Updating the SwissSMEX soil moisture monitoring network infrastructure to secure the continuity of the long-term data series and ensure the data quality

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FINAL REPORT

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1 Summary

Soil moisture is an essential climate variable (ECV) defined by GCOS. This property is being monitored in Switzerland since 2008 within the SwissSMEX project in 19 soil profiles at 17 stations. The GCOS Switzerland SMiLE-ECV-CH project (2019-2022) has proven the value of collecting in-situ soil moisture measurements across Switzerland as ground-truth reference, e.g., for the evaluation of remote sensing products of this ECV. A SMiLE-ECV-CH study on the SwissSMEX data quality and availability pointed out the impact on degrading sensor functionality over the course of time. Even though the soil moisture network is equipped with redundant measurement profiles at each of the 12 grassland stations, a third of all sensors and three entire stations (when considering depth-integrated profile soil moisture) have been lost since 2009. These findings got the attention of GCOS Switzerland for the current one-off support project, aiming at securing the continuity of the existing infrastructure.

The current project aimed at securing the continuity and quality of the network in the mid- to long-term by updating the SwissSMEX grassland stations with modern sensors. The installation of new high-quality sensors at all SwissSMEX grassland sites in a consistent array facilitates and secures the monitoring of soil moisture in Switzerland in the future and ensures the continuation of the long-term climatologies at these locations. A strategy for consistent long-term monitoring of soil moisture in Switzerland, including the Alpine region, is currently being planned on the national level with different institutions, under the coordination of MeteoSwiss and BAFU.

2 Scientific report

2.1 Introduction

Climate projections indicate an increasing risk of dry and hot episodes in Central Europe, including in Switzerland (Seneviratne et al., 2010, 2013; Vogel et al. 2017, Seneviratne et al. 2012). Land hydrological variables play an essential role for these projections. This is particularly the case for soil moisture, which is directly affecting the exchange of land moisture and energy with the atmosphere, and plays a key role in the development of droughts and heatwaves in summer in both present and future climate (Seneviratne et al., 2010, 2016, Vogel et al., 2017, Hirschi et al. 2011, Miralles et al. 2014). Since 2008, the SwissSMEX project (Mittelbach and Seneviratne, 2012) is monitoring soil moisture at 19 stations within 17 sites[1] (14 grassland, 1 arable and 4 forest stations). These constitute the main coordinated long-term measurement series for the soil moisture ECV in Switzerland. The SwissSMEX measurements have been used in several applications, for instance for the derivation of European-scale gridded estimates of soil moisture and evaporation (Orth and Seneviratne, 2015). The recent 2015, 2018 and 2022 droughts in Switzerland have highlighted the importance of monitoring and assessing changes in land hydrology, in particular soil moisture and land evaporation which are strongly related to drought impacts on agriculture, forestry, and ecosystems (Seneviratne et al., 2013).

The GCOS Switzerland SMiLE-ECV-CH project (2019-2022) provided an assessment of the monitoring capabilities for the soil moisture and land evaporation ECVs in Switzerland, addressing issues such as quality control of measured data. The quality assessment and intercomparison of the existing soil moisture data series of the SwissSMEX network has pointed out a degradation of data availability due to sensor failures over time, compromising the long-term continuity of the data series (see Figure 1). This encouraged the current follow-up project aiming at upgrading the soil moisture observation network and securing the continuity of the measurements with new sensors in a consistent fashion across all grassland sites. This project contributes directly to the GCOS Pillar 3 in the GCOS Switzerland Strategy.

The analyses have been performed by members of the land-climate dynamics group with Dr. Dominik Michel, Dr. Martin Hirschi, and Prof. Sonia I. Seneviratne as main investigators. Dr. Michael Rösch supported the technical field work. Ms. Rahel Buri was the administrative assistants on the project.

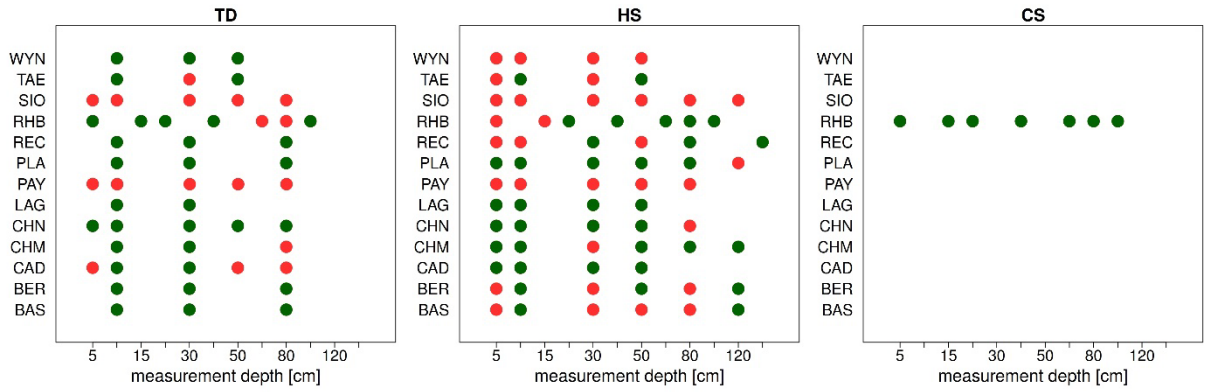

Figure 1: Status overview of sensor availability at the SwissSMEX grassland stations (as of Oct. 2022). Green dots indicate available data and functioning sensors, red dots indicate sensors with an error quote of more than 20% in the last 30 days, i.e., are considered out of order or not available. This is a condensed view incorporating all redundant sensor profiles per sensor type: TRIME-PICO TDR (TD), Campbell Scientific CS616 (CS), Decagon 10HS (HS).

[1] One site (Oensingen), including three stations, was discontinued in 2013.

2.2 Methods and activities

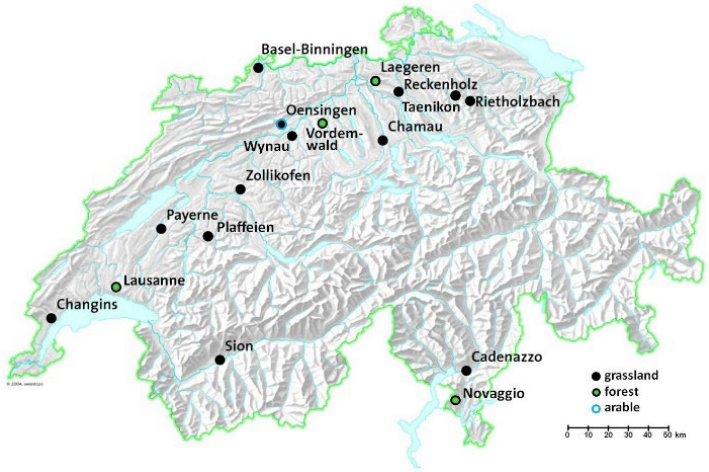

Figure 2: Location of the SwissSMEX soil moisture sites. The current project focuses on the available 12 grassland sites. Note that Oensingen was discontinued in 2013.

The station upgrade is limited to the available 12 grassland sites, which encompass the main data base of SwissSMEX (all-black dots in Figure 2). The grassland stations are all equipped with at least two volumetric water content (VWC) profiles: One using TRIME-PICO32/64 sensors (IMKO, Germany), and one using 10HS capacitance sensors (formerly Decagon, USA). The number of available depth levels from 5 cm to a maximum of 120 cm varies across the network. At some stations, there are redundant profiles of the same sensor type available. At the Rietholzabch site a third profile is in place, using CS616 water content reflectometers (Campbell Scientific, USA).

Over the course of the period May-June 2021 the soil moisture stations were first assessed individually with respect to the current station status, the options of re-using existing infrastructure (individual sensors, data loggers, modems etc.), and the conditions relevant for the installation of new sensors (soil structure, vehicular access). In general, updating the monitoring stations was planned without interference with the ongoing measurements (i.e., establish redundant measurements) in order to use the overlapping period for an inter-comparison of the sensors as well as a re-calibration of past measurements with the new high-standard sensors. Two scenarios for the station upgrade were evaluated, essentially using two different TDR sensors: One being the relatively new SoilVUE10 probe (Campbell scientific, USA, Figure 3) and the other the TRIME-PICO64, which was already operational at all SwissSMEX sites. From August to September 2021, three SoilVUE10 sensors with different lengths have been installed in Cadenazzo (CAD, 0.5 m sensor), Rietholzbach RHB (RHB, 0.5 and 1 m sensors) and Tänikon (TAE, 0.5 m sensor). Until May 2022, their soil moisture series have been monitored and evaluated against the long-term measurements, with additional gravitational probes at the Rietholzbach site, see Fig. 4. From June to August 2022, the remaining grassland stations have been upgraded with SoilVUE10 sensors (0.5 m sensors) as well as TRIME-PICO64 at 10 and 30 cm.

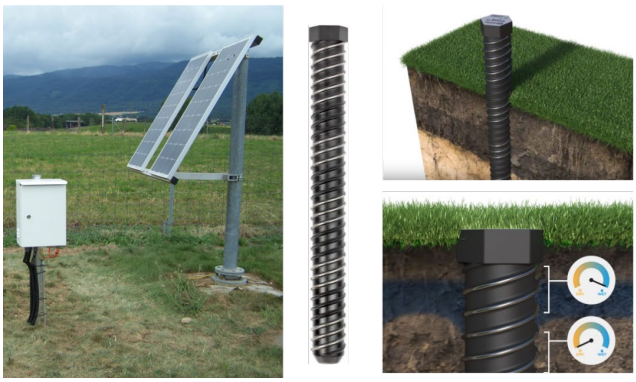

Figure 3: Example of a SwissSMEX station (left) and SoilVUE10 sensor (middle, right).

2.3 Results

In the Figures 4 and 5 the SoilVUE10 soil moisture data are displayed together with the available long-term data. Figure 4 shows data since August 2021 from the first three stations equipped with the new sensor (CAD, RHB, TAE), while Figure 5 shows all remaining available data series since January 2022. Note that automatic data updates from the Payerne station (not shown) are currently missing, as communication is not possible due to technical difficulties, yet the measurements are assumed to be running. In Sion, we are lacking updates for currently unknown reasons.

It is apparent that the dynamic of soil moisture is very well captured by the SoilVUE10 sensors at the eleven available stations, in comparison to the long-term TDR and capacitance measurements. However, in terms of the absolute value of volumetric soil moisture, it seems that the SoilVUE10 partly underestimates the water content at rather low water content levels, i.e., below 0.2 m^3/m^3. In RHB, the gravimetric probes at 5 to 35 cm depth, which are considered to reflect the true soil water content at a given point in time, indicate that the SoilVUE10 readings are substantially more accurate than the long-term TDR measurements. In this specific case, however, the long-term data are known to show unrealistically high values of more than 0.8 m^3/m^3. The reason for the underestimation of soil moisture in dry conditions with the SoilVUE10 will be investigated in detail in an ongoing MSc thesis at ETH.

The discrepancy of the long-term measurements to the new SoilVUE10 sensors might be influenced by the fact that the installation of the latter was mainly conducted during the dry summer of 2022. As the TDR method relies on good contact between the sensor and the soil, wet conditions are favorable for the installation, i.e., when the soil is soft. Namely in Sion, Bern, Tänikon and Wynau this was not the case, as the soil was either extremely dry and hard (Sion, Bern) or stony/gravelly (Tänikon, Wynau). At the last two stations, the soil is largely heaped up (construction) debris. It will be interesting to see whether the agreement of the long-term measurements and the new sensor types improves in wet conditions during winter 2022/2023.

Additionally, the variability of the SoilVUE10 is partly larger than that of the long-term sensors, e.g., in RHB at 5 cm depth. It is not known whether this is related to technical reasons and will also be investigated in the MSc thesis.

In general, it can be stated that the use of SoilVUE10 is a comparably cheap and quick method to obtain spatio-temporally highly resolved information on the soil moisture dynamics, i.e., wetting and drying. When long-term data are available, this would also allow to monitor drought events. If the absolute amount of water in the soil during dry periods is of interest, however, the SoilVUE10 sensors are outperformed by the more expensive TRIME-PICO TDR sensors, based on the currently available data.

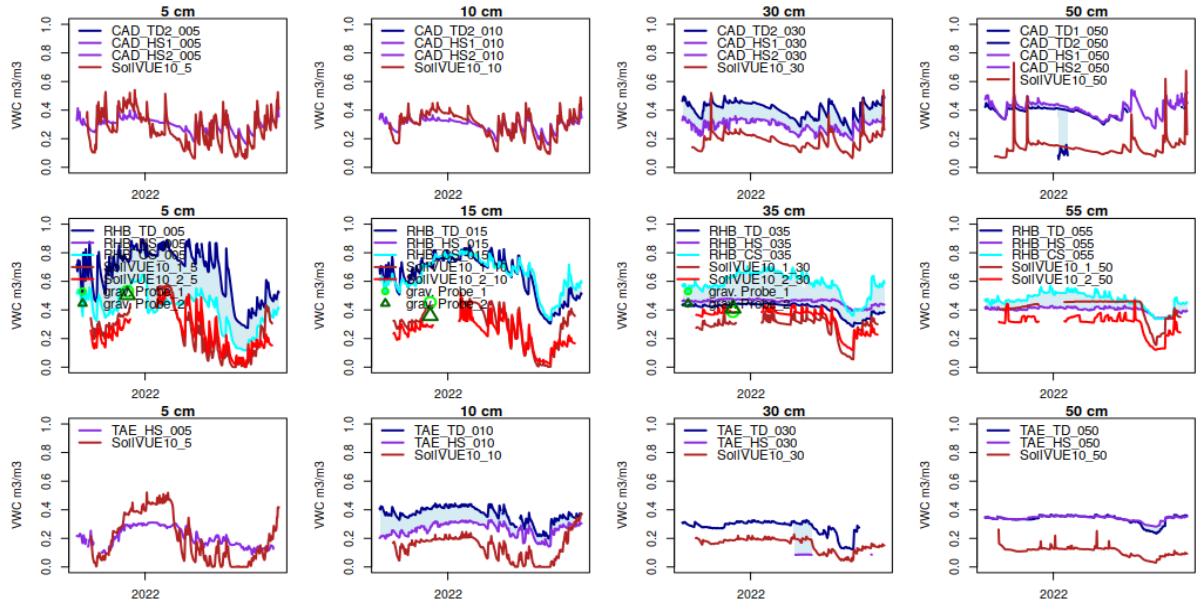

Figure 4: Daily values of volumetric soil moisture since August 2021 at 5, 10, 30 and 50 cm depth at Cadenazzo, Rietholzbach, Tänikon, measured with long-term SwissSMEX soil moisture sensors (blue/purple) and SOILVUE10 soil moisture sensors (red lines). The light blue shading indicates the range of the long-term measurements (if applicable).

2.4 Conclusions and limitations

The project could be concluded on time, with all the sensors operational at the pre-defined sites. Only from Payerne (PAY) and Sion (SIO) we are lacking station updates, as direct communication with these stations is currently not possible. At this stage, we are working on a solution for regular updates from PAY and we expect to be able to resolve the technical issues with SIO in the near future. We expect that at least in PAY the data series is continuous without any data gaps up to date. In SIO, a data gap due to the current technical issue is likely. In general, the agreement of the SoilVUE10 sensors to the long-term reference measurements is good, above all in terms of the soil moisture dynamic. In particular in very dry conditions, however, the new sensor seems to underestimate the water content. Having at least one complete hydrological year of data available at every station will be beneficial for reaching a more robust conclusion on the uncertainty and performance of the new SoilVUE10 sensor.

2.5 Outreach work, publication of results and data

The findings on the performance of the SoilVUE10 sensors have been communicated within the *Arbeitsgruppe Nationales Bodenfeuchtemessnetz* and contribute substantially to the national soil moisture monitoring strategy, which is currently being outlined and planned on the national level under the coordination of MeteoSwiss and BAFU.

The newly available soil moisture data are analyzed in detail in the ETH MSc thesis *In situ evaluation of different soil moisture sensor types in the SwissSMEX network*, which started on 1st October 2022.

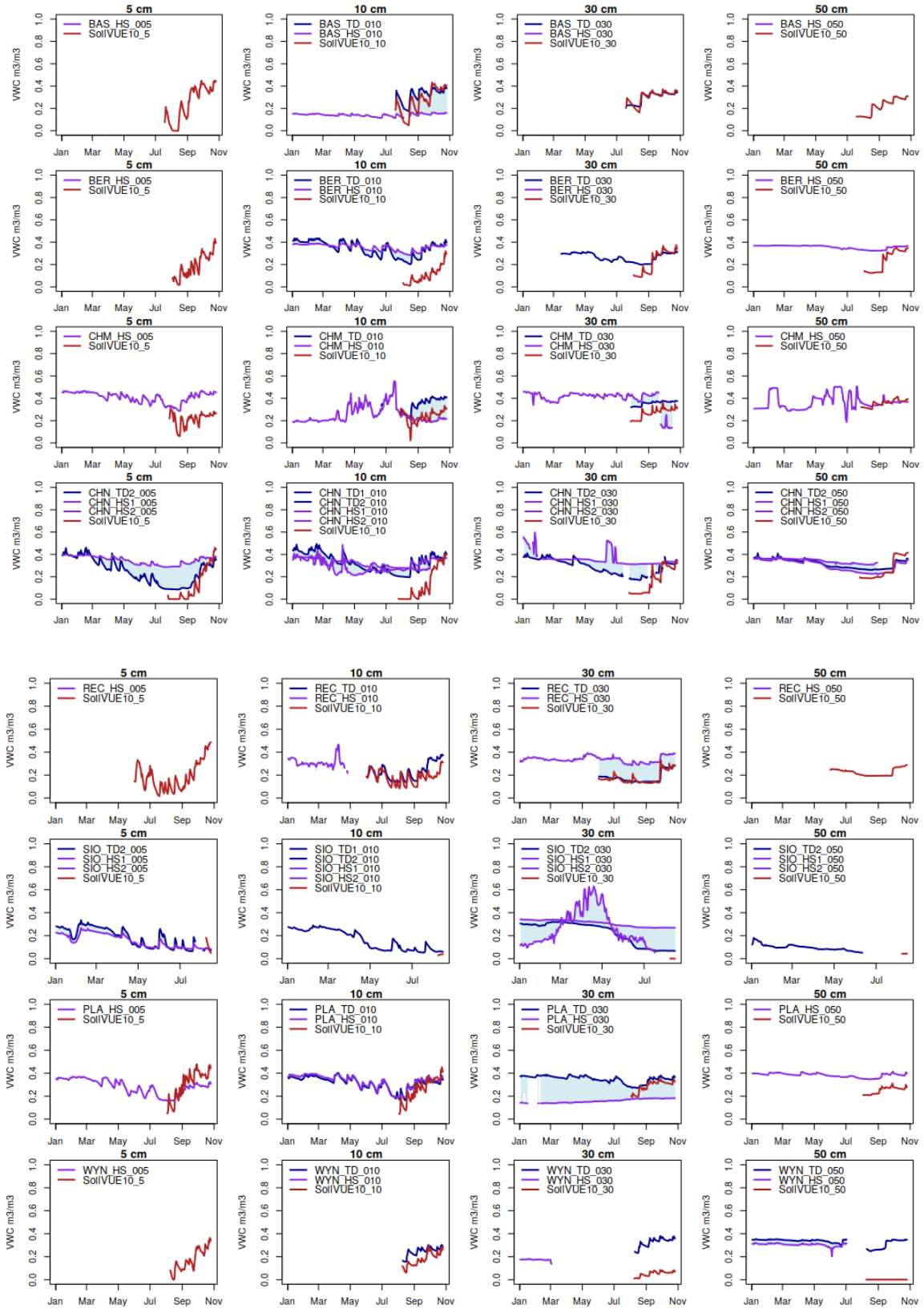

Figure 5: Daily values of volumetric soil moisture in 2022 at 5, 10, 30 and 50 cm depth at SwissSMEX grassland stations, measured with long-term SwissSMEX soil moisture sensors (blue/purple) and SOILVUE10 soil moisture sensors (red lines). The light blue shading indicates the range of the long-term measurements (if applicable).

2.6 Outlook

The connectivity problems in Payerne and technical issues in Sion should be resolved in the near future. We hope to gain more robust insight into the performance of the SoilVUE10 sensor under varying soil conditions from the analyses in the current MSc thesis. This will also help us assess the suitability of the new sensor for long-term measurements.

2.8 References

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