Area-representative validation of remotely sensed high resolution soil moisture using a cosmic-ray neutron sensor

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Motivation

- Information about soil moisture is essential:
  - rainfall estimation, irrigation scheduling, drought monitoring, modeling of groundwater depletion, hydrological model and flood forecasting, runoff prediction.
- Traditional soil moisture probes provide point scale measurements, which is often not representative of the soil moisture conditions over a larger area. CRNS probes provide SM estimates over a larger area (approx. 20 ha). This makes them particularly interesting for the validation of satellite-based SM estimations.

Aim

- comparison of different high-resolution, satellite-based SM products with
  - Point-scale in situ measurements
  - area-representative in situ measurements
- investigate point-scale measurement vs larger area measurement

Datasets I - Earth Observation data

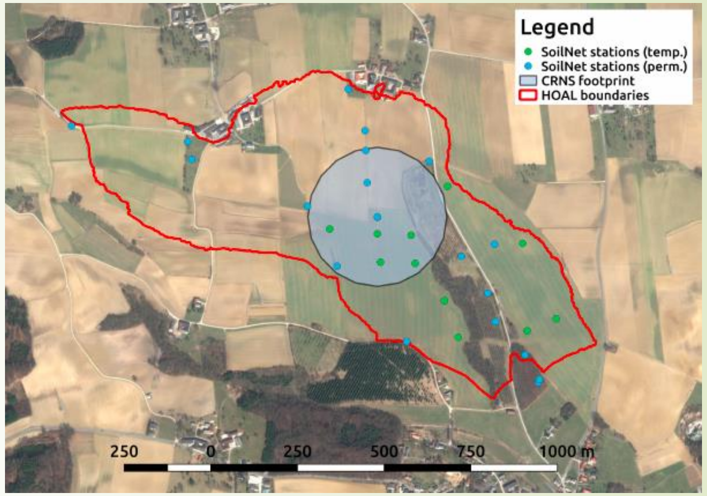
- SSM 1km
  - Input Sentinel-1 C-band SAR backscatter values - terrain geo-corrected and radiometrically calibrated
  - Change detection model – long term dry/wet conditions
  - relative water content of the top few centimeters soil - % saturation (1-100)
  - every 1.5-4 days over Europe
  - data can be obtained from Copernicus (https://land.copernicus.eu/global/products/ssm)

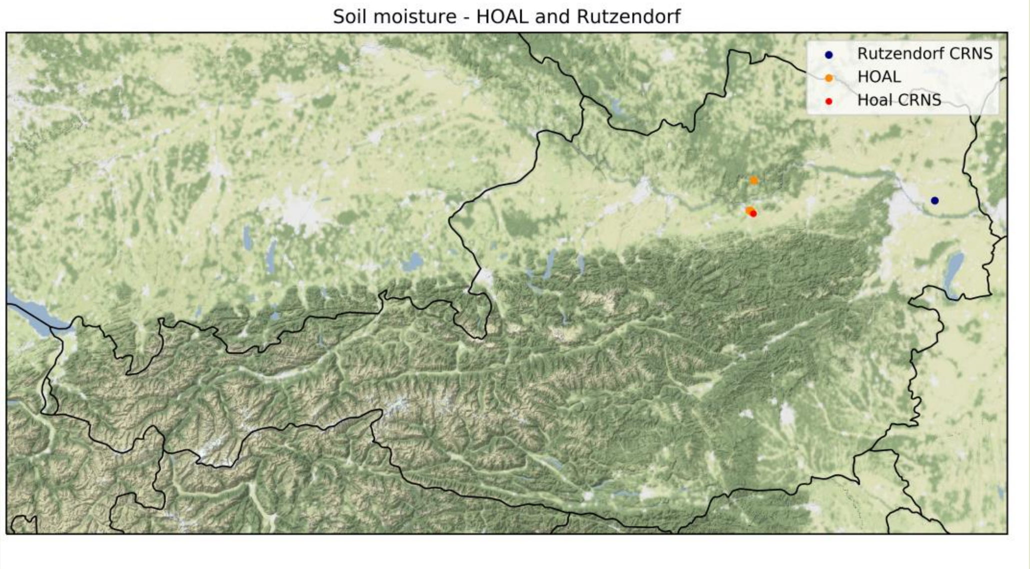
- SWI 1km
  - based on Surface Soil Moisture from Sentinel-1 C-band SAR and EUMETSAT H-SAF Metop ASCAT surface soil moisture
  - two-layer water balance model
  - moisture condition at several depths, daily basis
  - mainly driven by precipitation via infiltation
  - data can be obtained from Copernicus (https://land.copernicus.eu/global/products/swi)

- S1ASCAT
  - combination of Sentinel-1 backscatter and Meteo ASCAT backscatter
  - radar and scatterometer data
  - directional resampling method
  - improved vegetation parameterization, trend correction and snow masking
  - outputs: SSM (0-1 cm) and RZSM (0-40 cm)
  - research product that is currently developed at our institute

Datasets II – In situ data

- HOAL SoilNet (Petzenkirchen, Lower Austria)
  - 20 permanent stations in grassland, forest and field edges
  - 11 temporary stations in the middle of the fields
  - Agricultural catchment (66 ha)
  - Since 2013
- Hoal CRNS (Petzenkirchen, Lower Austria)
  - estimate SWC at scales 1-10 ha
  - Since 2013
- Rutzendorf CRNS (Lower Austria)
  - Filtered SWC data with Savitzky-Golay filter





CRNS (Cosmic-Ray Neutron Sensor)

- intensity of low-energy (1 keV) neutrons depends on the hydrogen content of soil
- neutron intensity and soil moisture content are inversely correlated
- measurement depth depends strongly on soil moisture, ranging from 0.76 m in dry soils to 0.12 m in wet soils
- soil moisture is calculated from neutron count data using calibration functions.
- Cosmic-Ray Neutron Probe (CRNP) installed in Petzenkirchen recorded hourly values of moderated neutron counts (counts per hour, cph), atmospheric pressure (hPa), air temperature (∘C), and relative humidity (%)
- further information can be found in paper by Trenton Franz et al.

Cosmic-Ray Neutron Probe

Photo taken from the paper:
Franz, Trenton E., et al. "Using cosmic-ray neutron probes to monitor landscape scale soil water content in mixed land use agricultural systems." Applied and Environmental Soil Science 2016 (2016).

Methods

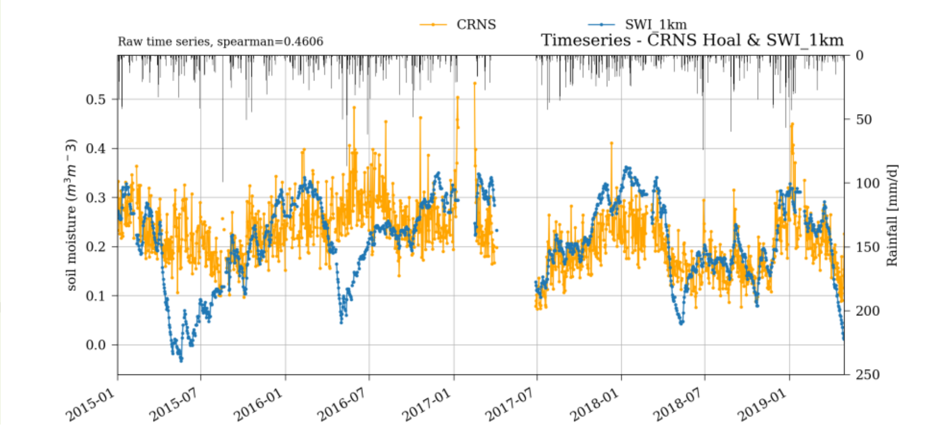
- Pre-processing:
  - Masking out for frozen conditions (ERA 5 data for snow cover and temperature)
  - Temporal matching
    - In situ soil moisture with S1ASCAT, SSM 1km and SWI 1km
  - Scaling (mean standard)
- Spearman correlation coefficient

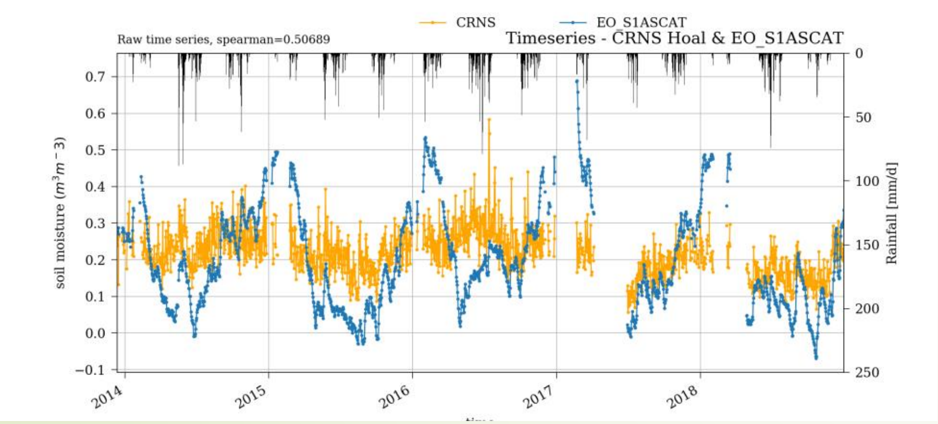
$$\rho_{XY} = \frac{\sigma_{rXrY}}{\sigma_{rX}\sigma_{rY}}$$

- $uRMSD = \sqrt{\frac{1}{N}\sum_{i=1}^{N}\left(X_i - Y_i^X\right)^2}$

Hoal CRNS (Cosmic-Ray Neutron Sensor)

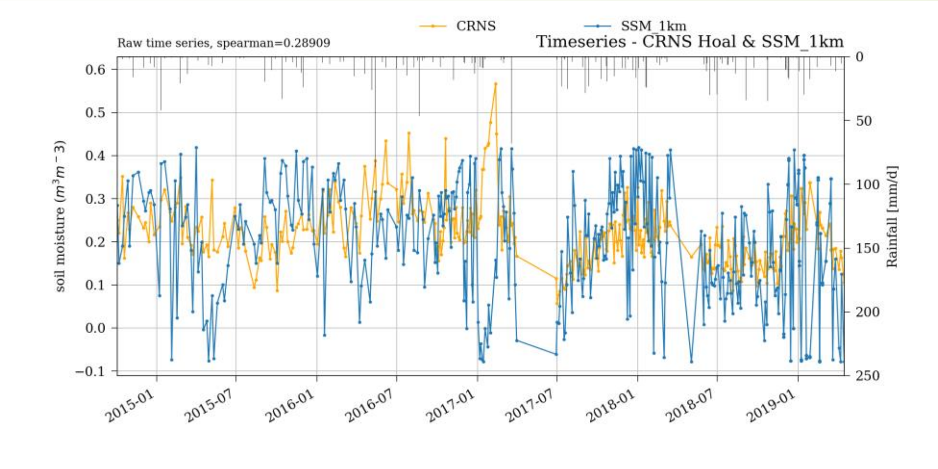
SWI 1km (SWI_010), $R_S = 0.46$





S1ASCAT (RZSM), $R_S = 0.51$

SSM 1km, $R_S = 0.29$



Field (CRNS footprint)	2016	2017	2018	2019
Northeast	Wheat	Corn	Corn	Wheat
Northwest	Corn	Wheat	Corn	Barley
South	Rapeseed	Wheat	Corn	Wheat

Crop types in the CRNS footprint

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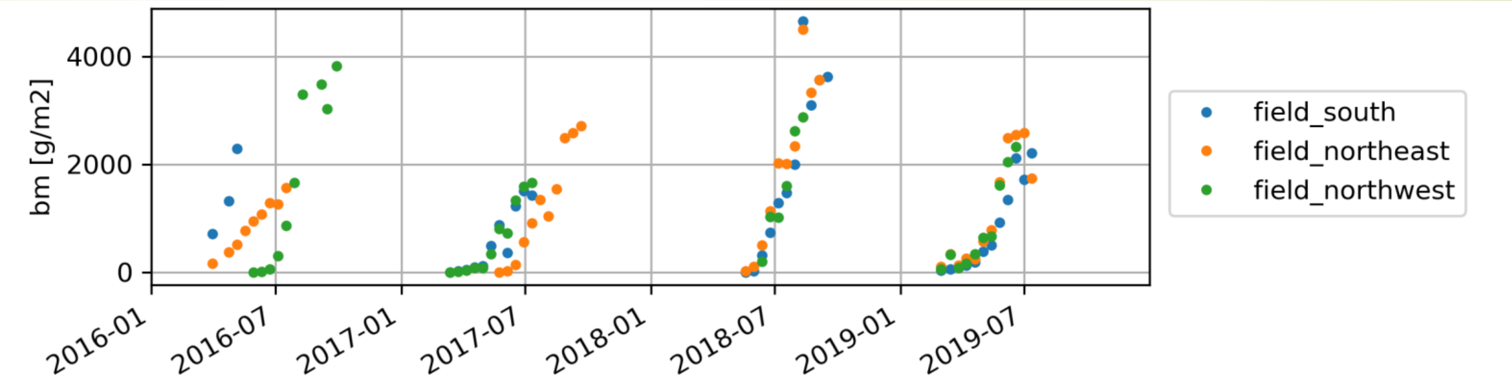
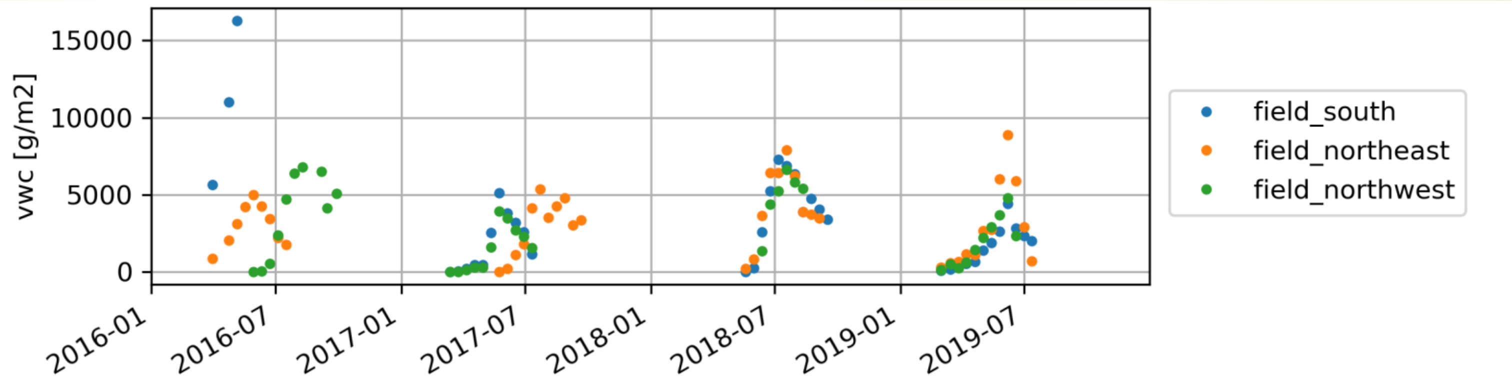
Hoal vegetation sampling

Biomass

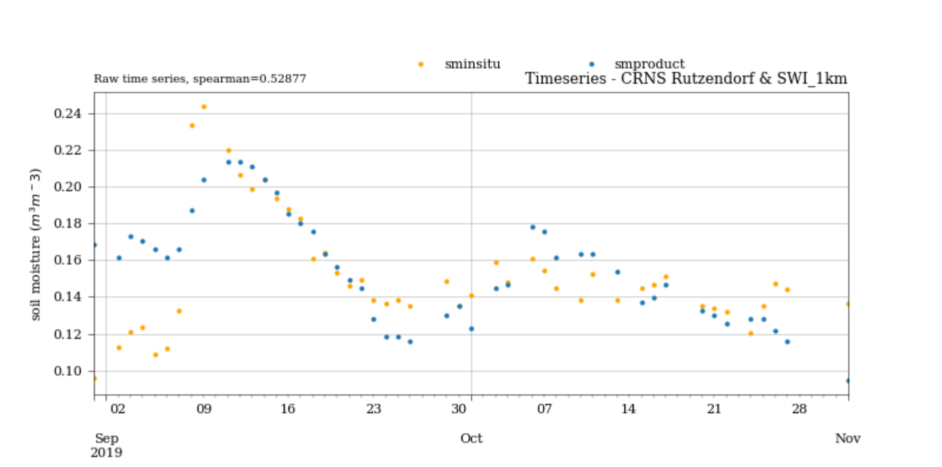


Vegetation water content

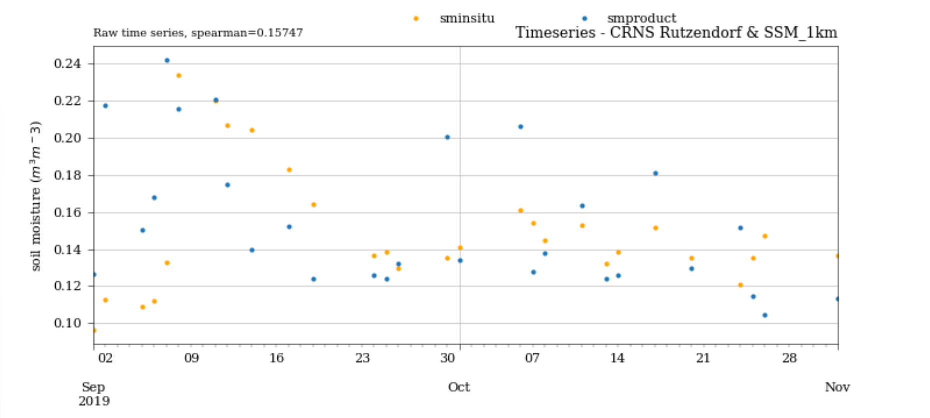


Rutzendorf CRNS (Cosmic-Ray Neutron Sensor)

- Raw time series of SWI 1km (SWI_010) and Rutzendorf CRNS
- $R_S = 0.53$

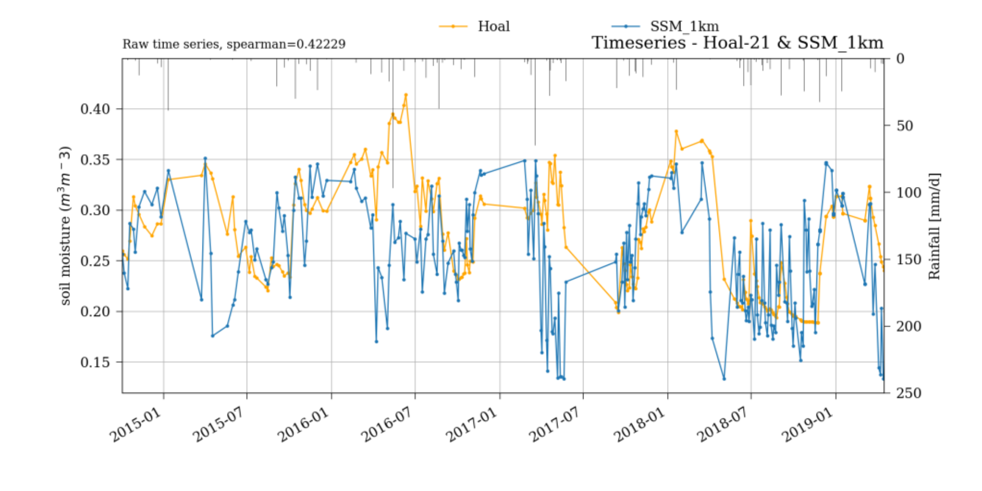


- Raw time series of SSM 1km and Rutzendorf CRNS
- $R_S = 0.16$
- S1ASCAT product is not yet processed for 2019 –> no figure for S1ASCAT and Rutzendorf CRNS

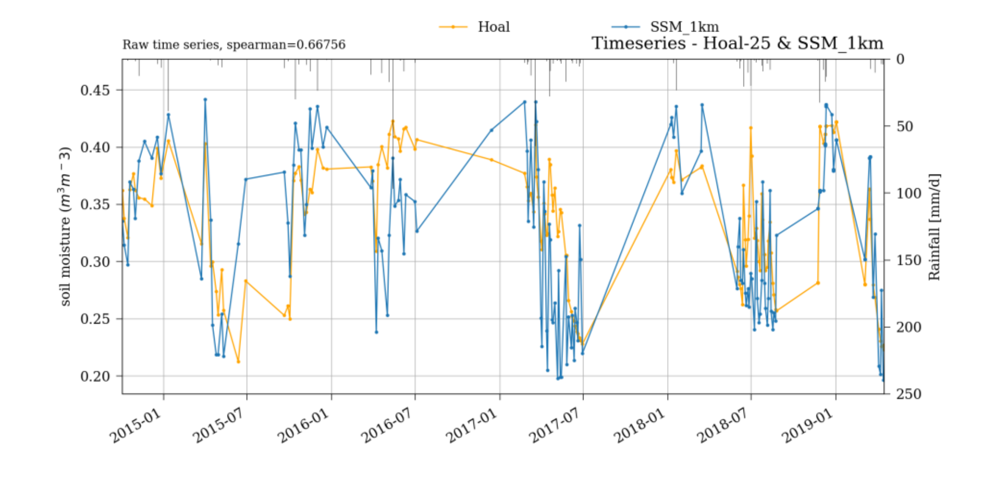


Results - SSM 1km and Hoal 21 & 25

- Raw time series of permanently installed Hoal-21 (SSM) and SSM 1km
- $R_S = 0.42$



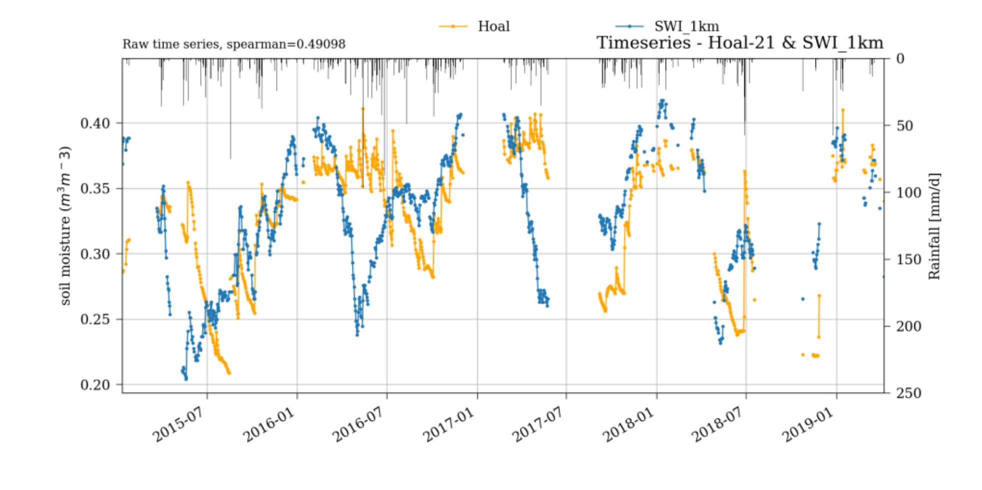
- Raw time series of temporary installed Hoal-25 (SSM) and SSM 1km
- $R_S = 0.67$



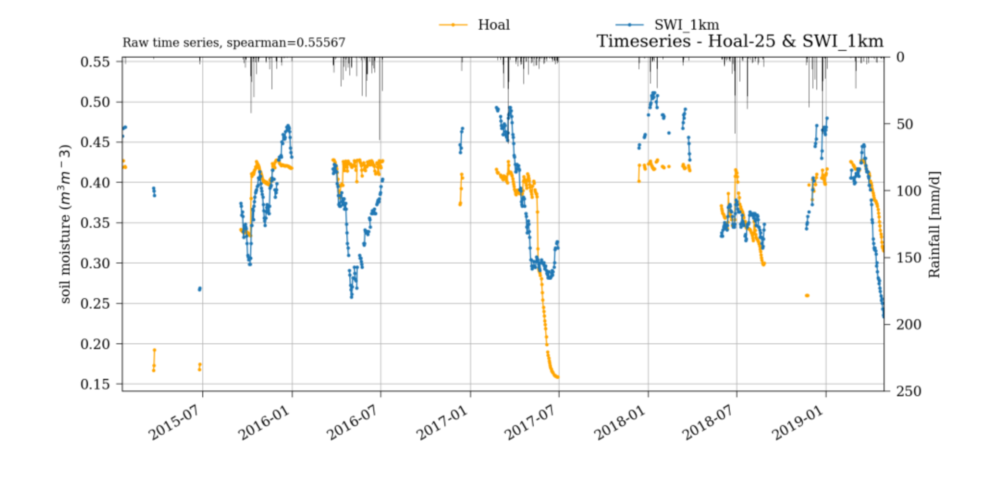
- Both stations are installed within the Hoal CRNS footprint

Results - SWI 1km and Hoal 21 & 25

- Raw time series of permanently installed Hoal-21 (RZSM) and SWI 1km (SWI_010)
- $R_S = 0.49$



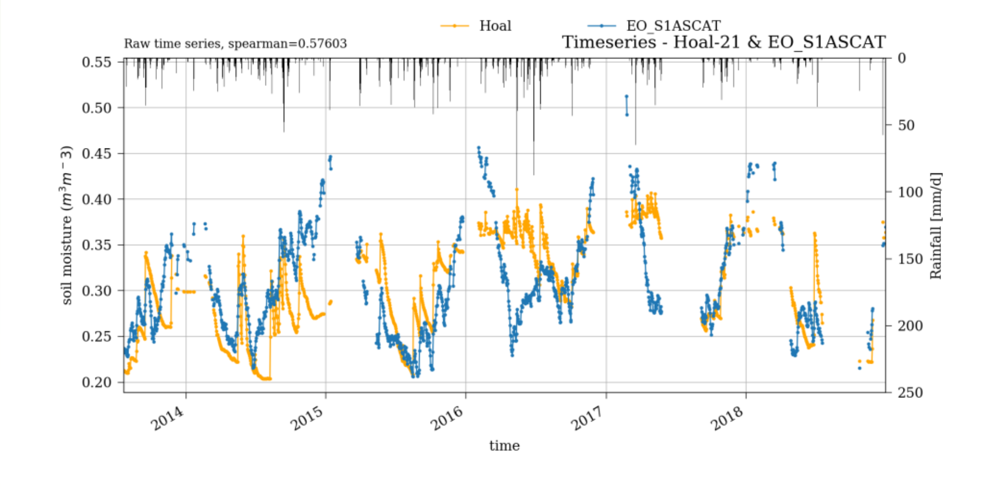
- Raw time series of temporary installed Hoal-25 (RZSM) and SWI 1km (SWI_010)
- $R_S = 0.55$



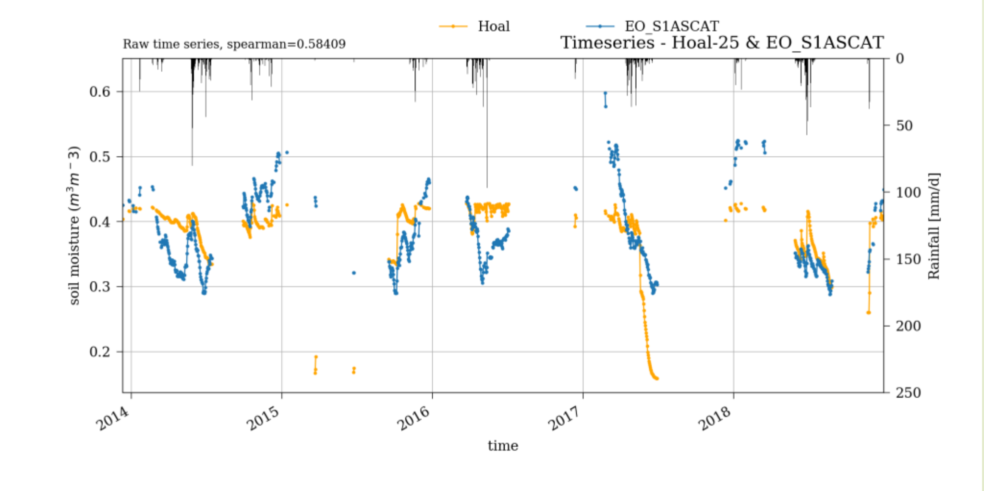
- Both stations are installed within the Hoal CRNS footprint

Results - S1ASCAT and Hoal 21 & 25

- Raw time series of permanently installed Hoal-21 (RZSM) and S1ASCAT 500m (RZSM)
- $R_S = 0.58$



- Raw time series of temporary installed Hoal-25 (RZSM) and S1ASCAT 500m (RZSM)
- $R_S = 0.58$

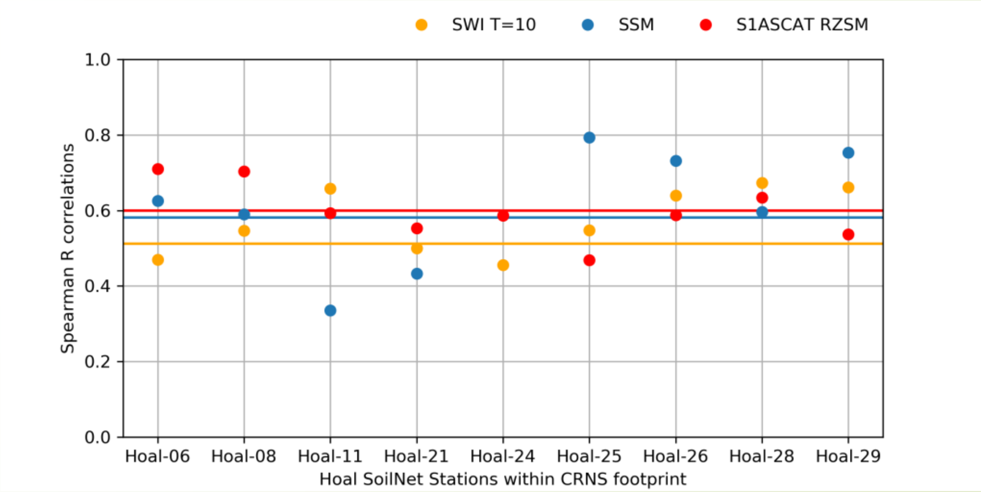


- Both stations are installed within the Hoal CRNS footprint

Results

- Correlations of the satellite products and SoilNet/CRNS are in a similar range (0.4 to 0.8).
- In some cases, CRNS has the lowest uRMSD, but in other cases it doesn't, requiring in-depth analysis of the time series and comparison to the crops grown in the respective fields during the study period. E.g., rapeseed or corn could cause higher biases because of the high vegetation water content.
- CRNS validation does not perform better than all, but a considerable number of point-scale sensors.
- SSM 1km product is most dependent on the location of the in situ sensor, it has the largest spread of correlation values. This could be because no vegetation correction is applied in this product.
- The seasonality of the new S1ASCAT product improved significantly due to the improved vegetation correction that is applied in this product.

Time	Depth	SWI 1km		SSM 1km		S1ASCAT	
		Rs	uRMSD	Rs	uRMSD	Rs	uRMSD
HOAL SoilNet	SSM	0,537	0,057	0,525	0,051	0,515	0,058
	RZSM	0,572	0,046			0,597	0,043
Hoal CRNS	SSM	0,431	0,085	0,289	0,140	0,448	0,123
	RZSM	0,461	0,085			0,507	0,123
Rutzendorf CRNS	SSM	0,338	0,030	0,157	0,042	no matched data	
	RZSM	0,529	0,026				



- Rutzendorf CRNS fits well to SWI 1km but not so well to SSM 1km – possible reason could be applied vegetation correction.

Summary & Outlook

- In general, CRNS definitely has the advantage to be representative of a larger area, as point-scale sensors are very dependent on their locations, e.g. related to topography and planted crop types.
- In the HOAL, the CRNS shows highest SM values in 2016, when rapeseed was planted in large parts of the footprint. However, 2016 was also the wettest year of the study period.
- Comparison with a fine-scale network of low-cost in situ sensors in Rutzendorf will be investigated for a more detailed analysis over this site.

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