# SARSENSE: A C- AND L-BAND SAR REHEARSAL CAMPAIGN IN GERMANY IN PREPARATION FOR ROSE-L

*Carsten Montzka[1], Cosimo Brogi[1], David Mengen[1], Maria Matveeva[2], Stephani Baum[2], Dirk Schüttemeyer[3], Bagher Bayat[1], Heye Bogena[1], Alex Coccia[4], Gerard Masalias[4], Verena Graf[2], Jannis Jakobi[1], Francois Jonard[1,5], Yueling Ma[1], Francesco Mattia[6], Davide Palmisano[6], Uwe Rascher[2], Guiseppe Satalino[6], Thomas Jagdhuber[7], Anke Fluhrer[7], Maike Schumacher[8], Marius Schmidt[1], and Harry Vereecken[1]*

[1]Forschungszentrum Jülich, Institute of Bio- and Geosciences: Agrosphere (IBG-3), Jülich, Germany
[2]Forschungszentrum Jülich, Institute of Bio- and Geosciences: Plant Sciences (IBG-2), Jülich, Germany
[3]European Space Agency, Mission Science Division, Noordwijk, Netherlands
[4]Metasensing BV, Noordwijk, The Netherlands
[5]Universite catholique de Louvain, Earth and Life Institute, Louvain-la-Neuve, Belgium
[6]Consiglio Nazionale delle Ricerche (CNR), Institute for Electromagnetic Sensing of the Environment (IREA), Bari, Italy
[7]German Aerospace Center, Microwaves and Radar Institute, Wessling, Germany
[8]University of Hohenheim, Data Assimilation in the Earth System, Stuttgart, Germany

## ABSTRACT

In summer 2019 the SARSense campaign was held in Jülich, Germany, to provide insights into the potentials and specifications of the ESA Copernicus candidate mission ROSE-L (Radar Observation System for Europe). ROSE-L will consist of two satellites that carry a polarimetric L-band SAR. Since the L-band signal can penetrate through many natural materials such as vegetation, dry snow and ice, the mission will provide additional information that cannot be gathered by the Copernicus Sentinel-1 C-band SAR mission.
The overall objective of the SARSense 2019 campaign is to analyze the mission design concerning its potential for agricultural monitoring services including target applications such as soil moisture monitoring, irrigation management, crop type discrimination, food security and precision farming. The SARSense in situ measurements of soil moisture, soil temperature, vegetation properties, UAS-based multispectral and thermal mapping, as well as the airborne SAR observations are presented as well as strategies for soil moisture retrieval and first analysis.

***Index Terms—*** SAR, L-Band, ROSE-L, Airborne Campaign

## 1. INTRODUCTION

The L-band Radar Observation System for Europe (ROSE-L) is one of the six ESA second-generation Copernicus (Copernicus2.0) missions that have been put forward during the Space19+ ministerial meeting in November 2019. ROSE-L will carry an L-band Synthetic Aperture Radar (SAR) to target applications such as: soil moisture monitoring, land cover mapping, crop type and status discrimination, forest type/forest cover, biomass estimation, food security and precision farming, maritime surveillance and natural and anthropogenic hazards. In addition, the mission will contribute to the operational monitoring of the cryosphere and polar regions including sea ice mapping and land ice monitoring.
As compared to the C-band of the Sentinel-1 SAR mission, the longer L-band signal is capable of penetrating through vegetation, thus providing additional information due to the observation of a larger soil volume (up to ~5cm depth). As ROSE-L is planned to fly in short distance from Sentinel-1, synergies between the different microwave frequencies are envisaged, but still needs to be specified.
Within this context, the SARSense field campaign was performed on the TERENO research station Selhausen located near Jülich, Germany [1]. The site was selected because of its diverse agricultural cropping structure, heterogeneous subsurface and multiple research activities that support the hydro-ecological characterization of the region. In situ measurements, unmanned aerial systems (UAS) mapping, as well as airborne C- and L-band SAR observations were performed simultaneously to address the main objectives of SARSense, i.e.:

- To investigate the use of L- and C-band SAR data for soil moisture retrieval at high resolution (i.e., <100m). Both the case of temporally collocated L- and C-band SAR time series and that of independent acquisitions will be investigated.
- To extend the existing airborne SAR programme to new test sites (i.e., Jülich, Germany) and acquire reference L- and C-band airborne SAR datasets collocated in time and space over different well-defined land covers.
- To document the added value of L-band SAR in addressing current EO measurement gaps (soil moisture, vegetation biomass, etc.) and enhanced continuity together with other missions such as Sentinel-1.
- To support specification of the time interval between Sentinel-1 and L-band SAR coverage for time-critical application products, e.g., soil moisture.
- To support trade-off and definition of other key mission parameters in the coming mission phases (noise floor, resolution).

A description of the activities is given in the following together with first soil moisture retrieval and vegetation parameter estimation results.

## 2. THE TERENO SITE SELHAUSEN

The region for the SARSense 2019 campaign encompasses the TERENO (Terrestrial Environmental Observatories) Rur hydrological observatory with a focus on the Selhausen test site (50.865°N, 6.447°E, about 100–110 m asl) [1]. The Selhausen test site consists of 52 agricultural fields covering an area of about 1 by 1 km (Figure 1) and represents the heterogeneous agricultural area of the lower Rhine valley. Main crops are sugar beet, winter wheat, winter barley, maize, and rapeseed.

The region belongs to the temperate maritime climate zone, with a mean annual temperature and precipitation of 10.2°C and 714 mm, respectively. The soil was classified as a Cambisol with a silty loam texture.

An eddy covariance (EC) flux station in Selhausen is maintained according to ICOS class 1 standards (www.icos-ri.eu). Besides flux measurements and typical meteorological parameters, the phenological development of the crops and farming activities are also recorded on a weekly to monthly basis. Groundwater level, water conductivity, and temperature in a groundwater well next to the EC station are continuously measured.

Large-scale investigations were performed by using multi-configuration electromagnetic induction (EMI) systems pulled by an all-terrain vehicle to noninvasively investigate the structure, composition, and hydraulic state of the subsurface. Results show that the Selhausen area is characterized by a series of river terraces, where satellite-based leaf area index data obtained after a dry period showed distinct patterns due to the presence of paleochannel structures in the subsurface of the upper terrace [2, 3]. It could be shown that these patterns in leaf area index correlated well with electric conductivity patterns obtained for deeper soil layers [4].

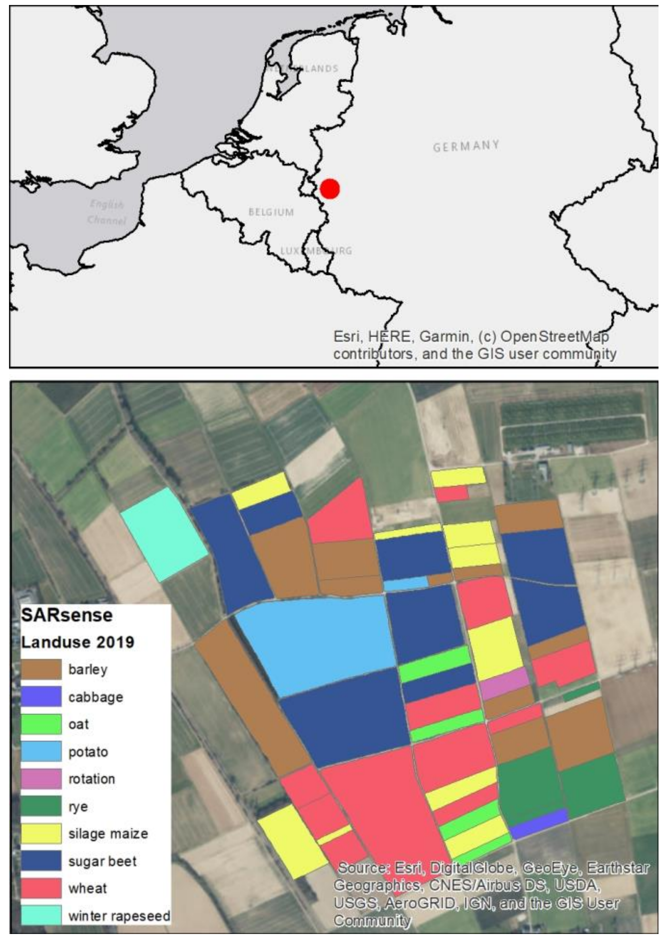


Figure 1: Location of the SARSense region Selhausen, Germany, (top) and land use during campaign (bottom).

During SARSense another airborne campaign was performed in Selhausen (FLEXSense), rehearsing the mission strategies for the Earth Explorer FLEX and the second-generation Copernicus LSTM and CHIME missions. Airborne observations with the instruments HyPlant (hyperspectral, solar induced fluorescence) and TASI (multispectral thermal) were obtained in line with supporting in situ and UAS measurements. This opens the opportunity to link information on soil moisture, plant structure, and vegetation functioning from multiple sensors [5].

Active and passive airborne L-band microwave measurements were obtained in the area since 2010 [6-8], as it is a soil moisture validation site for several satellite missions (SMOS, SMAP, ALOS-2). SARSense is also supported by hydrological simulations and data assimilation studies [9, 10] and space-borne multispectral vegetation estimations [2, 11].

## 3. IN SITU MEASUREMENTS

At the following six dates in situ soil moisture measurements were performed simultaneously with airborne observations:

- Week 25: 19.06.2019 and 21.06.2019
- Week 26: 25.06.2019 and 27.06.2019
- Week 32: 08.08.2019 and 09.08.2019

Vegetation measurements and UAV flights were also performed temporally close to those dates.
Soil moisture and soil temperature were recorded with Hydra Probes within the whole Selhausen study area (Figure 2).

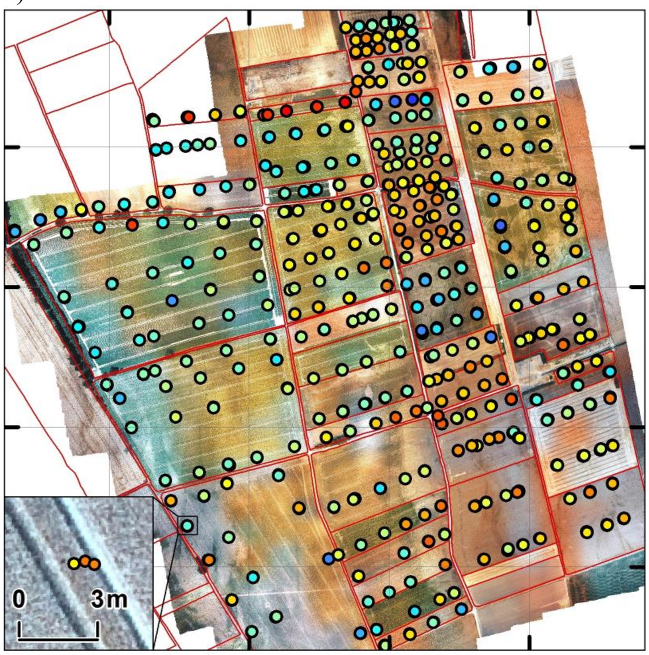


Figure 2: Example of soil moisture sampling (circles) on June 21st, 2019 at the Selhausen site. Colours represent the soil moisture from red = 0% to blue = 22%.

The sampling scheme considered the subsoil texture as well as the crop cultivation. Each point was measured three times within an area of ~1m$^2$ to account for small-scale soil moisture variability. In total, more than 5000 soil moisture measurements were obtained during the six campaign days.
A SoilNet wireless sensor network with SMT100 sensors (Trübner Precision Instruments, Germany) consisting of five profiles (depths of −0.01, −0.05, −0.1, −0.2, −0.5, and −1 m) is operated in one field to measure soil moisture and soil temperature in near real-time. The Jülich cosmic rover recorded neutron counts on June 27th and August 8th 2019 for the full flight area to estimate areal soil moisture [12]. It consists of an array of 9 detector units, each holding 4 $_{10}BF^{3}$-filled tubes, summing up to a total of 36 cosmic-ray probes. A joint soil moisture and vegetation analysis with L-band SAR and cosmic ray neutron count signals is foreseen [13, 14]. Unmanned Aerial Systems (UAS) measurements were performed during the campaign period providing RGB maps, temperature data (FLIR VUE Pro 640) as well as 5 channel multispectral (Micasense RedEdge-M) measurements. Vegetation sampling was performed according to the heterogeneity in soil and vegetation, providing leaf area index, fresh and dry weight as well as gravimetric vegetation water content.

## 4. AIRBORNE SAR MEASUREMENTS

The airborne polarimetric (dual linear, V and H) SAR datasets at C- and L-band were acquired and processed by Metasensing. The dual-frequency system was operated on board a Cessna 208 at a nominal altitude of 5500 ft, resulting in a left side looking configuration with an antenna look angle of 45°. While at C-band the planned 200 MHz signal bandwidth could be transmitted, at L- band only 50 MHz were allowed by the local authorities, resulting in a coarser image resolution. An example of processed SAR data is given in Figure 3.

Figure 3: Example of processed SAR data (HH) simultaneously acquired during the SARSense campaign. Top: L-band, bottom: C-band.

## 5. CONCLUSIONS

During the SARSense campaign 2019 an extensive set of measurements was collected enabling the detailed analysis of SAR signals regarding both soil and vegetation characteristics in a central European agricultural system, like Selhausen. The differences between L- and C-band SAR are analyzed with respect to the ROSE-L mission targets/goals, but also according to the added value of an L-band SAR mission.
In the presentation we will include strategies for soil moisture retrieval and first analyses, e.g. with the approaches of [15-18]. An analysis of soil moisture and vegetation effects on cosmic ray neutron counts and L-/C-band SAR as well as potential synergies is foreseen. Similarly, synergies between SAR and hyperspectral, solar induced fluorescence and thermal measurements will be analyzed.

## 6. ACKNOWLEDGEMENTS

The SARSense campaign was performed under ESA Contract No. 4000125444/18/NL/LF. We acknowledge also support from the German Federal Ministry of Economics and Energy for the AssimEO project under the grant 50EE1914A and from the Helmholtz research infrastructure MOSES (Modular Observation Solutions for Earth Systems).

## REFERENCES

[1] H. R. Bogena *et al.*, "The TERENO-Rur Hydrological Observatory: A Multiscale Multi-Compartment Research Platform for the Advancement of Hydrological Science," *Vadose Zone Journal,* vol. 17, no. 1, Jul 2 2018.

[2] M. Ali, C. Montzka, A. Stadler, G. Menz, F. Thonfeld, and H. Vereecken, "Estimation and Validation of RapidEye-Based Time-Series of Leaf Area Index for Winter Wheat in the Rur Catchment (Germany)," *Remote Sensing,* vol. 7, no. 3, pp. 2808-2831, 2015.

[3] C. Brogi *et al.*, "Large-scale soil mapping using multi-configuration EMI and supervised image classification," *Geoderma,* vol. 335, pp. 133-148, Feb 1 2019.

[4] S. Rudolph *et al.*, "Linking satellite derived LAI patterns with subsoil heterogeneity using large-scale ground-based electromagnetic induction measurements," *Geoderma,* vol. 241–242, no. 0, pp. 262-271, 3// 2015.

[5] C. von Hebel *et al.*, "Understanding Soil and Plant Interaction by Combining Ground-Based Quantitative Electromagnetic Induction and Airborne Hyperspectral Data," *Geophysical Research Letters,* vol. 45, no. 15, pp. 7571-7579, Aug 16 2018.

[6] S. Hasan, C. Montzka, C. Rüdiger, M. Ali, H. Bogena, and H. Vereecken, "Soil moisture retrieval from airborne L-band passive microwave using high resolution multispectral data," *ISPRS Journal of Photogrammetry and Remote Sensing,* vol. 91, pp. 59-71, 2014.

[7] C. Montzka *et al.*, "Estimation of Radiative Transfer Parameters from L-Band Passive Microwave Brightness Temperatures Using Advanced Data Assimilation," *Vadose Zone Journal,* vol. 12, no. 3, Aug 2013.

[8] C. Montzka *et al.*, "Investigation of SMAP fusion algorithms with airborne active and passive L-band microwave remote sensing," *IEEE Trans. Geosc. Rem. Sens.,* vol. 54, no. 7, pp. 3878 - 3889, 2016.

[9] H. Post *et al.*, "Evaluation and uncertainty analysis of regional-scale CLM4.5 net carbon flux estimates," *Biogeosciences,* vol. 15, no. 1, pp. 187-208, Jan 10 2018.

[10] X. Han, H.-J. Hendricks Franssen, X. Li, Y. Zhang, C. Montzka, and H. Vereecken, "Joint Assimilation of Surface Temperature and L-Band Microwave Brightness Temperature in Land Data Assimilation," *Vadose Zone Journal,* vol. 12, no. 3, 2013.

[11] T. G. Reichenau *et al.*, "Spatial Heterogeneity of Leaf Area Index (LAI) and Its Temporal Course on Arable Land: Combining Field Measurements, Remote Sensing and Simulation in a Comprehensive Data Analysis Approach (CDAA)," *Plos One,* vol. 11, no. 7, Jul 8 2016.

[12] J. Jakobi, J. A. Huisman, M. Schrön, J. Fiedler, C. Brogi, and H. Bogena, "Error estimation with for soil moisture measurements from with cosmic-ray neutron sensing and with implications for rover surveys," *Frontiers in Water,* to be submitted.

[13] J. Jakobi, J. A. Huisman, H. Vereecken, B. Diekkruger, and H. R. Bogena, "Cosmic Ray Neutron Sensing for Simultaneous Soil Water Content and Biomass Quantification in Drought Conditions," *Water Resources Research,* vol. 54, no. 10, pp. 7383-7402, Oct 2018.

[14] B. Fersch, T. Jagdhuber, M. Schron, I. Volksch, and M. Jager, "Synergies for Soil Moisture Retrieval Across Scales From Airborne Polarimetric SAR, Cosmic Ray Neutron Roving, and an In Situ Sensor Network," *Water Resources Research,* vol. 54, no. 11, pp. 9364-9383, Nov 2018.

[15] T. Jagdhuber, I. Hajnsek, and K. P. Papathanassiou, "An Iterative, Generalized Hybrid Decomposition for Soil Moisture Retrieval under Vegetation Cover Using Fully Polarimetric SAR," *IEEE Journal of Selected Topics in Applied Earth Observations and Remote Sensing,* pp. 1-12, 2014.

[16] F. Mattia, G. Satalino, V. R. N. Pauwels, and A. Loew, "Soil moisture retrieval through a merging of multi-temporal L-band SAR data and hydrologic modelling," *Hydrology and Earth System Sciences,* vol. 13, no. 3, pp. 343-356, 2009.

[17] J. D. Ouellette *et al.*, "A Time-Series Approach to Estimating Soil Moisture From Vegetated Surfaces Using L-Band Radar Backscatter," *Ieee Transactions on Geoscience and Remote Sensing,* vol. 55, no. 6, pp. 3186-3193, Jun 2017.

[18] S. H. Alemohammad, T. Jagdhuber, M. Moghaddam, and D. Entekhabi, "Soil and Vegetation Scattering Contributions in L-Band and P-Band Polarimetric SAR Observations," *Ieee Transactions on Geoscience and Remote Sensing,* vol. 57, no. 11, pp. 8417-8429, Nov 2019.