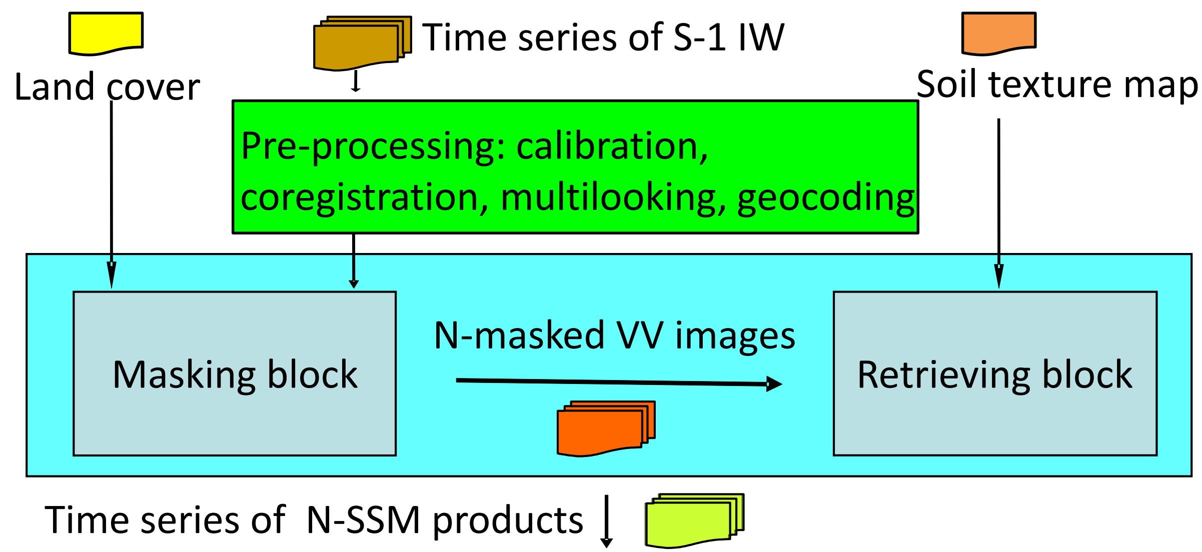
$$\frac{(\sigma_0)_{DoY(i+1)}}{(\sigma_0)_{DoY(i)}} \approx \frac{\left|\alpha_{pp}(\vartheta,\epsilon)\right|^2_{DoY(i+1)}}{\left|\alpha_{pp}(\vartheta,\epsilon)\right|^2_{DoY(i)}} \approx \frac{SSM_{DoY(i+1)}}{SSM_{DoY(i)}}$$

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 **MO**isture retrieval from multi-temporal **SAR** data (SMOSAR)



Validation plan: local scale

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

Site	Lat., Lon (centre)	Climate zone (Köppen-Geiger climate classification)	Land cover (International Geosphere-Bioshere Program)	Hydrological network (extension and number of stations)
Apulian Tavoliere (Italy)	41°22’13”N 15°29’23”E	Csa (warm temperature, summer dry, hot summer)	croplands	4km^2, 12 stations
Biebrza (Poland)	53°37’12”N 22°55’48”E	Dfb (snow, fully humid, warm summer, warm summer	marshlands grasslands	0.25 km^2 9 stations 0.13 km^2, 9 stations
Yanco (Australia)	34°50’39”S 146°07’13”E	BSk (arid, steppe, cold arid)	croplands grasslands	3600km^2 13 permanent (oznet network) and 24 semi-permanet (SMAP network)
Little Washita (USA, Oklahoma)	34°53’53”N 98°04’44”W	Cfa (warm temperature, fully humid, hot summer)	grasslands	625km^2, 20 stations
TxSON (USA, Texas)	30°18'26"N 98°46'13«W	Cfa (warm temperature, fully humid, hot summer)	grasslands	1300km^2 , 40 stations
South Fork (USA, Iowa)	42°27‘20"N 93°23’25’’W	Dfa (Snow, fully humid, hot summer)	croplands	1200km^2, 20 permanent (USDA & NASA & University of Iowa) and 40 temporary (SMAPVEx16 network)
Elm Creek (Canada)	98°0’23”W 49°40’48” N	Dfb (Snow, fully humid, warm summer)	croplands	300 km^2 , 9 stations

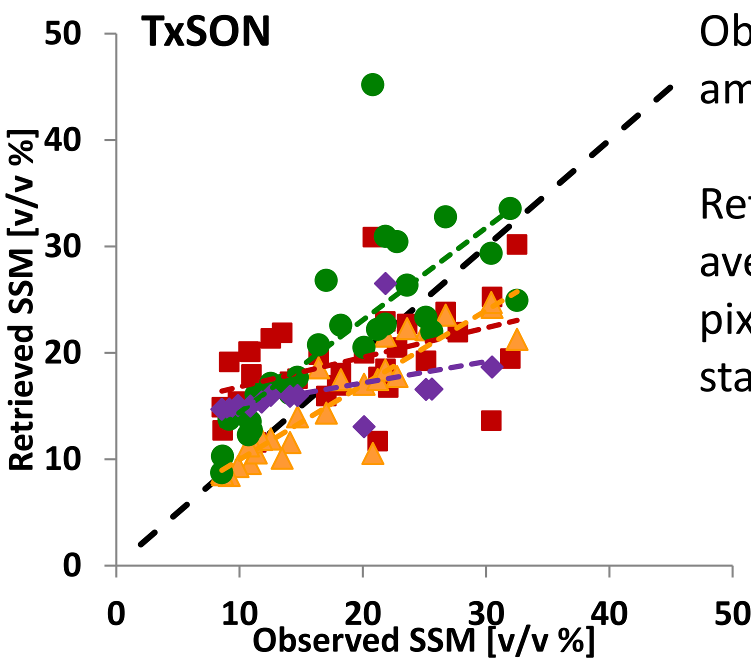





Additional test sites:

- Wallerfing test site (Germany), ground campaign April-Sep 2016
- REMEDHUS network (Spain), 20 stations located within an area of 1225 km^2
- The Hydrological Observatory (HOBE) in Denmark, 30 stations located in one SMOS pixel

SSM retrieved vs observed at low resolution (site scale)

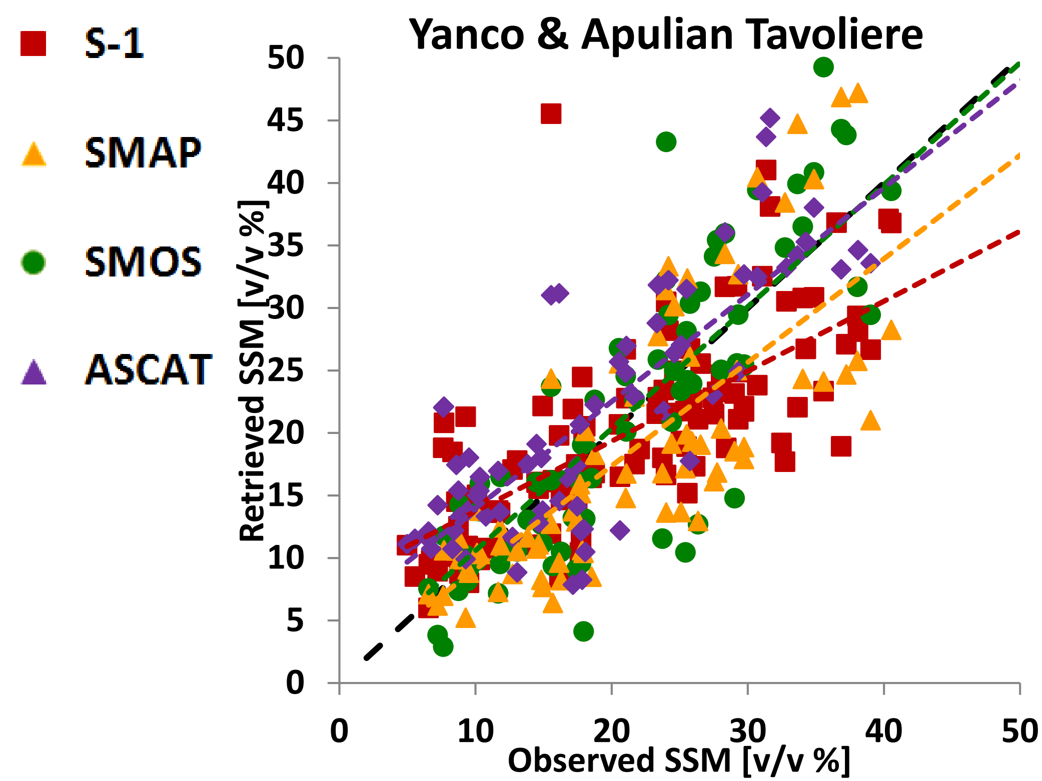


Obs. SSM: average among all stations

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

	S-1	SMAP	SMOS	ASCAT
# dates	107	78	78	38
Correlation (R)	0.72	0.77	0.77	0.84
rmse % [v/v]	7.12	7.39	7.92	6.45
ubrmse % [v/v]	7.00	6.79	7.91	5.9
Mean-x (<x>) % [v/v]	21.41	21.68	21.68	19.39
Mean-y (<y>) % [v/v]	20.13	18.76	21.98	21.98

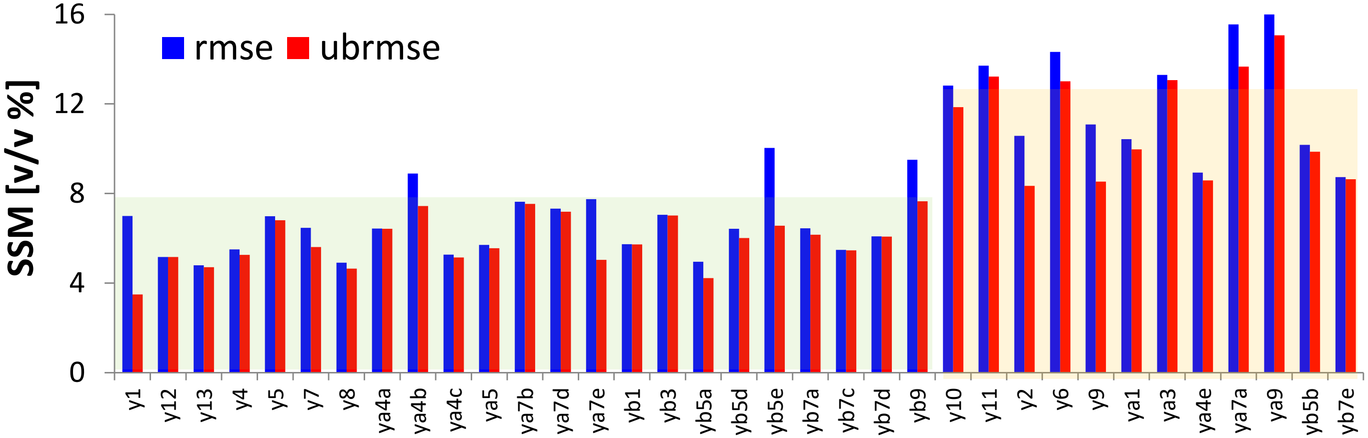
	S-1	SMAP	SMOS	ASCAT
# dates	34	29	29	13
Correlation (R)	0.46	0.92	0.77	0.45
rmse % [v/v]	6.45	3.85	6.25	6.25
ubrmse % [v/v]	6.44	2.99	5.29	6.25
Mean-x (<x>) % [v/v]	18.90	17.98	18.04	16.52
Mean-y (<y>) % [v/v]	19.27	15.56	21.38	16.47



rmse & ubrmse per station (250m res)

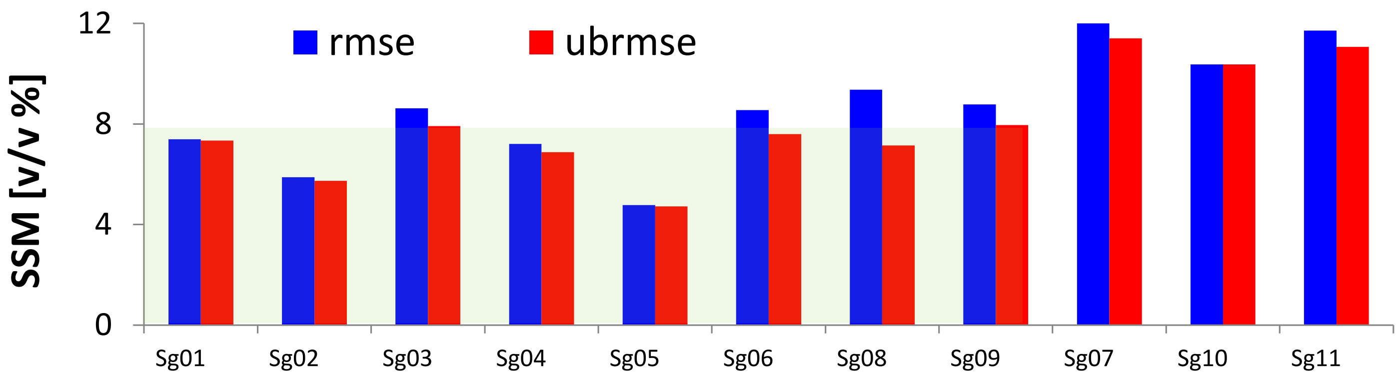
single pixel SSM & no outlier analysis

Yanco



35 stations
20 rmse < 8 v/v %
23 ubrmse < 8 v/v %

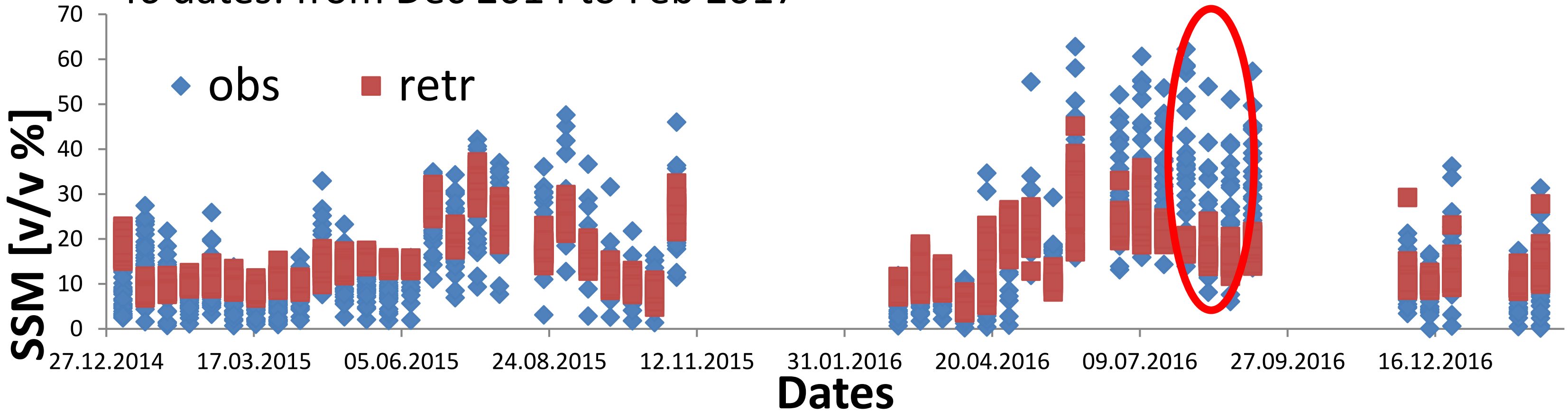
Apulian Tavoliere



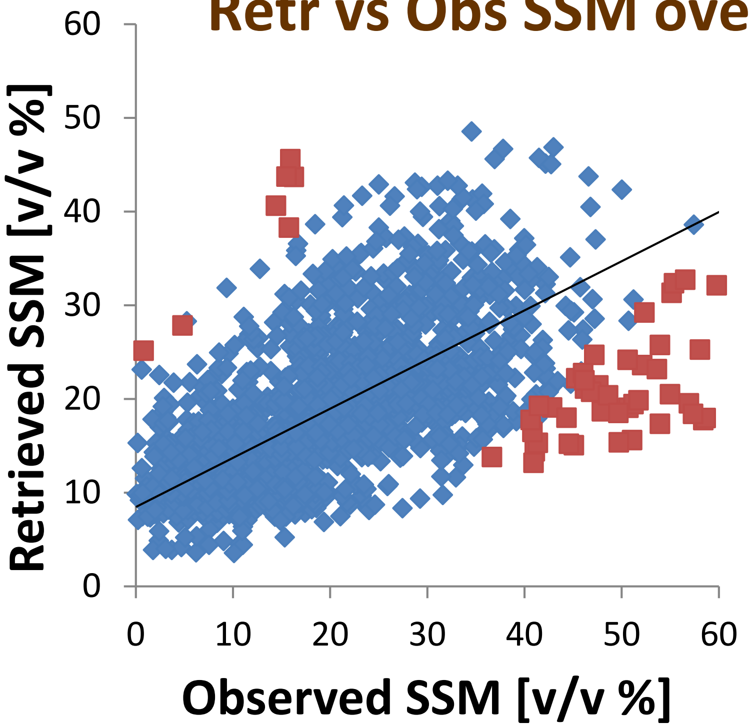
11 stations
6 rmse < 8 v/v %
8 ubrmse < 8 v/v %

Time series of obs & retr SSM over Yanco (250m res)

46 dates: from Dec 2014 to Feb 2017



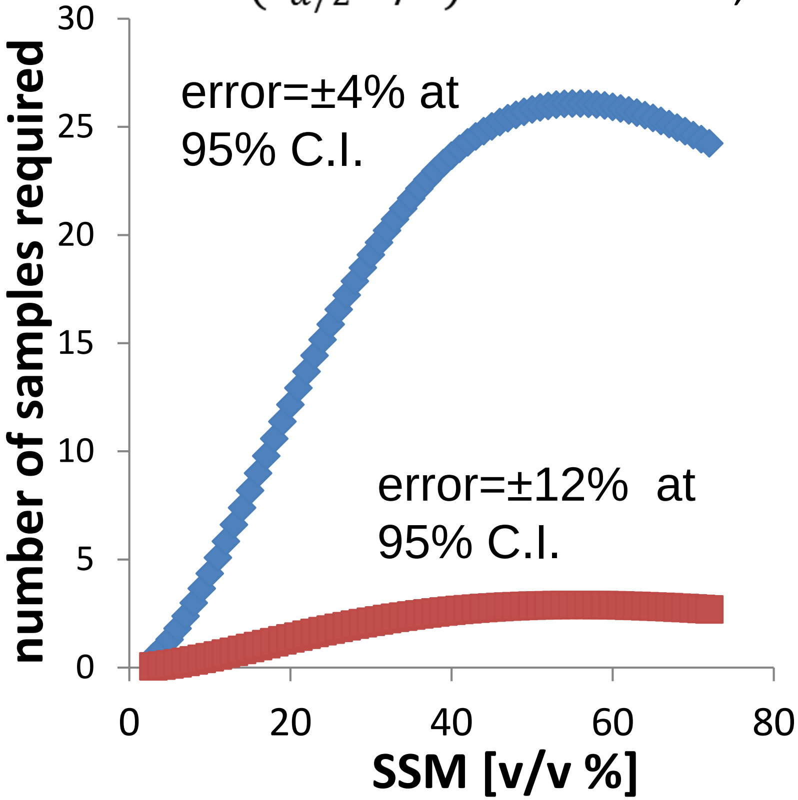
Retr vs Obs SSM over Yanco & Apulian Tavoliere (250m res)



# 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

$n = \left(z_{\alpha/2}\, \sigma / e\right)^2$ Jacobs et al., RSE, 2004



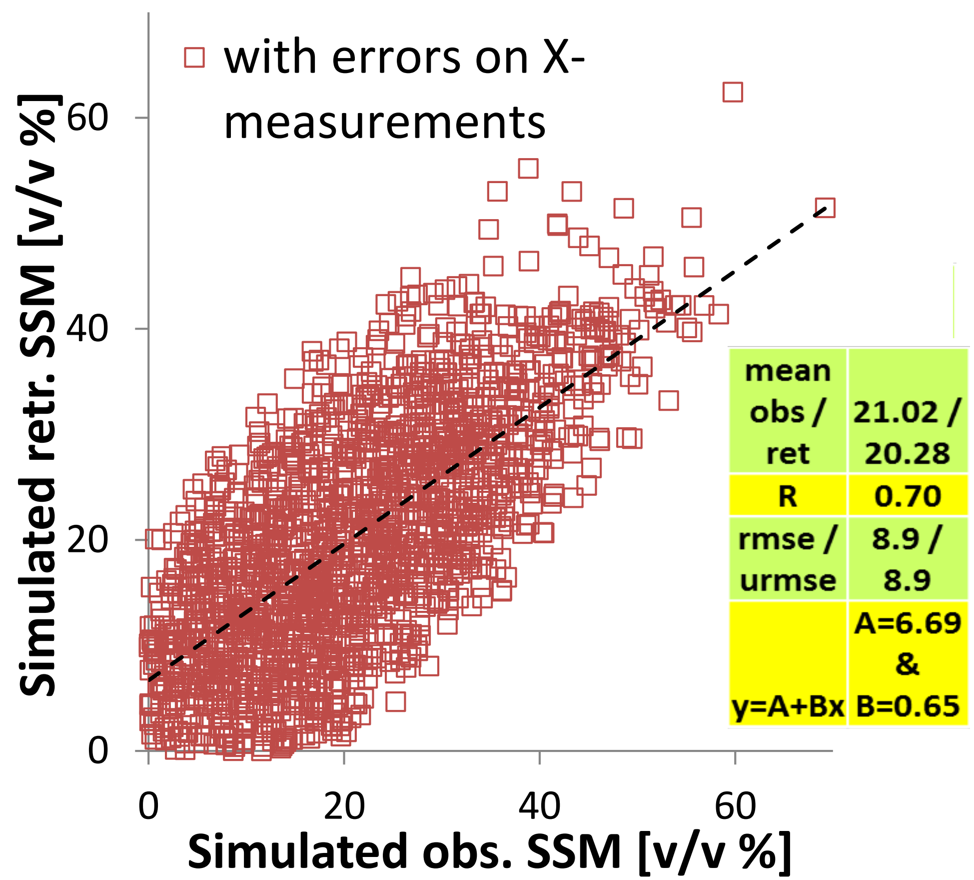
12 SSM observations over an area of ~ 9 x 9 km²

$$SSM_{retr} = \alpha + \beta\, SSM_{obs} + \epsilon$$

$$\widetilde{SSM}_{obs} = SSM_{obs} + \delta$$

$$E(\delta) = 0 \;\&\; cov(\varepsilon, \delta) = 0$$

$$std(\delta) = 8\,[\tfrac{v}{-}\%]$$



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 ~8 v/v % & R ~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 Traitment 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: $ASCAT' = \frac{ASCAT}{100} * (MAX_{obs} - MIN_{obs}) + MIN_{obs}$

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 .