Annex I – JRP protocol

Version Date: 13 October 2022

21GRD08 SoMMet

Metrology for multi-scale monitoring of soil moisture

Start date: 01 October 2022

Duration: 36 months

Coordinator
Miroslav Zboril
PTB

Glossary

ARPAE	Regional Environmental Protection Agency of Emilia-Romagna, Italy
BSS	Bonner sphere spectrometers
CEOS	Committee on Earth Observation Satellites
cKF	Colorimetric Karl Fischer Titration
COSMOS	Cosmic-ray soil moisture monitoring network, originated in the USA; nowadays, several COSMOS networks exist worldwide, e.g., COSMOS-UK, TERENO (Germany), CosmOz (Australia), COSMOS-India
CRNS	Cosmic-Ray Neutron Sensing method, also cosmic-ray sensing or ground albedo neutron sensing
DWD	Deutscher Wetterdienst, German Weather Service
EAA	Environment Agency Austria
ECV	Essential Climate Variables
eLTER RI	EU Project on Integrated European Long-Term Ecosystem Critical Zone & Socio-ecological Research Infrastructure, a European Strategy Forum on Research Infrastructure (ESFRI)
ESA-ESRIN	ESA Centre for Earth Observation
EUMETSAT	European Organisation for the Exploitation of Meteorological Satellites
FAO	Food and Agriculture Organisation
GCOS	Global Climate Observing System
GSRN	GCOS Surface Reference Network
IAEA	International Atomic Energy Agency
ICWRGC	International Centre for Water Resources and Global Change
ISMN	International Soil Moisture Network
LoD	Loss-on-Drying method
MC	Monte Carlo simulation
MCNP	Monte-Carlo N-Particle Transport Code
MeV	Mega electron Volt (energy unit)
NASA	National Aeronautics and Space Administration
NIR	Near Infrared
QA/QC	Quality Assurance and Quality Control
SAR	Synthetic Aperture Radar
SC-MINT	Standing Committee on Measurement, Instrumentation and Traceability
SM	Soil Moisture
SMAP	Soil Moisture Active and Passive, NASA Satellite mission
SMOS	Soil Moisture and Ocean Salinity, ESA Satellite mission
SSM	Surface Soil Moisture
TERENO	Terrestrial Environmental Observatories in Germany
TGA	Thermogravimetric Analysis
UAS	Unmanned Aircraft System
UNESCO	United Nations Educational, Scientific and Cultural Organisation

Contents

Section A: Key data

A1 Project data summary

Coordinator contact details:

Coordinator:	Miroslav Zboril
Address:	PTB, Bundesallee 100, DE-38116 Braunschweig, Germany
Phone:	+49 531 592 6536
Email:	miroslav.zboril@ptb.de

Participant details:

a. Participants

no.	Participant Type	Short Name	Organisation legal full name	Country
1	Internal Beneficiary	PTB	Physikalisch-Technische Bundesanstalt	Germany
2	Internal Beneficiary	CIEMAT	Centro de investigaciones energeticas, medioambientales y tecnologicas	Spain
3	Internal Beneficiary	CMI	Cesky Metrologicky Institut	Czechia
4	Internal Beneficiary	DTI	Teknologisk Institut	Denmark
5	Internal Beneficiary	INRIM	Istituto Nazionale di Ricerca Metrologica	Italy
6	Internal Beneficiary	IRSN	Institut de Radioprotection et de Surete Nucleaire	France
7	Internal Beneficiary	JV	Justervesenet	Norway
8	Internal Beneficiary	SMU	Slovenský Metrologický Ústav	Slovakia
9	Internal Beneficiary	TUBITAK	Türkiye Bilimsel ve Teknolojik Arastirma Kurumu	Türkiye
10	External Beneficiary	CNR	Consiglio Nazionale delle Ricerche	Italy
11	External Beneficiary	CTU	České Vysoké Učení Technické v Praze	Czechia
12	External Beneficiary	IAPAN	Instytut Agrofizyki Polskiej Akademii Nauk	Poland
13	External Beneficiary	PoliMi	Politecnico di Milano	Italy
14	External Beneficiary	UFZ	Helmholtz-Zentrum fuer Umweltforschung GmbH - UFZ	Germany
15	External Beneficiary	UHEI	Ruprecht-Karls-Universitaet Heidelberg	Germany
16	External Beneficiary	UNIBO	Alma mater studiorum Università di Bologna	Italy
17	External Beneficiary	UP DE	Universität Potsdam	Germany
18	Associated Partner	UKCEH	UK Centre for Ecology & Hydrology	United Kingdom

A2 Financial summary

	Internal Beneficiaries	External Beneficiaries	Unfunded Beneficiaries	Associated Partners	Total
Labour (€)	988 954.00	658 000.00		55 300.00	1 702 254.00
Subcontracts (€)					
T&S (€)	101 300.00	80 500.00		5 000.00	186 800.00
Equipment (€)					
Other Goods, Works and Services (€)	88 200.00	36 500.00		2 500.00	127 200.00
Internally Invoiced Goods and Services (€)	62 550.00				62 550.00
Indirect (€)	294 613.50	193 750.00		15 700.00	504 063.50
Total costs (€)	1 535 617.50	968 750.00		78 500.00	2 582 867.50
Costs as % of Total costs	59 %	38 %	0 %	3 %	
Total Eligible Costs (€)	1 535 617.50	968 750.00			2 504 367.50
EU contribution (€)	**1 535 617.50**	**968 750.00**			**2 504 367.50**
EU contribution as % of total EU contribution	61 %	39 %	0 %	0 %	
Months	180.0	163.6		10.0	353.6

A3 Work packages summary

WP No	Work Package Title	Active Participants (WP leader in bold)	Months
WP1	SI-traceable measurement of soil moisture on point to field scale	**DTI**, PTB, CIEMAT, CMI, INRIM, IRSN, JV, SMU, TUBITAK, CNR, IAPAN, UFZ, UHEI, UKCEH, UNIBO, UP DE, PoliMi	86.2
WP2	Development of validation practices for CRNS methodology in outdoor conditions	**UP DE**, PTB, DTI, INRIM, IRSN, JV, SMU, TUBITAK, CMI, CNR, CTU, IAPAN, PoliMi, UFZ, UHEI, UKCEH, UNIBO, CIEMAT	86.6
WP3	Comparison and harmonisation of soil moisture observation methods on multiple spatial and temporal scales	**UNIBO**, PTB, DTI, INRIM, IRSN, TUBITAK, CNR, CTU, IAPAN, UFZ, UHEI, UKCEH, UP DE	62.9
WP4	Multi-scale and multi-disciplinary soil moisture data fusion	**CNR**, PTB, DTI, INRIM, IRSN, TUBITAK, IAPAN, UFZ, UHEI, UKCEH, UNIBO, UP DE	52.2
WP5	Creating impact	**INRIM**, all participants	41.2
WP6	Management and coordination	**PTB**, all participants	24.5
		Total months	**353.6**

Section B: Overview of the research

B1 Summary of the project

Overview

Water and soil are vital resources that are seriously affected by climate change and degradation. Water at the land surface, primarily in the form of soil moisture, is a key resource influencing agriculture, forestry, groundwater recharge, weather, climate, and greenhouse gas emissions. Several soil moisture observation systems exist on multiple scales, but they need to be harmonised. The overall objective of this project is to develop novel metrological tools and establish a metrological foundation for soil moisture measurements on multiple lateral scales, ranging from decimetre to kilometre, ensuring the traceability and harmonisation of the various soil moisture measurement methods.

Need

Soil moisture is one of the Essential Climate Variables (ECVs) as defined by the Global Climate Observing System (GCOS) of the World Meteorological Organisation (WMO). Soil moisture influences the land-atmosphere interactions on both weather and climate timescales. Long-term carbon storage and release in soil is strongly influenced by soil moisture - only a healthy and adequately moist soil can act as carbon sink in the strategies for greenhouse gases (GHG) reduction and adaptation to climate change impacts. Soils are a cross-cutting theme within the European Green Deal (EGD), communicated by the European Commission (EC) in 'EC COM/2019/640 final', as the sectors of water management, agriculture, forestry, and biodiversity are inherently interdependent. Soil quality and soil moisture play a key role in the future EGD policies, namely in the future Common Agricultural Policies unified under the Farm to Fork Strategy ('EC COM/2020/381 final'), policies for environmental protection (Biodiversity Strategy for 2030, 'EC COM/2020/380 final') and the climate change action (The European Climate Law, 'EC COM/2020/80 final').

Soil moisture measurements at point scales, performed by practical users in agriculture and hydrology (e.g., farmers, agronomists) or by scientists dealing with soil moisture as an ECV, are not immediately representative of the soil moisture at the larger scales that are relevant for practical applications. Point scale measurements use physical tactile sensors which are invasive and subject to local issues. To overcome this, complex sampling designs and interpolation methods can be implemented, however uncertainties need to be improved and practical calibration guidelines developed. Remote observation of the Earth can be used for real-time and continuous assessment of soil moisture on the kilometre-scale however intermediate scale soil moisture methods such as Cosmic-Ray Neutron Sensing (CRNS) are needed so that gap from point scale to remote sensing can be bridged. The necessary hardware and data processing tools need to be harmonised and reliable calibration, validation and characterisation methods developed. Several comparison campaigns of soil moisture measurement methods at different spatial and temporal scales have been performed however many research areas (e.g., for the remote sensing of surface temperature for meteorology and climatology) have recognised the need for the integration of observations at different spatial scales based on different methods. There is a need for new on-field comparison campaigns to provide researchers with datasets using traceable methods which can be used to review the existing approaches and develop novel methods to overcome the limitations and different estimates of the soil moisture measurand derived from existing methods. In addition, there is also a need to set out appropriate validation practices for the deep-sensing CRNS method, including fusion of supporting soil data, moisture profiles, and vegetation information, and to harmonise the different methods across scales, in a holistic and yet metrologically traceable approach. Furthermore, there is a need for 'the next logical step', i.e., for performing the data fusion of the multi-scale soil moisture measurements to generate high-quality, temporally, and spatially consistent soil moisture information, useful for land surface sciences and applications, such as climate observations, weather forecasting, hydrology, and agriculture.

Objectives

The overall aim of this project is to develop novel and traceable methods and establish a metrological infrastructure for soil moisture measurements covering lateral scales ranging from the decimetre to kilometre.

The specific objectives of the project are:

1. To develop metrological framework, including primary and secondary transfer standards, to ensure SI-traceable point-scale soil moisture measurements with uncertainties of 5 % under laboratory conditions. To develop metrological framework for validation of existing cosmic-ray neutron sensing (CRNS) devices, currently available in the market, under laboratory conditions.
2. To develop new validation practices for cosmic-ray neutron sensing (CRNS) methodology for use in outdoor conditions. This includes the application and validation of neutron transport models used to

interpret CRNS detector signals specific to the soil moisture measurand, and the standardisation of the CRNS on-field calibration procedure for soil moisture assessment on lateral scales ranging from 10^2 m to 10^3 m and to depths of up to 1 metre.

3. To investigate the constraints and accuracy of soil moisture measurement methodologies using intercomparison campaigns on local and remote sensing. In addition, to develop procedures, summarized in good practice guides, to overcome (i) temporal and spatial differences regarding the sensing domains of soil moisture measurement methods and (ii) the influence of other state variables such as air humidity and soil temperature affecting the measurements.

4. To develop a multi-scale metrological system and metrologically traceable methods for soil moisture monitoring, covering lateral scales ranging from 10^{-1} m to 10^3 m and to depths of up to 1 metre and temporal scales ranging from hours to days, to assess the soil moisture with traceable relative uncertainty of 20 % or better. This includes the development of a cross-disciplinary harmonisation system on the medium sub-kilometre-scale and the establishment of (i) metrological traceability of soil moisture measurements using point-scale sensors (from Objective 1) and satellite measurement techniques and (ii) fit for purpose modelling. In addition, to develop techniques to support the harmonisation of soil moisture assessment.

5. To cooperate with user communities to define design criteria for emerging and future hydrological and meteorological/climatological soil moisture networks using the combination of point-, intermediate- and large-scale methods. To cooperate with the EMN COO and relevant international organisations (e.g., WMO) to facilitate the dissemination of the project outputs.

<u>Progress beyond the state of the art and results</u>

Several soil moisture observation systems have been developed, ranging from invasive point-scale soil moisture sensors to large-scale remote sensing products. In addition, more recently, a non-invasive intermediate scale soil moisture method, cosmic-ray neutron sensing (CRNS) has found widespread use. Despite several initiatives, no harmonisation approaches under metrology standards are available. This project will address this gap by developing the metrological tools needed for traceable and validated soil moisture measurements. For the first time, metrological tools for all three domains/scales will be considered in a holistic approach, to harmonise soil moisture monitoring across scales.

Metrologically traceable methods for multi-scale soil moisture measurements: New traceable methods for the measurement of soil moisture in outdoor conditions on lateral scales in the range of 10^{-1} m to 10^3 m with relative combined uncertainty of 20 % will be developed. To achieve this, new standards and methods for the traceability of the point-scale soil moisture measurements under laboratory conditions will be developed. The measurement supply chain will be extended to outdoor conditions by transfer standards and an improved on-field sampling method developed.

New traceability scheme and validation practices for CRNS method: A traceability scheme for CRNS methodology will be developed. The neutron response functions of the CRNS devices will be validated using calculations and neutron reference fields. This will allow for an effective validation of current and upcoming CRNS device designs. The combination of metrology for neutron radiation, temperature, and humidity will allow, for the first time, a traceable benchmarking of CRNS devices under outdoor conditions, leading to new validation practices. There will be improved understanding of the CRNS footprint, of systematic effects, and of the uncertainty of the soil moisture retrieval.

New on-field comparison campaigns on local and remote sensing: New soil moisture data will be systematically collected at established experimental field sites, operated by participants and selected according to their relevance for the calibration and validation practices of soil moisture retrieval by CRNS and remote sensing. This data will be a clear improvement over previous historical data sets as they will be based on newly characterised devices of point-scale and CRNS methods, and the measurements will be designed for the purpose of harmonisation. The data will be used to investigate the limitations and accuracy of the individual methods. New approaches and methods will be developed to overcome the temporal and spatial differences regarding the sensing domains of the individual methods.

Cross-disciplinary harmonisation system for soil moisture monitoring: Based on the newly collected data sets, and on the historical time series, novel procedures for harmonising soil moisture assessments on different temporal scales and on lateral scales ranging from point scale to kilometre scale will be developed. New recommendations for the calibration and validation practices of the soil moisture retrieval by remote sensing, as well as new methodologies for data fusion, will be developed.

<u>Outcomes and Impact</u>

Outcomes for industrial and other user communities

The calibration procedure developed in this project will allow manufacturers of hydro-meteorological equipment (used in the meteorological, hydrological, agricultural, environmental and related fields) to certify the performance of their instruments based on standard procedures. This would enable them to respond to the needs of national meteorological services for maintenance-reduced instrumentation and fully automated weather stations. The growth of the global automated weather station market is likely to result in significant financial benefits.

Manufacturers of laboratory equipment for instrument calibration will also benefit from the calibration procedure and metrological framework developed within this project, since they will be able to provide compliant calibration devices for soil moisture instruments. This will enable them to market standardised and interoperable equipment and services that will underpin the harmonisation efforts in application areas such as weather monitoring and forecasting, and precision farming.

The development of the traceability scheme and validation practices for the CRNS method as part of this project, as well as the recommendations on networks design and validation practices, will support the existing and upcoming CRNS networks in Europe and worldwide. This positive effect will be in form of SI-traceable CRNS devices, more reliable and interoperable data sets from CRNS networks, harmonised data for further use in hydrology, meteorology, and agriculture. The improvements in the metrological basis of the CRNS method are also important for further joint initiatives such as Joint FAO and IAEA Programmes.

Organisations providing advice to policy makers (such as the European Union of Water Management Associations (EUWMA), the European Environment Agency (EEA)) will benefit from the calibration procedure and harmonisation of various soil moisture measurements developed in the project, as they will have access to local hydrological conditions that are interoperable and comparable on the European scale. This will provide them with improved soil and environmental scenario analysis for not only current purposes but also future planning of the managements of water and soil resources, e.g., in agricultural policies.

This project will directly liaise with industrial stakeholders via the formation of a Stakeholder Committee. This group will include representatives from agro-meteorological services, national meteorological services, WMO members of expert teams, regional instrument centres, manufacturers centres, and will help the project's results to directly impact such representatives.

In addition, this project will also produce and publish 3 good practice guides for end-users:

- Good practice guide for calibration practices for CRNS soil moisture data retrieval in outdoor field conditions covering on lateral scales ranging from 10^2 m to 10^3 m and to depths of up to 1 metre
- Good practice guide for harmonising soil moisture measurement methods to overcome temporal and spatial differences (lateral scales ranging from point scale to km scale) and the influence of other state variables such as air humidity and soil temperature affecting the measurements
- Good practice guide for interdisciplinary data fusion of soil moisture measurements on multiple scales

Outcomes for the metrology and scientific communities

SI-traceable metrology for water content in materials has been partly established over the last decade. However, at present, no countries have BIPM Calibration and Measurement Capabilities (CMCs) for moisture measurement, and SI-traceable measurements of soil moisture on primary level have, to our knowledge, not been reported. One important outcome of this project is to establish primary-level soil moisture measurements with developed uncertainty budgets. TUBITAK will establish a new calibration service for soil moisture measurements. DTI will integrate the results of the project in its existing services related to field trials and plant technology (https://www.dti.dk/specialists/agrotech/36805). DTI will also offer new consultancy and laboratory services to the scientific community on the traceability of soil moisture measurement using point scale sensors. In general, the established metrological foundation for soil moisture measurement should allow traceable calibration and validation of secondary measurement standards such as those based on traditional loss-on-drying and of transfer standards.

For soil moisture measurement there are currently unresolved issues with appropriate transfer standards and sampling methods. This project will address these issues and the transfer of the metrological chain of traceability to outdoor conditions, using new transfer standards based on visible and near-infrared spectral reflectance measurements for on-site calibrations. This improved metrological basis will be used for improving the CRNS methodology and should have direct impact on networks in Europe (e.g., TERENO, COSMOS-UK, eLTER) and worldwide (COSMOS, CosmOz, COSMOS-India). Harmonised multi-scale soil moisture data, with reliable uncertainties, will improve hydrological modelling, climate and weather forecasting by ensuring better comparability between data sets obtained with different methods.

The project will also host two one-day stakeholder events to disseminate results of the project and promote the uptake of the technology and measurement infrastructure developed. The first workshop will train participants from the stakeholder community, specifically those from hydro-meteo agencies, agrometeorological consortia, and manufacturers. The second one-day “Soil Moisture Workshop” will present and discuss the project results, including the project’s three good practice guides, to stakeholders, including WMO representatives, national meteorological and agro-meteorological representatives.

Finally, the project will provide output to the metrology and scientific communities via input to the EMN COO by interacting closely with the EMN COO network members. The consortium will also liaise with the EMN’s associated projects dealing with establishing the metrology for ECVs observation.

Outcomes for relevant standards

Currently, most of the guidance for soil moisture measurements in the field is contained in good practice guidelines (e.g., IAEA technical documents on field estimation of soil water content and on CRNS, Committee on Earth Observation Satellites (CEOS) good practice protocol for remote sensing, and methods for soil analysis by the American Society of Agronomy), and there is a lack of relevant validation and standardisation. Standardised procedures based on suitable calibration devices would benefit manufacturers and users of soil moisture instruments. Indeed, their use is currently limited due to insufficient standardised calibration procedures and the lack of both metrological comparison and harmonisation among different sensor typologies and gravimetric/volumetric manual soil moisture measurements.

This project will support standardisation work for soil moisture measurements by providing a technical report to CEN TC444 Environmental Characterisation WG5 Physical tests for consideration and adoption as well as to ISO TC-190 Soil quality WG1 Soil and Climate Change SC3 Chemical and physical characterisation for update of an existing standard. The project will also provide input to WMO Standing Committee on Measurements, Instrumentation and Traceability (WMO SC-MINT), WMO Commission for Observation, Infrastructure and Information Systems (INFCOMM), WMO Commission for Instruments and Methods of Observation (CIMO) expert team on Operational Metrology, WMO Global Climate Observing System (GCOS) Surface Reference Network, WMO SC-MINT expert team on Measurement Uncertainty (ET-MU), EURAMET Technical Committee for Thermometry (TC-T) and BIPM Consultative Committee for Thermometry Working Group for Humidity (CCT-WG-Hu).

Members of the consortia sit in and chair relevant WMO expert teams and a goal of the project is also to provide input to guidance material such as updates to the WMO ‘Guide to Meteorological Instruments and Methods of Observation’ (WMO Guide No. 8).

Longer-term economic, social and environmental impacts

A wider impact of the project results is expected on companies operating in the fields of hydro-meteorological warnings, water resources management, flood control, agriculture and hydro-power plants. These companies generally provide services based on the monitoring of hydro-meteorological variables and the processing of the related measurements to support the final users’ decisions about the configuration of industrial systems, even in real time. The use of calibrated soil moisture type instruments, in conjunction with the other meteorological observables, would improve the management capabilities of the users since decisions would be based on traceable measurements, and enable more comparable data in space and time. With more reliable data it would therefore be possible to promptly inform the weather services, local agro-meteorology consortia and users, about the risk of drought and flood. The accuracy of such information is vital for the issuing of effective and timely warnings. This main economic impact would therefore be two-fold; an increase in trustworthy and timelier irrigation plans, with direct benefits on agricultural and farming production (such as an increase in crop yields) and reduction of water waste for irrigation and hence increased water availability. A reduction in maintenance costs for hydro-meteorological agencies and agro-meteorology consortia and users is foreseen. This project has the potential to increase the demand for such systems, possibly lowering their commercial costs.

Based on a general lack of traceability and data quality in historical observation, the Global Climate Observing System (GCOS) is preparing the creation of the GCOS Surface Reference Network (GSRN). Among the ECVs prescribed by GSRN, soil moisture is one of the fundamental observed quantities for a reference site. The non-contact systems (CRNS) developed in the project will offer more reliable data and are nearly immune to maintenance and mechanical drifts and shocks, thus becoming a more robust candidate for long-term data series recording. In addition, this project is expected to have a substantial impact in climate science through the GCOS and other similar initiatives.

The involvement of the consortium in BIPM and the WMO, at the operational level and in the supporting research, guarantees fast and efficient communication and feedback. Coordinating the efforts and avoiding duplication of work or contrasting conclusions, will increase the chances of successfully transferring the results into standardisation documents soon after the conclusion of the project. Improvements in traceability and better measurement facilities for soil moisture measurements, with lower and metrologically reliable uncertainty, will have direct impacts on the global environment which serves a healthy food system for people in the European Green Deal framework. Therefore, the project has an indirect impact on the health and quality of life of human society. As mentioned earlier, more reliable and traceable soil moisture observations are also the basis for supporting decision making in many water-related sectors, from irrigation management and planning to flood forecasting and early warnings.

B2 Excellence

B2.a Overview of the objectives

The overall aim of this project is to develop novel and traceable methods and establish a metrological infrastructure for soil moisture measurements covering lateral scales ranging from the decimetre to kilometre.

The specific objectives of the project are:

1. To develop metrological framework, including primary and secondary transfer standards, to ensure SI-traceable point-scale soil moisture measurements with uncertainties of 5 % under laboratory conditions. To develop metrological framework for validation of existing cosmic-ray neutron sensing (CRNS) devices, currently available in the market, under laboratory conditions. (**WP1**)
2. To develop new validation practices for cosmic-ray neutron sensing (CRNS) methodology for use in outdoor conditions. This includes the application and validation of neutron transport models used to interpret CRNS detector signals specific to the soil moisture measurand, and the standardisation of the CRNS on-field calibration procedure for soil moisture assessment on lateral scales ranging from 10^2 m to 10^3 m and to depths of up to 1 metre. (**WP2**)
3. To investigate the constraints and accuracy of soil moisture measurement methodologies using intercomparison campaigns on local and remote sensing. In addition, to develop procedures, summarized in good practice guides, to overcome (i) temporal and spatial differences regarding the sensing domains of soil moisture measurement methods and (ii) the influence of other state variables such as air humidity and soil temperature affecting the measurements. (WP2, **WP3**, WP4)
4. To develop a multi-scale metrological system and metrologically traceable methods for soil moisture monitoring, covering lateral scales ranging from 10^{-1} m to 10^3 m and to depths of up to 1 metre and temporal scales ranging from hours to days, to assess the soil moisture with traceable relative uncertainty of 20 % or better. This includes the development of a cross-disciplinary harmonisation system on the medium sub-kilometre-scale and the establishment of (i) metrological traceability of soil moisture measurements using point-scale sensors (from Objective 1) and satellite measurement techniques and (ii) fit for purpose modelling. In addition, to develop techniques to support the harmonisation of soil moisture assessment. (WP2, WP3, **WP4**)
5. To cooperate with user communities to define design criteria for emerging and future hydrological and meteorological/climatological soil moisture networks using the combination of point-, intermediate- and large-scale methods. To cooperate with the EMN COO and relevant international organisations (e.g., WMO) to facilitate the dissemination of the project outputs. (**WP5**)

B2.b List of deliverables

Relevant objective (Activity delivering the deliverable)	Deliverable number	Deliverable description	Deliverable type	Participants (Lead in bold)	Delivery date
1 (A1.2.9)	D1	Report on the calibration of soil-moisture measurement devices using a primary method, based on evolved water vapour detection, and transfer standards, such as “standardised” loss on drying (LoD) or fibre-coupled spectrometers, to ensure SI-traceable point-scale soil moisture measurements with uncertainties of 5 % under laboratory conditions	Report	**DTI,** TUBITAK, CMI, UNIBO, UP DE, PTB, JV	Mar 2025 (M30)
1 (A1.3.5)	D2	Report on the traceability scheme and uncertainty model for validation of neutron response functions of CRNS neutron-measuring devices under laboratory conditions	Report	**CMI,** PTB, CIEMAT, IRSN, SMU, UFZ, UHEI, UP DE, UNIBO, PoliMi	Feb 2024 (M17)
2 (A2.2.4)	D3	Report on the comparison and validation of existing neutron transport models used to interpret CRNS signals measured under outdoor conditions	Report	**UP DE**, UFZ, UHEI, PTB, IRSN, CTU, CMI, DTI, SMU, UKCEH, UNIBO	Dec 2024 (M27)
2 (A2.3.4)	D4	Good practice guide for calibration practices for CRNS soil moisture data retrieval in outdoor field conditions covering on lateral scales ranging from 10^2 m to 10^3 m and to depths of up to 1 metre	Good practice guide	**UP DE**, UFZ, UHEI, PTB, IRSN, CTU, TUBITAK, UNIBO, DTI, CMI, SMU, INRIM	Sep 2024 (M24)
3 (A3.1.4)	D5	Report on the comparison of soil moisture measurement methods and their different sensing domains (local and remote) including details on the constraints and accuracy of the methods and requirements for harmonisation.	Report	**UNIBO,** IAPAN, UP DE, UKCEH, CNR, TUBITAK, CTU, UFZ, DTI, UHEI, PTB	Sep 2024 (M24)
3, 4 (A3.2.4)	D6	Good practice guide for harmonising soil moisture measurement methods to overcome temporal and spatial differences (lateral scales ranging from point scale to km scale) and the influence of other state variables such as air humidity and soil temperature affecting the measurements	Good practice guide	**UNIBO**, CNR, UKCEH, IAPAN, DTI, CTU, UFZ, UP DE, UHEI, INRIM, PTB, IRSN	May 2025 (M32)

4 (A4.1.3)	D7	Report on the comparison of the existing data fusion practices for soil moisture measurements on multiple lateral (from 10^{-1} m to 10^{3} m and to depths of up to 1 metre) and temporal (from hours to days) scales to assess the soil moisture with traceable relative uncertainty of 20 % or better	Report	**CNR**, IAPAN, UNIBO, TUBITAK, DTI, UKCEH, UP DE, PTB	Jun 2025 (M33)
4 (A4.2.4)	D8	Good practice guide for interdisciplinary data fusion of soil moisture measurements on multiple scales	Good practice guide	**CNR**, IAPAN, UNIBO, DTI, TUBITAK, UKCEH, UP DE, IRSN, PTB, INRIM, UFZ, UHEI	Sep 2025 (M36)
(n/a)	D9	Evidence of contributions to or influence on new or improved international guides, recommendations, and standards with a specific focus on the following guides and committees: CEN TC444 WG5, ISO TC-190 WG1 SC3, WMO SC-MINT, WMO INFCOMM, WMO CIMO expert team on Operational Metrology, WMO GCOS Surface Reference Network, WMO SC-MINT ET-MU, EURAMET TC-T, BIPM CCT WG-Hu. Examples of early uptake of project outputs by end-users. Updated dissemination, communication and exploitation plan.	Reporting documents	**INRIM**, all participants	Sep 2025 (M36)
n/a	D10	Delivery of all technical and financial reporting documents as required by EURAMET	Reporting documents	**PTB**, all participants	Sep 2025 (M36) + 60 days

B2.c Need for the project

Water at the land surface, primarily in the form of soil moisture, is a key resource influencing agriculture, forestry, groundwater recharge, weather, climate, and greenhouse gas emissions. Soil moisture is one of the Essential Climate Variables (ECVs) as defined by the Global Climate Observing System of the World Meteorological Organisation [1]. Soils are a cross-cutting theme within the European Green Deal (EGD) [2] as the water sector, agriculture, forestry, and biodiversity are inherently strongly interdependent. Soil quality and soil moisture play a key role in the future EGD policies, namely in the future Common Agricultural Policies unified under the Farm to Fork Strategy [3], policies for environmental protection (Biodiversity Strategy for 2030 [4]) and the climate change action (The European Climate Law [5]).

There is no unified approach for measuring soil moisture; instead, different approaches are used, utilising indirect measurements from which the soil moisture is estimated, and which typically provide information on very different scales (time, lateral extension, and soil depth) and are difficult to compare and combine. The issues of comparability and compatibility of soil moisture measurement methods and data sets translate into open problems for manufacturers and practical users of the devices (e.g., in agriculture, hydrology) and for scientific communities dealing with soil moisture for the purpose of weather and climate monitoring, modelling, and forecasting. For example, farmers and agronomists, aiming to optimise the water use, need sensors which measure the soil moisture reliably on an absolute scale as a part of their irrigation systems. Even the state-of-the-art sensors, however, differ strongly in this respect, hindering the straightforward use of such sensors in practice. Companies, developing intelligent sensors and automated solutions for optimised irrigation systems, need soil moisture sensors which are characterised in an SI-traceable way, to be able to offer solutions for a large suite of customers. Scientists, dealing with large-scale soil moisture assessments based on remote sensing data, need new intermediate-scale methods such as the CRNS, to validate their methods, because the point-scale soil moisture sensors are not representative on the vast ground areas covered by satellites. Overall, there is therefore a strong need for calibration procedures and harmonised methods over multiple scales, providing a consistent set of data that can be used by end users and policy makers to optimise water management policies.

Metrologically traceable methods for multi-scale soil moisture measurements

Soil moisture measurements at point scales, performed by practical users in agriculture and hydrology (farmers, agronomists, developers of intelligent water management solutions, researchers dealing with monitoring and modelling of droughts, floods, landslides), or by scientists dealing with soil moisture as an ECV, are not immediately representative of the soil moisture at the larger scales that are relevant for practical applications such as agriculture, weather forecasting, and climate change studies. Point scale measurements use physical tactile sensors which are invasive and subject to local issues for example the sensor not making good contact with the soil, or the soil type at the point of measurement not being representative of the entire area. To overcome these issues, complex sampling designs and interpolation methods can be implemented, however studies have shown substantial uncertainties for all types of measurement methods and state that calibration routines as applied by calibration laboratories are insufficient (not representative for the application) [6]. Practical calibration guidelines based on metrological research that consider the local variables for the different point scale soil moisture measurement methods are needed.

There is also a need for new point sensors, metrologically traceable to a primary soil moisture measurement standard, that can be used as transfer standards in on-site calibrations. Manual soil sampling to measure water content can be laborious and expensive, and reference methods, such as the loss-on-drying (LoD) method, where a sample is dried by heating it for a period of time and the water content determined as the difference in mass before and after drying, do not provide a valid prompt result, as volatiles other than water also evaporate during drying. The most common LoD procedure uses heats up to 105°C for 24 hours but studies showed that the optimum heating cycle depends on the soil composition [7,8]. Thus, there is a need for standardised methods considering soil composition to be developed for determining the water content in soil samples.

Other techniques, such as remote observation of the Earth from satellites, are used for the assessment of soil moisture, among other ECVs, on the kilometre-scale. Here, the end users, scientists in sectors dealing with soil moisture as part of the global water cycle (hydrological modelling, numerical weather predictions, climate change observation, benefit from the immense coverage of the Earth surface by the satellite-based techniques. Still, the validation of remote sensing data has been based mostly on point-scale measurements; with all the difficulties this entails. There is a need to add intermediate scale soil moisture methods such as CRNS that can bridge the gap from point scale to remote sensing, which can provide real-time, continuous, high-quality data on an intermediate scale and can be part of a traceability chain over the different scales [9]. Soil moisture data on the intermediate scale, traceable to SI standards under field conditions, are required to improve the representativeness and efficiency of the ground truthing of remote sensing. The need of an improved metrological basis in the soil moisture product validation is recognised by the Earth Observation Programmes of the European Space Agency.

Traceability scheme and validation practices for CRNS method

The CRNS [10] method is a promising candidate for soil moisture monitoring on the intermediate scale, capable of bridging the spatiotemporal gaps between the *in-situ* and remote sensing techniques. A great improvement in the metrology related to neutron fluence measurements in environmental conditions is needed to address the current limitations and open problems when applying this method. The on-field calibration and validation of the devices and models used so far is not performed in accordance with metrological standards. The hardware and data processing are not yet harmonised within its own research field and with the already established methods for soil moisture determination. Currently, the calibration and validation of CRNS is accomplished by comparing the data to an aggregate of independent point measurements [11], which is labour-intensive, site-specific, and not traceable to metrology standards [12]. The neutron signal is also affected in a complex way by the systematic effects of atmospheric and land use-specific variables as well as by other hydrogen pools (e.g., biomass, ponded water, snow, building materials). Reliable characterisation, harmonisation, and improvements of the neutron detection and their soil moisture results are major challenges that have not yet been addressed adequately.

On-field comparison campaigns on local and remote sensing

Several comparison campaigns of soil moisture measurement methods at different spatial and temporal scales have been performed during the last decades based on extensive field activities. In most of the cases, point-scale measurements are considered as the ‘ground-truth’ for intermediate CRNS studies or for remote sensing soil moisture products (calibration-validation, or ‘cal-val’ sites). Moreover, these comparisons are performed independently by the different scientific communities dealing with the specific methods without common standards or traceable approaches. The need for the integration of observations at different spatial scales based on different methods has been recognised in many research areas such as e.g., remote sensing of surface temperature for meteorology and climatology, remote sensing of carbon dioxide (CO_2) atmospheric concentration for CO_2 emission inventories, and ECVs' remote sensing-based monitoring for global climate studies in general; but it is not established for soil moisture observations. There is a need for new on-field comparison campaigns to provide researchers with datasets using traceable methods which can be used to review the existing approaches and develop novel methods to overcome the limitations and different estimates of the soil moisture measurand derived from existing methods. These aims are of great importance for the research community dealing with calibration and validation practices of satellite-based soil moisture products [13,14,15]. The overall aim is to provide traceable and comparable soil moisture data sets, across temporal and lateral scales, for the end users in the sectors of numerical weather predictions and climate change observation.

Cross-disciplinary harmonisation and data fusion for soil moisture monitoring

The methods for soil moisture observations are characterised by specific investigated support volume (spatial area and soil depth), temporal and spatial resolution and accuracy. In the case of remote sensing, the CEOS has already set out standardised practices for the surface soil moisture product validation [15,16]. However, these methods and practices can cover only the shallow-depth top layer of the ground, while the substantial part of the root zone remains 'unseen'. There is a challenging need to set out appropriate validation practices for the deep-sensing CRNS method, including fusion of supporting soil data, moisture profiles, and vegetation information, and to harmonise the different methods across scales, in a holistic and yet metrologically traceable approach. Furthermore, there is a need for 'the next logical step', i.e., for performing the data fusion of the multi-scale soil moisture measurements to generate high-quality, temporally, and spatially consistent soil moisture information, useful for land surface sciences and applications, such as climate observations, weather forecasting, hydrology, and agriculture.

B2.d Progress beyond the state of the art

Metrologically traceable methods for soil moisture measurements

SI-traceable metrology for water content in materials has been partly established over the last decade such as the reference methods for measuring the water content of materials that was established in a previous EMRP project, SIB64 METefnet [17]. Traditionally, reference measurements for water determination in soil are based on the Loss-on-Drying (LoD) method, but the reliability of this method used with soil is questionable as it detects both water and volatile organic components.

This project will go beyond the start of the art by adapting and validating, one of the primary methods [18], developed in METefnet, based on evolved water vapor detection using dewpoint measurement soil moisture measurements. For the first time, this primary measurement standard will then be used to establish traceability for the transfer standards developed in the project for on-field measurement. On the secondary level, the project will also go beyond the state of the art by improving the LoD method to secure reliability and good reproducibility over different soil types so that it is suitable for use as a "transfer standard" e.g., for calibration of sensors used in the field as well as creating a 'standardised' procedure for the method that considers soil composition in the optimum heating cycle.

Currently, soil moisture is most frequently measured on the point scale using various invasive *in-situ* methods [9], such as frequency-domain or time-domain reflectometry or capacitance measurements. Setting up the sensors in networks allow characterisation of hydrological processes at scales of a hundred meters. However, studies have shown that these methods exhibit significant variability in the field, that calibrations in laboratories are not representative and calibrations performed in the field are required if reliable, accurate moisture data are to be obtained [6].

The project will go beyond the state of the art by characterising sensors of different types and producing recommendations for representative calibration.

To establish the link between the primary water content measurement standard (either directly or via the improved LoD method, validated by comparison to the primary standard) and the field sensors, a reliable transfer standard is needed. The project will develop the framework for a soil measurement technique based on visible and near-infrared (Vis-NIR) spectral reflectance measurements. The wavelength-dependent variations of reflected light from soil can be correlated with physical and chemical properties of soil, including the water content of the soil under the test. Both a point-wise measurement performed at a single point by means of a fibre-coupled spectrometer, and a two-dimensional measurement by scanning of a push broom hyperspectral imager over a certain area, are within this framework.

The project will go beyond the state of the art by performing an evaluation of the capacity of Vis-NIR spectral reflectance measurements for remote *in-situ* soil moisture measurements with particular attention on sample pre- and post-processing of obtained spectral data, analysis of co-variations in data sets, and mathematical data pre-processing to achieve acceptable model performance. This will also include the development of the "Turkish Soil Spectral Library": The library will contain a catalogue of representative spectral patterns (from the spectral reflectance measurements) and the corresponding *in-situ* soil moisture measurements for different soil types present in the Republic of Türkiye. The Vis-NIR-based portable transfer standard for soil moisture measurement will also be deployed and benchmarked on at least one of the project's high-level experimental sites where soil moisture measurement will be carried out at different temporal and spatial scales.

<u>Traceability scheme and validation practices for CRNS method</u>

The CRNS method makes use of the secondary neutrons created in the collisions of primary cosmic rays with the nuclei of atoms of the Earth's atmosphere. These secondary neutrons hit the Earth's surface and interact with the soil up to a certain depth. Depending on the hydrogen content of the soil, a portion of these neutrons is directed back above ground. The fluence rate of the backscattered albedo neutrons is used as a measure for the mean soil moisture representative for the whole support volume around the CRNS probe. A big advantage is the coverage of a substantial part of the root zone (depth of the order of 50 cm) which otherwise remains inaccessible to the shallow-depth remote sensing [16]. The CRNS technique is used for monitoring soil moisture and snow in a non-invasive and low-maintenance way, on lateral scales ~10 ha, using stationary and mobile platforms [19,20,21]. Worldwide, there are currently five major hydrological monitoring networks deploying the CRNS method [22–26]. The calibration and validation of the devices and models used, however, is not carried out in accordance with metrological standards.

The project will go beyond the state of the art by combining the metrology of neutron radiation and of temperature and humidity which will allow, for the first time, a traceable benchmarking of the CRNS devices performance in laboratory and outdoor conditions. New validation practices for CRNS method in outdoor conditions will be set up. The understanding of the CRNS sensing volume ("footprint"), systematic effects and the uncertainty of the soil moisture retrieval by CRNS will also be improved.

<u>On-field comparison campaigns on local and remote sensing</u>

Currently, there are several on-field comparison campaigns in Europe and worldwide, either on calibration/validation sites of the satellite remote sensing techniques, or on the field sites devoted to the CRNS method. However, such campaigns typically lack the metrological framework and the full combination of the three scales, ranging from point-scale sensors via intermediate scale (CRNS) to the km scale (satellite remote sensing). In addition, the targeted continuous operation of at least (1– 2) years is often not possible for such comparison campaigns of a few research institutions only.

The project will go beyond the state of the art by bringing together metrology experts and experts in the field of point-, intermediate- and large-scale soil moisture observations to establish high-level experimental sites where soil moisture measurement can be carried out at different temporal and spatial scales. Unique data sets based on the different methods will be collected. These data sets will provide the basis for the comparison of limitations and accuracy of the different soil moisture measurement methodologies. Novel procedures to overcome the temporal and spatial differences regarding the sensing domains will be developed.

The high-level experimental sites will be based on existing experimental sites operated by the participants, but the field activities and the experimental designs will be optimised. In this context, not only soil moisture observations will be addressed, but also the monitoring of variables important for the correction and assessment of the signals (e.g., soil properties, roughness, land use, biomass) will be performed. The characterisation of these test beds will outline the recommendations that could be considered in other emerging and future experimental sites and for further soil moisture comparisons.

<u>Cross-disciplinary harmonisation system and data fusion method for soil moisture monitoring</u>

Several soil moisture observation systems exist ranging from point-scale invasive sensors to large scale remote sensing products. Each method relies on specific spatial and temporal resolutions, support volume and accuracy. The data availability and heterogeneity of the different method is nowadays particularly relevant since the launch of the ESA Sentinel-1 Earth Observation mission that has inaugurated a new era of high resolution (i.e., 0.1 km to 3.0 km) surface soil moisture products that will complement those operationally delivered at low resolution (e.g., ≥ 25 km) by missions such as ESA/SMOS, NASA/SMAP and EUMETSAT/ASCAT [14]. In addition, non-invasive intermediate scale soil moisture method like CRNS has been established in several national networks providing unique data sets to bridge the scale gap between point-scale sensors and large-scale remote sensing products.

More recently, drone-based unmanned aircraft systems (UAS) have also emerged as extremely flexible and cost-effective remote sensing platforms with highly stabilised flight parameters and accurate coordinates, capable to carry the most demanded remote sensors (such as video and thermal cameras and hyperspectral cameras, etc.) simultaneously. In the meantime, the usefulness of acquired soil moisture data (particularly by hyperspectral sensors with hundreds of spectral bands), along with the sensing quality and calibration tasks, depends also on the flight parameters of the platforms. In this respect, drone-based remote sensing allows to easily adapt overall pre-, in- and post-flight stages to the particular requirements of certain measurement procedures. The development of such adaptive data collection strategies in remote sensing presents an interesting approach for soil moisture measurements, which opens new possibilities for the more complex model-based data collection approaches. Such adaptive data collection by means of high-resolution remote sensing of soil moisture at the field scale, in combination with the opportunities of the "big data" era for the managing, sharing, analysing, and visualising of spectral datasets (often comprising millions of soil moisture spectra) will allow studying soil water dynamics in near real-time scale, and efficiently manage water resources [27]. Some comparisons between these methods have been performed however such a broad range of soil moisture products needs to be harmonised and characterised in terms of accuracy and uncertainty to meet the user requirements for various land applications.

This project will go beyond the state of the art by establishing a solid metrological framework for the reliable estimation of the uncertainties and sensing volumes of the individual methods, which will be in turn used for research and development of harmonisation and data fusion approaches on the multiple lateral and temporal scales.

Valuable reference data sets have been collected over *in-situ* soil moisture networks deployed for the assessment of low-resolution satellite products [27]. However, such experimental facilities need to be upgraded to higher spatial resolutions by devising approaches to mitigate uncertainties across several spatial scales [28]. Moreover, reference measurements need to be traceable to SI standards and monitored in time to ensure credibility of the validation process [29].

This project will go beyond the state of the art by providing the metrological framework and the scientific basis for a standardised and consistent approach to compare and combine the different assessments.

B2.e Gender dimension

This project proposal addresses the needs of stakeholders and end-users for improved metrological tools and devices for more reliable measurements of soil moisture on multiple scales. The progress will be achieved by joint research in the fields of metrology of temperature and humidity, metrology of neutron radiation and soil moisture assessments on point, intermediate and large scales. Due to the very technical and fundamental nature of these topics, the gender dimension is considered to not be applicable to this project.

However, consideration of gender dimension may be applicable in the sectors which concern the wider impact of this project. For example, when it comes to the impact of the project as it concerns applications such as water management in agriculture and climate change mitigation, there are situations in which a gender imbalance can be present in the sense that women may be more adversely affected by the climate change than men when conditions deteriorate. Therefore, any steps toward improving the situation will lead to a positive development concerning the gender dimension.

In terms of its dissemination activities, the project will communicate in a manner that highlights to all genders the benefits of improved metrological tools and devices for more reliable measurements of soil moisture.

B2.f Open science

The project will adopt open science practices as an integral part of the project. The development of novel methods and SI-traceable standards, as well as the comparison and harmonisation of methods, will be carried out in line with the open methodology practices. This includes the open documentation of newly developed methods, open access to scientific data, evaluation and selection criteria. It is intended that the project's results, reports, recommendations, and good practice guides will be made freely available in open access peer-reviewed publications and in open access repositories as well as on the project website.

(i) Early and open sharing of research

The consortium will consider and aim at submitting pre-prints of the project manuscript(s) to a suitable open access platform. The scientific publication process (of submission, review, revision and publication) can take a significant amount of time, depending on the selected journal. To accelerate the dissemination of results ahead of the publishing date, preprints will be posted by the project in widely known and accessible repositories, selecting those most relevant to their stakeholders. Possible target pre-print archives for the project will include: preprints.org, techrxiv.org and arxiv.org.

(ii) Research output management

The project will manage the digital research data generated in the project responsibly, in line with the FAIR (Findable, Accessible, Interoperable, and Reusable) principles and according to the requirements in the Grant Agreement. This will include:

- establishing a data management plan (DMP) and regularly updating it,
- as soon as possible and within the deadlines set out in the DMP, deposit the data in a trusted repository (i.e., possibly listed in the Registry of Research Data Repositories),
- as soon as possible and within the deadlines set out in the DMP, ensure open access — via the repository — to the deposited data, under the latest available version of the Creative Commons Attribution International Public License (CC BY) or a licence with equivalent rights, following the principle 'as open as possible, as closed as necessary', according to the Grant Agreement,
- providing information via the repository about any research output or any other tools and instruments needed to re-use or validate the data,
- ensuring metadata of deposited data will be open under the CC BY licence or equivalent, in line with the FAIR principles and provided with information as per the conditions in the Grant Agreement.

(iii) Measures to ensure reproducibility of research outputs

The project will provide information about the research outputs/tools/instruments needed to validate the conclusions of scientific publications or to validate/re-use research data. The project will provide digital or physical access to the results needed to validate the conclusions of scientific publications. The project will ask its Stakeholder Committee to provide input and feedback on the project's work plan to support the robustness and reproducibility of its methods and research outputs.

Where applicable, the Stakeholder Committee will get involved into the process of publishing methods developed within this project. This should provide a better opportunity to identify methodological flaws or other inconsistencies in the project's research. Review, discussion and re-use of our methods and results will also make our work less exposed to errors and should enable it to benefit from stakeholder feedback and improved methods.

The project will disseminate its results to relevant standardisation bodies such as CEN TC444 WG5, ISO TC190 WG1 SC3, WMO SC-MINT and WMO INFCOMM to provide a further layer of peer review of the project's methods and results. The aim is for the project's results to be used as input to WMO CIMO Guide to Instruments and Methods of Observation No. 8 and/or ISO 11461:2018.

(iv) Providing open access to research outputs

The project will undertake responsible management of research data in line with the FAIR principles and open access to research data under the principle 'as open as possible, as closed as necessary', as per the Grant Agreement.

The project will provide open access to scientific publications under the conditions in the Grant Agreement:

- at the latest at the time of publication, a machine-readable electronic copy of the published version or the final peer-reviewed manuscript accepted for publication, will be deposited in a trusted repository for scientific publications,
- immediate open access will be provided to the deposited publication via the repository, under the latest available version of CC BY or a licence with equivalent rights,
- information will be given via the repository about any research output or any other tools and instruments needed to validate the conclusions of the scientific publication,
- metadata of deposited publications will be open under a CC 0 or equivalent licence (e.g., CC BY), in line with the FAIR principles and provided with information as per the conditions in the Grant Agreement.

Possible open access platforms for the publication of the project's outcomes include:

- The first choice will be the discipline-specific repositories, including e.g., PANGAEA (Open Access Data Publisher for Earth & Environmental Science, https://www.pangaea.de/), BonaRes (Repository for Soil and Agricultural Research Data, https://www.bonares.de/), and further relevant repositories located using the Registry of Research Data Repositories (https://www.re3data.org/).

- An institutional repository such as the Open Access Repository of the Physikalisch-Technische Bundesanstalt (PTB-OAR, https://oar.ptb.de).
- A generic repository such as Zenodo (https://zenodo.org) which enables researchers, scientists, EU projects and institutions to share multidisciplinary research results that are not part of the existing institutional or subject-based repositories of the research communities.

The project will provide free links to the project's good practice guides and reports on the project website and individual participants websites to promote their availability to stakeholders.

(v) Participation in open peer-review

Peer review is traditionally an anonymous process, however there are calls for journals with an open peer-review process, where reviewers' reports and authors' replies are available alongside the papers and supplemental material. Recently opened *Open Research Europe* (https://open-research-europe.ec.europa.eu/) uses an open peer-review practice and is free of charge for H2020 funded projects, thus the project will consider it as target journal for its publications.

(vi) Involving all relevant knowledge actors in the co-creation of R&I agendas and contents

Project workshops involving key stakeholders and end users such as agro-meteorological services, national meteorological services, WMO members of expert teams, EMN Climate and Ocean Observation members, regional instrument centres, manufacturers will be used to gain input on developing the project's research agenda and roadmaps.

Project workshops involving key stakeholders and end users will be used to gain input and feedback on the project's results and impact activities. The project's Stakeholder Committee/EURAMET TC's and SDO TCs will provide input and feedback to the project on the production of the project's results and impact activities.

The project will consider and aim at creating forums and/or discussion groups, for example using Mattermost or Slack, where exchange of information between stakeholders with the project participants can occur. The project will use social media and knowledge sharing channels (e.g., LinkedIn, Twitter) to involve stakeholders and gain their feedback on the project.

Close cooperation and research mobility between the participants from universities, industry and NMIs/DIs will be used to support the transfer of knowledge between these communities. Young researchers, PhDs and Postdocs will be invited to take part in the project, to participate in training and to join stakeholder workshops to provide feedback.

B2.g Research data management and management of other research outputs

Types of data/research outputs

The data/research outputs generated will be from measurements carried out under laboratory and outdoor conditions, observational data of the measurement conditions, soil samples analysis, calibrations, comparisons and validations, satellite-based data. The project will collect the following types of data, e.g., numerical data, images, text description data. Research outputs will include new definitions of primary and secondary standards, software tools, calibration methods, protocols, materials, analysis of satellite-based data series, ground-based soil moisture data series. The estimated overall size of the data/research outputs is expected to be of the order of 10 TB. The existing data will originate from several sources, which will include participants' pre-existing data, data from the scientific literature, real-world measurement data, simulation data, technical descriptions of the sensors and devices used within the project. The data generated in this project will be combined with existing data from the sources stated above.

Findability of data/research outputs

The data/research outputs (protocols, reports, software, data series) will be findable as each will be identifiable with a digital object identifier (DOI) or other commonly used persistent and unique identifier. The metadata will provide information on the following: bibliographic information (author(s), dataset description, date of deposit, venue, possibly embargo); information on funding (the European Partnership on Metrology funding program, grant project name, acronym and grant number); licensing terms. Where applicable, the metadata will include persistent identifiers for related publications and research outputs. The data/research outputs will be deposited and published in trusted repositories located using the Registry of Research Data Repositories (https://www.re3data.org/).

Software will be stored, documented and version-controlled in a suitable repository, e.g., GitHub (https://github.com/). Protocols produced by the project will be stored in a suitable protocol exchange repository, e.g., Protocol Exchange (https://protocolexchange.researchsquare.com/), protocols.io (https://www.protocols.io/).

Accessibility of data/research outputs

Although the consortium does not envisage intellectual property rights (IPR) applying to the data and research outputs generated by this project (hence their open access and the associated timeline), the project management board (PMB) consisting of one representative from each participant, including the leaders of each work package, will be responsible for IPR considerations. Foremostly, the relevant participant(s), generating any data and research output, will be responsible for IPR considerations on a case-by-case basis.

The IPR considerations will be managed using the DMP, the Consortium Agreement, the Grant Agreement and the project's exploitation plan. Open access will be decided on a case-by-case basis and agreed with the data owners (for cases where confidentiality is required for proprietary information). Timeline: open access will be granted as soon as is reasonably possible. If necessary, open access will not be provided to some of the data/research outputs due to IPR considerations (e.g., whilst a patent application is pending). The data/research outputs will remain accessible for the lifetime of the repository.

There are no restrictions on the use of the published data/research outputs for verification purposes, but users will be required to acknowledge the project and the funding source in any resulting publications, according to the Creative Commons Attribution International Public License (CC BY) 4.0.

Interoperability of data/research outputs

The datasets will use the trusted repository's basic metadata schema for administrative data, which is compliant with the recommended standards used by DataCite (https://search.datacite.org/), OpenAIRE (https://www.basesearch.net/) and BASE search (https://www.basesearch.net/). To guarantee the interoperability of project's data/research outputs, individual datasets will be described using affirmed discipline-specific vocabularies, standards, formats, and methodologies, including but not limited e.g., GUM, OBO foundry, DICOM, NetCDF, HDF5, CityGML, INSPEC, ISO 9001. Due to the thorough usage of standard terminologies, no specific compatibility mappings will be necessary.

The project's datasets that will be deposited in the chosen trusted repository will include qualified references to other datasets from the same project and/or previous research.

Reusability of data/research outputs

The data/research outputs will either be licensed under the latest available version of the CC BY license or a license with equivalent rights as set out in the Grant Agreement. Users will be required to acknowledge the consortium and the source of the data in any resulting publications. Alternatively, the Public Domain Dedication License (CC 0) will be used.

All tools, software and models used for data generation or recommended for data validation, interpretation, and re-use will be documented within a short README file (e.g., Markdown) will be provided together with the data/research outputs, to enable their analysis and re-use.

The data are in a common format and can be read using widely available software (open source or commercial).

Any data published in open-access journals will be usable by third parties after the datasets have been deposited in a trusted repository. The data that does not relate to peer-reviewed publications will be made available for re-use on a case-by-case basis.

Curation and storage/preservation costs

The estimated curation and storage/preservation costs for making the data and research outputs FAIR are 11 000 € (personnel costs) for the project duration of 3 years. These costs will be kept to a minimum by using i) suitable trusted repositories from the Registry of Research Data Repositories (https://www.re3data.org/) where no additional costs are associated with long-term preservation, and ii) by making only relevant data and outputs FAIR. The estimated curation and storage/preservation costs are included in the project's budget and will be claimed if compliant with the Grant Agreement's conditions.

Participant, person or team responsible for data management and quality assurance

This consortium will not establish a data access committee (DAC). The coordinator, with support from the participants, will have overall responsibility for the management of data/research outputs and quality assurance. The coordinator will be responsible for coordinating updates to the data management plan and for deciding on a case-by-case basis which data/research outputs will be kept and for how long. The participant(s) that produced the data will be responsible for organising backup and storage, archiving, and for depositing the data/research outputs within the chosen repositories.

B3 *Potential outcomes and impact from the project*

B3.a Projected outcomes for industrial and other user communities

The main industrial sector impacted by the results of the project is the hydro-meteorological equipment industry, i.e., the community of instrument manufacturers and providers of products and services in the meteorological, hydrological, agricultural, environmental, and related fields. Interest in the field of soil moisture measurements is increasing to meet the evolving users' requirements and the growing variety of instruments. However, the measuring principles, calibration and performance assessment of this new class of instruments with both traditional soil moisture measurements (such as gravimetric or volumetric soil moisture) and satellite remote sensing results still remains a challenge.

The calibration procedure developed in this project will allow manufacturers of hydro-meteorological equipment to certify the performance of their instruments based on standard procedures. This would enable them to respond to the needs of national meteorological services for maintenance-reduced instrumentation and fully automated weather stations. Sources [30] indicate the magnitude of this market: "*The global automated weather station market is expected to grow from USD 296.73 million in the year 2019 to USD 717.5 million in 2029 at a compound annual growth rate (CAGR) of 8 % in the forecast period.*"

Manufacturers of laboratory equipment for instrument calibration will also benefit from the calibration procedure and metrological framework developed within this project, since they will be able to provide calibration devices for soil moisture instruments that are compliant with the standardised procedure developed in this project. This will enable them to market standardised and interoperable equipment and services that will underpin the harmonisation efforts in application areas such as weather monitoring and forecasting, and precision farming.

The development of the traceability scheme and validation practices for the CRNS method as part of this project, as well as the recommendations on the networks design and validation practices, will support the existing and upcoming CRNS networks in Europe and worldwide. This positive effect will be in form of SI-traceable CRNS devices, more reliable and interoperable data sets from CRNS networks, harmonised data for further use in hydrology, meteorology, and agriculture. The improvements in the metrological basis of the CRNS method are also important for programmes such as Joint FAO/IAEA Programme "Nuclear Techniques in Food and Agriculture", particularly in the current research project "Enhancing Agricultural Resilience and Water Security Using Cosmic Ray-Neutron Technology (D1.20.14)" [12] exploiting the CRNS methodology for soil moisture monitoring in agricultural systems and early warning systems for flood and drought management.

This project will directly liaise with industrial stakeholders via the formation of a Stakeholder Committee. This group will include representatives from agro-meteorological and hydrological services, national meteorological services, WMO members of expert teams, regional instrument centres and will help the project's results to directly impact such representatives.

In addition, this project will also produce and publish 3 good practice guides for end-users:

- Good practice guide for calibration practices for CRNS soil moisture data retrieval in outdoor field conditions,
- Good practice guide for harmonising soil moisture measurement methods on different temporal scales and on lateral scales ranging from point scale to km scale,
- Good practice guide for interdisciplinary data fusion of soil moisture measurements on multiple scales.

Organisations providing advice to policy makers (such as the European Union of Water Management Associations (EUWMA), the European Environment Agency (EEA), the European Soil Partnership (ESP) of the Food and Agriculture Organization of the United Nations (FAO), the European Soil Data Centre (ESDAC) of the European Joint Research Centre (JRC)) will benefit from the calibration procedure and harmonisation of various soil moisture measurements developed in the project, as they will have access to local hydrological conditions that, once the project's results are exploited in future, shall be interoperable and comparable on the European scale. This will provide them with improved soil and environmental scenario analysis for not only current purposes but also future planning of the managements of water and soil resources, e.g., in agricultural policies. The interoperable and comparable soil moisture data on the European scale, available in the future, can be used by European soil data centres and networks for further use and validation of various agricultural and environmental modelling. Standardising soil moisture metrics based on moisture metrics transform those values into percentiles or deviations from normal to help decision makers understand how current conditions compare to historical conditions at a given time and place.

B3.b Projected outcomes for the metrological and scientific communities

Results from this project will enable Europe to potentially have a leading role in the development of the first international calibration standard for soil moisture instruments.

SI-traceable metrology for water content in materials has been partly established over the last decade. However, at present, no countries have BIPM Calibration and Measurement Capabilities (CMCs) for moisture measurement, and SI-traceable measurements of soil moisture on primary level have not been reported. One important outcome of this project is to establish primary-level soil moisture measurements with developed uncertainty budgets. DTI will integrate these outcomes of the project into its existing services related to field trials and plant technology (https://www.dti.dk/specialists/agrotech/36805). DTI will also offer new consultancy and laboratory services to the scientific community on the traceability of soil moisture measurement using point scale sensors. TUBITAK will establish a new calibration service for soil moisture measurements. This should allow traceable calibration and validation of secondary measurement standards such as those based on traditional loss-on-drying and of transfer standards.

For soil moisture measurement there are currently unresolved issues with appropriate transfer standards and sampling methods. This project will address these issues and the transfer of the metrological chain of traceability to outdoor conditions, using new transfer standards for point-scale soil moisture sensors, in combination with improved sampling methods. In addition, transfer standards based on visible and near-infrared spectral reflectance measurements for on-site calibrations will be researched. The improved metrological basis will be used for improving the CRNS methodology and should have direct impact on networks in Europe (e.g., TERENO, COSMOS-UK) and worldwide (COSMOS, CosmOz, COSMOS-India).

The new on-field comparison campaigns (local and remote sensing), carried out within this project, will lead to the publication of good practice guides. These outputs will directly impact the scientific community dealing with soil moisture retrieval from satellites-based data, as the community is actively developing calibration and validation practices for large-scale soil moisture assessments based on point-scale soil moisture measurements on ground [13,15,16]. The gap between the point-scale (*in situ*) and the kilometre-scale (satellite-based horizontal resolution) is recognized as one of the most important research gaps that must be closed. With the harmonisation and data fusion practices researched within its framework, this project will provide the metrological support required for this community.

The project will also host two one-day stakeholder events to disseminate results of the project and promote the uptake of the technology and measurement infrastructure developed. The first event will be a one-day conference followed by one-day training course to disseminate results of the project, promote the uptake of the technology and measurement infrastructure developed as well as gather knowledge for stakeholders to feedback into the project. The second one-day workshop on soil moisture be held at the end of the project and again present and discuss the project results, including the project's three good practice guides. Stakeholders targeted will be WMO representatives, national meteorological and agro-meteorological representatives.

Finally, the project will provide output to the metrology and scientific communities via input to the EMN COO by disseminating the project's three good practice guides and peer-reviewed publications to the EMN COO's associated projects and international initiatives dealing with soil moisture, other Essential Climate Variables and Earth Observation in general, such as the Quality Assurance Framework for Earth Observation (QA4EO) and the project 18NET04 Climate Ocean (Support for a European Metrology Network for climate and ocean observation). In addition, the project's participants will liaise with projects, networks and data centres including, but not limited to, FRM4SM (Fiducial Reference Measurements for Soil Moisture), GTN-H (Global Terrestrial Network – Hydrology), and ISMN (International Soil Moisture Network).

B3.c Projected outcomes for relevant standards

This project will contribute to standardisation of methods for soil moisture measurements including input to ISO 11461:2018 Soil quality. The project is expected to generate results that will be very valuable to standardisation work within the committees in the table below. The participants who are members of corresponding technical committees will inform them about the results of this project and will endeavour to ensure they are incorporated in any updates to the standards or guidelines. For example, the representatives on the corresponding committee or working group from the project participants will jointly ask the chairperson to include a point in the agenda to briefly present the outcomes of the project related to the working group activities and ask for comments from the other committee/working group members. Where appropriate a written report will be submitted for consideration by the committee or working group.

Standards Committee / Technical Committee / Working Group	**Participants involved**	**Likely area of impact / activities undertaken by participants related to standard / committee**
CEN TC 444 Environmental Characterisation WG5 Physical tests	**DTI**	CEN TC 444 is responsible for providing a platform for the development of European Standards and other technical documents in relation to various kinds of products, materials, services and processes DTI will prepare a Technical Report incorporating guidelines on recommended procedures for the traceable calibration of soil moisture instruments (A1.1.7) for consideration and adoption by CEN TC 444/WG5. The committee meets once or twice a year. The project and project results obtained (A1.1.7) will be presented at the first committee meeting after completing the report and guideline in 2024.
ISO TC190 Soil quality WG1 Soil and Climate Change SC3 Chemical and physical characterisation	**DTI**	ISO TC 190/WG1 is responsible for Soil and Climate Change and ISO TC 190/WG1 SC3 is responsible for Chemical and physical characterisation. DTI will work with the representatives of the sub-committees to propose that ISO adopts the project's Technical Report developed through CEN TC 444 as part of ISO 11461:2018 Soil quality — Determination of soil water content as a volume fraction using coring sleeves — Gravimetric method. The committee meets once a year.
World Meteorological Organisation Standing Committee on Measurements, Instrumentation and Traceability (WMO SC-MINT) (or WMO Commission for Observation, Infrastructure and Information Systems INFCOM Editorial Board)	**INRIM**	The WMO SC-MINT and INFCOM committees are devoted to the periodic revision of the WMO Guide to Instruments and Methods of Observation (Guide No. 8). INRIM will prepare a proposal to include recommendations about soil moisture instruments in an update to the WMO Guide to Instruments and Methods of Observation No. 8. The proposal will be presented at a meeting of the Surface and Sub Surface Expert Team (or similar if during the next intersessional period this expert team will change name or structure). The committee meets at least twice a year.
WMO Global Climate Observing System (GCOS) Surface Reference Network	**INRIM**	INRIM will prepare a proposal for the design of reference grade surface stations, including *in-situ* soil moisture measurements based on demonstrated traceability of this kind of instruments. INRIM will submit this to the GCOS Surface Reference Network, by email or directly attending the GSRN Task Team Meeting for inclusion into the guide on the measurement requirements for Climate Reference Stations taking part to GSRN, in order to include reference grade measurements of soil moisture among the climate reference variables for the GSRN. The network task team meets once a year.
WMO SC-MINT expert team on Measurement Uncertainty (ET-MU)	**INRIM**	INRIM will foster discussions with SC-MINT ET-MU about adopting a uniform procedure for the comparison of different typologies of soil moisture measurements methods and instruments. INRIM will propose by email that the project's recommendations on uncertainty evaluation (A1.2.9) are included in an update to the Guide to Instruments and Methods of Observation No. 8. The expert team meets normally every two months.
EURAMET Technical Committee for Thermometry (TC-T)	**DTI**, INRIM, JV, TUBITAK	At the next meeting in 2023, TC-T will be informed about the activities of the project by DTI, INRIM, JV and TUBITAK. The next meeting will be held alongside COOMET TC 1.10 Thermometry and Thermal Physics, therefore this organisation will also be informed about this project's results. The results from the work on transfer standards for moisture measurements and calibration standards (A1.2.9) will be presented to EURAMET's TC-T's sub-committee for humidity on an ongoing basis. EURAMET TC-T meets annually in April-May.

BIPM Consultative Committee for Thermometry Working Group for Humidity (CCT-WG-Hu)	**TUBITAK,** DTI	BIPM's CCT-WG-Hu will be informed by TUBITAK and DTI about the activities of the project with regards to the project's work on moisture content measurements. BIPM CCT-WG-Hu meets every 2-3 years.

B3.d Projected wider impact of the project

Economic impact

A wider impact of the project results is expected on companies operating in the fields of hydro-meteorological warnings, water resources management, flood control, agriculture and hydro-power plants. These companies generally provide services based on the monitoring of hydro-meteorological variables (precipitation, flow rate, evaporation, soil moisture etc.) and the processing of the related measurements to support the final users' decisions about the configuration of industrial systems, even in real time. The use of calibrated soil moisture type instruments, in conjunction with the other meteorological observables, would improve the management capabilities of the users since decisions would be based on traceable measurements, and enable more comparable data in space and time.

With more reliable data it would therefore be possible to promptly inform the weather services, local agro-meteorology consortia and users, about the risk of drought and flood. The accuracy of such information is vital for the issuing of effective and timely warnings. This main economic impact would therefore be two-fold; an increase in trustworthy and timelier irrigation plans, with direct benefits on agricultural and farming production (such as an increase in crop yields) and reduction of water waste for irrigation and hence increased water availability.

A reduction in maintenance costs for hydro-meteorological agencies and agro-meteorology consortia and users is foreseen. This project has the potential to increase the demand for such systems, possibly lowering their commercial costs.

Environmental impact

Based on a general lack of traceability and data quality in historical observation, the Global Climate Observing System (GCOS) is preparing the creation of the GCOS Surface Reference Network (GSRN). "*A set of high-quality long-term fiducial reference measurements of Essential Climate Variables will enable future generations to make rigorous assessments of future climate change and variability, providing society with the best possible information to support future decisions."* [31]. Among the ECVs prescribed by GSRN, soil moisture is one of the fundamental observed quantities for a reference site. As for temperature, where contact thermometers suffer of heat transfer effects, changing the temperature response with respect to the calibration in laboratory, non-contact systems can surpass limitations and biases of the direct involvement of the sensor in the measuring principle. Non-contact systems will offer more reliable data and are nearly immune to maintenance and mechanical drifts and shocks, thus becoming a more robust candidate for long-term data series recording.

In addition, this project is therefore expected to have a substantial impact in climate science through the GCOS and other similar initiatives. Since project participants are members of GSRN and other WMO and GCOS teams there will be a direct flow of information to this relevant scientific stakeholder community throughout the duration of the project.

Social impact

The involvement of participants in BIPM and the WMO, at the operational level and in the supporting research, guarantees fast and efficient communication and feedback. Coordinating the efforts and avoiding duplication of work or contrasting conclusions, will increase the chances of successfully transferring the results into standardisation documents soon after the conclusion of the project.

Improvements in the traceability and better measurement facilities for soil moisture measurements, with lower and metrologically reliable uncertainty, will have direct impacts on the global environment which serves a healthy food system for people in the European Green Deal framework. Therefore, the project has an indirect impact on the health and quality of life of human society.

As mentioned earlier, more reliable and traceable soil moisture observations are also the basis for supporting decision making in many water-related sectors, from irrigation management and planning to flood forecasting and early warnings. For these reasons it is expected that based on the results of this project many more actors, users and stakeholders will be affected, with consequences from farmers' behaviours to risk assessment, civil protection and climate change mitigation strategies.

B3.e Summary of the project’s impact pathway

SPECIFIC NEEDS	EXPECTED RESULTS	DCE MEASURES
What are the specific needs that triggered this project? Decision makers need more reliable quality assured data for weather and climate change monitoring and forecasting, and to optimise water management strategies to support the prevention of extreme events such as floods, droughts, heatwaves, and wildfires. Decision makers and end users in agronomy and hydrology need harmonised data of soil moisture on intermediate scale (10^2 m – 10^3 m) that are interoperable and comparable within the community, to optimise irrigation plans in everyday practice as well as water and soil management strategies in long-term agricultural policies. Scientific community of Earth Observation via remote sensing methods need improved methodology for calibration and validation of satellites-based soil moisture assessments, that is more representative on the sub-kilometre-scale and more effective than the point-scale soil moisture sensors utilised nowadays. To achieve these goals, decision makers, end users and scientific communities need soil moisture measurements that are traceable to the SI with reliable estimates of uncertainty and are harmonised across scales and communities.	*What do you expect to generate by the end of the project?* **Novel methodology for calibration of soil moisture measurement devices** using a primary method, based on evolved water vapour detection, and transfer standards, such as "standardised" loss on drying (LoD) or fibre coupled spectrometers, to ensure SI-traceable point-scale soil moisture measurements with uncertainties of 5 % under laboratory conditions. **New calibration services** for point-scale soil moisture measurements, new consultancy and laboratory services to the scientific community on the traceability of soil moisture measurement using point scale sensors. **New traceability scheme and validation practices** for CRNS method, allowing to transform the neutron count rate signal into the soil moisture measurand. **Good practice guide** for calibration practices for CRNS soil moisture data retrieval in outdoor field conditions covering on lateral scales ranging from 10^2 m to 10^3 m and to depths of up to 1 metre. **Good practice guide** for harmonising soil moisture measurement methods to overcome temporal and spatial differences (lateral scales ranging from point scale to km scale) and the influence of other state variables such as air humidity and soil temperature affecting the measurements. **Good practice guide** for interdisciplinary data fusion of soil moisture measurements on multiple scales. **Three PhD students trained.**	*What dissemination, communication and exploitation measures will you apply to the results?* **Communication:** Promotion of the project's objectives and results to organisations such as standardisation organisations, agro-meteorological services, national meteorological services, WMO members of expert teams, regional instrument centres, manufacturers of soil moisture measurement devices, developers of intelligent solutions for agriculture, and to the wide audience. **Dissemination:** Presentation of the project’s results at conferences, the projects workshops and training courses and in peer-reviewed journals. Engagement with soil moisture networks on national and international level, such as the ISMN, and with the stakeholder and end-users of data, such as the Earth Observation Programmes experts. **Exploitation:** Engagement with current, emerging, and future CRNS networks, and with related organisations and standardisation committees.
TARGET GROUPS	**OUTCOMES**	**IMPACTS**
Who will use or further up-take the results of the project? Who will benefit from the results of the project? **End-users:** Manufacturers and developers of point-scale soil moisture sensors, CRNS devices and intelligent solutions for agriculture. Researchers dealing with soil moisture observations. Institutes and private companies offering field-test services. **Metrological and scientific communities:** Fields of hydrology, climate and weather observation and modelling, precision agriculture. Measurement institutes (e.g., National Metrology Institutes, Designated Institutes, National Measurement Laboratories) that will offer new or improved calibration services for existing, new, or future soil moisture measurement devices. **Stakeholders:** Organisations providing advice to policy makers on diverse topics where soil moisture plays an important	*What change do you expect to see after successful dissemination and exploitation of project results to the target group(s)?* **Improved performance of the point-scale soil moisture sensors**, with the possibility of certification according to newly established standards under laboratory conditions. **Increased uptake and improved interoperability of the soil moisture measurement devices** in agriculture and hydrology, thanks to the improved comparability and reliable estimates of uncertainty. **Increased uptake of the CRNS methodology** in emerging and future hydrological and meteorological/climatological soil moisture networks, thanks to the provided recommendations on networks design and validation practices. **Increased use of soil moisture data** for monitoring and modelling, thanks to their better understood uncertainties, sensing volumes and improved comparability	*What are the expected wider scientific, economic and societal effects of the project contributing to the expected impacts outlined in the work programme and call scope?* **Scientific:** Validated measurements of soil moisture can be transferred to real-world, outdoor conditions due to new standards and SI-traceable methods, enabling reliable high-quality data for hydrological, meteorological/climatological observations and subsequent modelling. **Economic/Technological:** Benefits on agricultural and farming production in terms of optimisation of irrigation plans to achieve higher crop yields while reducing the water waste and associated costs (energy and labour), with increased water availability. Benefits on hydro-meteorological agencies and agro-meteorology through reduction in maintenance costs for automated networks. **Societal:** Better soil moisture data (e.g., with better known uncertainties) available over multiple scales, for policy

role. Syndicates and Associations related to agriculture and hydrology.	across scales and methodologies; overall, the improvements lead to better consulting to policy makers.	decisions such as improved water management, and weather and climate forecasting. More efficient use of freshwater in agriculture, thanks to improved soil moisture monitoring on field/intermediate scale. Better understanding of the role of soil moisture in the global sector of climate change observation and mitigation.

B4 The quality and efficiency of the implementation

B4.a Overview of the consortium

The consortium comprises of 18 institutions from 11 European countries with nine leading NMIs/DIs and nine external participants.

- **PTB (coordinator)**, the German NMI, has vast experience in the metrology, spectrometry, and dosimetry of neutron radiation. PTB also has experience in coordinating and leading WPs of previous EMRP and EMPIR projects. In this project, PTB will contribute specially to the development of the traceability scheme of the CRNS method in laboratory and outdoor conditions.
- **CIEMAT**, the Spanish DI for ionising radiation, will provide neutron reference fields as well as expertise in Monte Carlo-based methods for neutron transport calculations, needed for the characterisation of CRNS neutron-measuring devices.
- **CMI**, the Czech NMI, will provide primary methods of moisture determination in solids (loss-on-drying, thermogravimetry, coulometric/volumetric Karl-Ficher titration) for the SI-traceability and uncertainty determination. In addition, CMI will provide neutron reference fields for the validation of the Monte Carlo models of CRNS probes, as well as expertise in modelling of their responses using the neutron transport code MCNP.
- **DTI (WP1 leader)**, a Danish DI, has laboratory facilities for moisture measurement and knowledge about agricultural field trials, sampling of soils, data collection and statistical analysis. DTI participated in the EMRP SIB64 METefnet project where they developed a primary measurement standard for moisture in solid materials that will be utilised in this project. DTI coordinates the EMPIR 19ENG09 BIOFMET project where issues, relevant to this project, such as sampling related to biomass and water content measurement, is being researched. DTI is member of EURAMET’s EMN ForOceanClimate.
- **INRIM (WP5 leader)**, the Italian NMI, launched and coordinated the EMRP ENV07 MeteoMet and ENV58 MeteoMet2 projects. These projects covered the design and construction of fixed and transportable calibration chambers for meteorological sensors and the study of the mutual influence between parameters (wind, pressure, temperature, humidity), calibration campaigns in-field including in extreme environment conditions (Everest, Arctic). INRIM has expert members in numerous institutions operating in environmental sciences, meteorology and climatology also serving as chairperson of BIPM working groups and WMO expert teams.
- **IRSN**, a French DI for ionising radiation, has experience in the metrology and spectrometry of neutron radiation. In this project, IRSN will contribute to the development of the traceability scheme of the CRNS method in laboratory and outdoor conditions.
- **JV**, the Norwegian NMI, has experience in the field of temperature and humidity measurements, calibration and uncertainty evaluation. During the ENV07 MeteoMet project, JV worked on metrological validation of climate data. In this project, JV will perform the survey of metrological needs of soil moisture assessments on multiple scales.
- **SMU,** the Slovak NMI, maintains the national standard of neutrons. In this project, SMU will contribute to Monte Carlo-based neutron transport calculations, needed for the characterisation of the CRNS devices under laboratory and outdoor conditions.
- **TUBITAK**, the Turkish NMI, has experience in humidity and temperature measurements, and particularly extensive experience in thermophysical properties measurements and non-contact temperature measurements. In this project, TUBITAK will contribute to the development of the methods for surface and volumetric moisture measurements. TUBITAK has taken part in many previous EMRP/EMPIR research projects.

- **CNR (WP4 leader)**, Consiglio Nazionale delle Ricerche, has expertise in Earth Observation (EO) data processing and interpretation, modelling microwave scattering from land surfaces, and retrieval of land bio-geophysical parameters from SAR and optical data. CNR will provide time series of soil moisture maps derived from Sentinel-1 and of ground data from the hydrological network.
- **CTU**, the Czech Technical University, has experience in soil hydrology, soil moisture monitoring and numerical modelling. CTU operates an agricultural experimental catchment for observing the water balance and rainfall runoff processes within an intensively cultivated landscape, which will serve as one of the experimental test sites. In this project, CTU provides and analyses point-scale and intermediate scale soil moisture data.
- **IAPAN**, the Institute of Agrophysics of Polish Academy of Sciences, has experience in satellite- and ground-based remote sensing for soil moisture assessment on multi-spatial and multi-temporal scales. In this project, IAPAN contributes to the harmonisation and fusion of the different soil moisture assessments.
- **PoliMi**, a scientific-technological university (Politecnico di Milano) has expertise in research and development of neutron-measuring instruments for various applications. In this project, PoliMi will be involved in the work regarding neutron-measuring devices for the CRNS method.
- **UFZ,** is the Helmholtz Centre for Environmental Research GmbH, has expertise in environmental geophysical monitoring and hydrological modelling. UFZ will contribute to the mobile CRNS campaigns, and to the development of the CRNS method, data processing, simulation, and field work.
- **UHEI**, the University of Heidelberg, has experience in nuclear and particle physics with a longstanding focus on the neutron. UHEI will contribute to the development of the CRNS method by detailed detector simulations and calibrations.
- **UNIBO (WP3 leader)**, University of Bologna, has expertise in soil hydrology and ground-based soil moisture observations. The team operates several experimental sites with both point-scale and CRNS sensors in Italy and cooperates with the Soil and Water division of the Joint IAEA/FAO Programme for promoting CRNS method for agricultural applications. In this project, UNIBO will lead the development of the harmonisation method.
- **UP DE (WP2 leader)**, University of Potsdam, is a university research group with experience in environmental sciences and soil hydrology. UP DE will lead the efforts to transfer metrology standards to an outside application at the field-scale as well to collect soil moisture data at field test sites for inclusion into the further evaluation of soil moisture retrieval. UP DE have been using the CRNS method for soil moisture measurements for 10 years and operate a unique field test laboratory for CRNS at a site close to Potsdam.
- **UKCEH**, the UK Centre for Ecology & Hydrology, are experienced in the calibration and quality assurance of the 50 stations in the COSMOS-UK soil moisture network and have developed automated data quality control. In this project, UKCEH will contribute to the characterisation of CRNS methodology in outdoor conditions and harmonisation of soil moisture field observations, remote sensing and models. UKCEH is an associated partner and is associated to all beneficiaries.

Section C: Detailed project plans by work package

C1 WP1: SI-traceable measurement of soil moisture on point to field scale

The aim of this work package is to provide and develop a metrological framework for on-site measurements of soil moisture on lateral scales ranging from 10^{-1} m to 10^{2} m. This includes setting up calibration facilities (under metrological laboratory conditions) for point-scale soil moisture measuring devices and for neutron probes used for CRNS, as well as the development of transfer standards for on-site calibration of point-scale soil moisture measuring devices. The improved methodologies will then be used in WP2 for the validation of the on-site instrumentation to ensure the traceability of the field measurements.

In Task 1.1, the needs for the metrological framework will be defined, in close cooperation with the stakeholders and end-users of different soil moisture assessment methods. In Task 1.2, measurement facilities for SI-traceable soil moisture measurements on the point scale will be established and validated. In Task 1.3, SI-traceable calibration procedures for CRNS neutron-measuring devices will be developed.

C1.a Task 1.1: Definition of the needed metrological framework

The aim of this task is to perform a survey of the needs of the stakeholders to define the methodologies and approaches needed for traceability for soil moisture measurements by end-user communities. This includes parameter ranges, required uncertainties and available measurements, data processing and documentary standards as well as a review of available methods.

Activity number	Activity description	Participants (Lead in bold)
A1.1.1 M6	JV, DTI, TUBITAK, UP DE, UFZ, UKCEH and UNIBO will perform a stakeholder analysis to determine the current requirements and needs of the stakeholders and end-users across the disciplines where soil moisture monitoring plays a key role, e.g., climate change observation, climate and weather forecasting, farming, hydrological modelling. The goal is to understand what is needed to develop a metrological framework for on-site measurements of soil moisture on lateral scales ranging from 10^{-1} m to 10^{2} m. The analysis will also gather information on the different methods used by stakeholders to estimate soil moisture and the currently available different measuring devices for measuring soil moisture. The stakeholder analysis will be performed in the form of a literature review and through meetings/questionnaire with selected stakeholders. The Stakeholder Committee (A5.1.1) will be invited to complete the questionnaire and support on identifying appropriate stakeholders to contact. • The questionnaire will be designed by JV with agreement from DTI, TUBITAK, UP DE, UFZ, UKCEH and UNIBO. • The stakeholders to be contacted will be identified by JV with agreement from DTI, TUBITAK, UP DE, UFZ, UKCEH and UNIBO. • The target number of stakeholders to be contacted will be agreed as part of this activity by JV. • JV with agreement from DTI, TUBITAK, UP DE, UFZ, UKCEH and UNIBO will decide which of them will contact which identified stakeholders (to avoid duplication). They will then distribute the questionnaire to the stakeholders. • DTI, TUBITAK, UP DE, UFZ, UKCEH and UNIBO will send their completed questionnaire to JV who will collate them and review the feedback. The goal is to receive at least 20 completed questionnaires. At M3, preliminary information will be collated. This information will focus on the end-users' requirements, technical possibilities and needs for metrology foundation of the individual methods of soil moisture measurement: remote sensing-based methods (A1.1.3), CRNS method (A1.1.4) and the point-scale soil moisture measurements (A1.1.5).	**JV**, DTI, TUBITAK, UP DE, UFZ, UKCEH, UNIBO

A1.1.2 M6	PTB, DTI, INRIM, TUBITAK, JV, CMI, UP DE and UKCEH will engage with the projects and networks currently dealing with soil moisture monitoring and open issues of missing soil moisture harmonisation on multiple scales. These projects and networks include, but are not limited to, EMPIR-funded projects 19SIP03 CRS (Climate Reference Station), DFG-funded project CosmicSense, CRNS networks TERENO and COSMOS-UK, climate observation networks, such as the EMN Climate Ocean, and others. This will be done to define the current state of the art in these projects with regards to soil moisture monitoring and open issues of missing soil moisture harmonisation on multiple scales. Synergies with these projects will be sought, to ensure an efficient and timely project uptake. At M3, preliminary information will be collated. This information will focus on the projects particularly investigating the individual methods of soil moisture measurement: remote sensing-based methods (A1.1.3), CRNS method (A1.1.4) and the point-scale soil moisture measurements (A1.1.5).	**PTB**, DTI, INRIM, TUBITAK, JV, CMI, UP DE, UKCEH
A1.1.3 M4	Based on preliminary input from A1.1.1 and A1.1.2, CNR with support from TUBITAK, IAPAN and UFZ will perform the review of requirements and technical possibilities for soil moisture assessment via remote sensing methods. This will include the needs for calibration and validation methods of soil moisture retrieval techniques from remote sensing methods. Input from the project's Stakeholder Committee (A5.1.1) will be sought.	**CNR**, TUBITAK, IAPAN, UFZ
A1.1.4 M4	Based on preliminary input from A1.1.1 and A1.1.2, UP DE with support from UHEI, UNIBO, CMI, PTB and UKCEH will perform the review of requirements and technical possibilities for CRNS methods. This will include the review of state-of-the-art devices used for CRNS and the identification of the metrology needs of CRNS on-field calibration procedures. Input from the project's Stakeholder Committee (A5.1.1) will be sought.	**UP DE**, UHEI, UNIBO, CMI, PTB, UKCEH
A1.1.5 M4	Based on preliminary input from A1.1.1 and A1.1.2, DTI with support from UNIBO, TUBITAK and CMI will perform the review of requirements and technical possibilities for point-scale soil moisture measurements. This will include the review of state-of-the-art point scale devices and calibration techniques currently being applied by manufacturers and calibration laboratories. Input from the project's Stakeholder Committee (A5.1.1) will be sought.	**DTI**, UNIBO, TUBITAK, CMI
A1.1.6 M6	DTI with support from TUBITAK, UP DE, UKCEH and CNR will define the traceability scheme for soil moisture measurements using the different approaches (remote sensing, CRNS and point scale) based on the outcome of A1.1.3 – A1.1.5.	**DTI**, TUBITAK, UP DE, UKCEH, CNR
A1.1.7 M9	DTI with support from JV, PTB, CNR, UP DE and TUBITAK will collate the information from A1.1.1 - A1.1.6 into a report detailing (i) the methodologies and approaches needed for traceability for soil moisture measurements by the end-user communities and (ii) for developing a metrological framework for on-site measurements of soil moisture on lateral scales ranging from 10^{-1} m to 10^{2} m. The report will include parameter ranges, required uncertainties and available measurements, data processing and documentary standards as well as a review of available methods.	**DTI**, JV, PTB, CNR, UP DE, TUBITAK

C1.b Task 1.2: Calibration facilities for point-scale sensors and transfer standards

The aim of this task is to establish and validate measurement facilities for SI-traceable soil moisture measurements on the point scale. As part of this, a complete traceability chain will be established and validated to enable the dissemination of primary water content measurements to field conditions.

Activity number	Activity description	Participants (Lead in bold)
A1.2.1 M6	Using input from previous EMRP project SIB64 METefnet, DTI will adapt their existing primary measurement standard for water content in materials for the measurement of soil moisture.	**DTI**
A1.2.2 M15	DTI, with the input from CMI and UNIBO, will test the adapted standard from A1.2.1, with at least two soil types (organic and mineral) and develop an uncertainty budget for the primary level. Soil samples of the two types (organic and mineral) will be provided by DTI and further supplementary samples will be requested by DTI from each of the high-level test sites, selected in A2.1.1, and provided by the hosts of those selected sites. The participants hosting the high-level test field sites will be responsible for collecting and shipping the	**DTI**, CMI, UNIBO

	soil samples to DTI. The tests will be designed to meet the requirements reviewed in A1.1.5 and refined in A1.1.6. At M10, preliminary information defining the soil samples will be made available.	
A1.2.3 M6	Using input from A1.1.5, DTI, UNIBO and CMI will develop a portable transfer standard for soil moisture measurement based on the loss-on-drying (LoD) method. This will be done to extend DTI's existing SI-traceable methodology to outdoor field conditions.	**DTI**, UNIBO, CMI
A1.2.4 M15	DTI, UNIBO and TUBITAK will develop a measurement strategy (temperature, drying time etc.) based on A1.1.7. DTI, UNIBO and TUBITAK will validate the instrument developed in A1.2.3 by comparing it to the adapted primary standard from A1.2.1 using the same soil types as in A1.2.2. Based on the validation DTI, UNIBO and TUBITAK will develop a model uncertainty budget. The target is uncertainties of 5 % under laboratory conditions.	**DTI**, UNIBO, TUBITAK
A1.2.5 M12	TUBITAK, CMI and DTI will each establish laboratory calibration facilities for SI-traceable soil moisture measurements on the point scale to characterise sensors and validate the portable transfer standard developed in A1.2.3. The calibration facilities at TUBITAK, CMI and DTI will be based on traditional LoD (TUBITAK, CMI and DTI), Thermogravimetric Analysis (TGA) and (Coulometric/volumetric Karl Fischer Titration) cKF methods (TUBITAK, CMI) and will be validated by comparison to the adapted primary standard from A1.2.1 using the same soil types as in A1.2.2. DTI will be responsible for shipping soil samples similar to those employed in A1.2.2 to TUBITAK and CMI.	**TUBITAK**, CMI, DTI
A1.2.6 M18	Using input from A1.1.5, A1.1.6, A1.2.1, A1.2.3 and A1.2.5, DTI, TUBITAK, CMI, UP DE and UNIBO will develop calibration procedures and model uncertainty budgets for point-scale soil-moisture measuring devices. The target is uncertainties of 5 % under laboratory conditions.	**DTI**, TUBITAK, CMI, UP DE, UNIBO
A1.2.7 M24	DTI, TUBITAK and CMI, with the help of UP DE and UNIBO, will use the calibration procedures developed in A1.2.6 to test at least 3 different types of point-scale sensors (A1.2.5). The 3 different types of point-scale sensors will be chosen and purchased by DTI, with the help of TUBITAK, CMI, UP DE and UNIBO and provided by DTI. The point-scale sensors will be metrologically characterised using the same soil types as used in A1.2.2 and DTI, TUBITAK and CMI's calibration facilities from A1.2.5.	**DTI**, TUBITAK, CMI, UP DE, UNIBO
A1.2.8 M27	TUBITAK will develop a portable transfer standard for soil moisture measurement based on visible and near-infrared spectral reflectance measurements. To validate the developed new facility, TUBITAK will use already existing three different facilities, namely the traditional LoD, Thermogravimetric Analysis (TGA) and (Colorimetric Karl Fischer Titration) cKF methods. The transfer standard will be metrologically characterised using the similar soil types as in A1.2.2 and TUBITAK's calibration facilities from A1.2.5 with particular attention to sample pre- and post-processing of obtained spectral data. Analysis of co-variations in data sets and mathematical data pre-processing will be performed, to achieve acceptable model performance. TUBITAK will initiate the development the Soil Spectral Library of Turkish soils. TUBITAK will develop a protocol to gather soil samples from different geographical regions of the Republic of Türkiye and a study to standardise and evaluate spectra within (350–2500) nm range of soils. Main soil attributes including clay, sand, pH, and base saturation, inorganic main constituents including several major alkaline metals will be targeted. By M21, the setup of the portable transfer standard based on Vis-NIR spectral reflectance measurements will be made available by TUBITAK for the deployment on at least one of the high-level test field sites in A2.1.2. Using the results from the development, tests, and characterisation measurements, TUBITAK, with the help of UNIBO, will evaluate the statistical and systematic uncertainties of the portable transfer standard. The target is total uncertainties of 5 % under laboratory conditions.	**TUBITAK**, UNIBO

A1.2.9 M30	Using input from A1.2.1 – A1.2.8, DTI together with TUBITAK, CMI, UNIBO, UP DE, PTB and JV will write a report on the calibration of soil-moisture devices using a primary method, based on evolved water vapour detection, and transfer standards, such as “standardised” loss on drying (LoD) or fibre-coupled spectrometers, to ensure SI-traceable point-scale soil moisture measurements with uncertainties of 5 % under laboratory conditions”. Once the report has been agreed by the consortium, the coordinator on behalf of DTI, TUBITAK, CMI, UNIBO, UP DE, PTB and JV will send **D1**: “*Report on the calibration of soil-moisture* measurement *devices using a primary method, based on evolved water vapour detection, and transfer standards, such as “standardised” loss on drying (LoD) or fibre-coupled spectrometers, to ensure SI-traceable point-scale soil moisture measurements with uncertainties of 5 % under laboratory conditions*” to EURAMET.	**DTI**, TUBITAK, CMI, UNIBO, UP DE, PTB, JV

C1.c Task 1.3: Calibration procedures for neutron-measuring devices of CRNS methodology

The aim of this task is to develop calibration procedures for neutron-measuring devices used with the CRNS method for measuring soil moisture content.

Activity number	Activity description	Participants (Lead in bold)
A1.3.1 M4	Using input from A1.1.4, CMI and PTB, with support from ISRN and CIEMAT, will review their existing metrology facilities which can be used for SI-traceable validation and characterisation of the neutron-measuring devices used for the CRNS method. Input from the project’s Stakeholder Committee (A5.1.1) will be sought.	**CMI**, PTB, ISRN, CIEMAT
A1.3.2 M4	Using input from A1.1.4, CMI with support from UHEI, UP DE, UFZ and UNIBO will review the state-of-the-art CRNS devices currently available on the market which are being used in existing and emerging CRNS networks. Input from the project’s Stakeholder Committee (A5.1.1) will be sought. Based on this review, CMI with support from UHEI, UP DE, UNIBO, UFZ and PoliMi will select at least three different types of CRNS devices. Special attention will be paid to the availability of detailed technical specifications for the devices.	**CMI**, UHEI, UP DE, UNIBO, UFZ, PoliMi
A1.3.3 M10	For each type of device selected in A1.3.2, the neutron response functions will be calculated by CIEMAT with the support from PTB, CMI, SMU, IRSN and UHEI. The calculations will be based on the geometrical models created by CIEMAT, PTB, CMI, SMU, IRSN and UHEI on the basis of specifications provided by the CRNS probes manufacturers. For the calculations, readily available state-of-the-art neutron transport codes and approaches will be used and systematically compared by CIEMAT, IRSN, PTB, CMI, SMU and UHEI.	**CIEMAT**, PTB, CMI, SMU, IRSN, UHEI
A1.3.4 M14	PTB, IRSN, CMI and CIEMAT will use their existing facilities for neutron reference fields (reviewed in A1.3.1) to experimentally validate the neutron response functions of the CRNS devices from A1.3.3. The CRNS devices, of types selected in A1.3.2, will be provided by the project participants who operate them on their test field sites. It is foreseen that for each selected type, one representative device will be investigated in the metrology laboratories. The owners of the devices will be responsible for their shipping to the metrology laboratories (PTB, IRSN, CMI and CIEMAT). After testing, the project participants running the metrology laboratories will be responsible for shipping the CRNS devices back to their respective owner. IRSN, CMI and CIEMAT will collate their results and send them to PTB. Based on the results, the instrumental effects of the neutron-measuring devices will be studied and quantified by PTB, IRSN, CMI, CIEMAT, SMU and UHEI. PTB will also study the instrumental background of the single CRNS device, sent to them, in the PTB Underground Laboratory UDO II. The other neutron metrology laboratories will investigate the instrumental background of the CRNS devices in their laboratory conditions, in absence of neutron radiation.	**PTB**, IRSN, CMI, CIEMAT, SMU, UHEI

A1.3.5 M17	Using input from A1.3.1 – A1.3.4, CMI with support from PTB, CIEMAT, IRSN, SMU, UFZ, UHEI, UP DE, UNIBO and PoliMi will develop a traceability scheme, an uncertainty analysis model and associated protocols for the characterisation of CRNS neutron-measuring devices for soil moisture content in laboratory conditions. The findings will be summarised in a report. Once the report has been agreed by the consortium, the coordinator on behalf of IRSN, PTB, CIEMAT, CMI, SMU, UFZ, UHEI, UP DE, UNIBO and PoliMi will send **D2**: "*Report on the traceability scheme and uncertainty model for validation of neutron response functions of CRNS neutron-measuring devices under laboratory conditions*" to EURAMET.	**CMI**, PTB, CIEMAT, IRSN, SMU, UFZ, UHEI, UP DE, UNIBO, PoliMi
A1.3.6 M30	Based on input from A1.1.4, A1.1.7, and A1.3.1 – A1.3.5, PTB, with support from UHEI, IRSN and SMU will develop a concept for a novel neutron reference field which will cover the specific needs for SI-traceable validation and characterisation of the CRNS devices. PTB, with support from UHEI, IRSN and SMU will write a report on this concept.	**PTB**, UHEI, IRSN, SMU

C2 WP2: Development of validation practices for CRNS methodology in outdoor conditions

The aim of this work package is to develop SI-traceable validation practices for CRNS methodology in outdoor conditions. In Task 2.1, three high-level test field sites will be selected and further enhanced, to enable the comparison and research of the different soil moisture assessment methods in subsequent tasks and work packages. In Task 2.2, the existing neutron transport models, used to interpret CRNS neutron signals specific to the soil moisture measurand, will be benchmarked on the test field sites, and validated. In Task 2.3, the approaches for the soil moisture assessment from the neutron count rates measured in the CRNS neutron probes will be reviewed, compared and a good practice guide developed.

C2.a Task 2.1: Selection and further enhancement of high-level test field sites

The aim of this task is to select and further enhance three high-level test field sites which will be used for the comparison of the different soil moisture assessment methods in WP3 and their data fusion in WP4. Where applicable, these sites will also be used for the development of validation practices for CRNS methodology in outdoor conditions in Tasks 2.2 and 2.3.

Activity number	Activity description	Participants (Lead in bold)
A2.1.1 M3	UP DE, UNIBO, CNR, CTU, DTI, INRIM and PTB will select three high-level test field sites, suitable for the comparison of at least two soil moisture assessment methods simultaneously (e.g., CRNS + point-scale sensors; point-scale sensors + remote sensing; CRNS + remote sensing). Six possible sites have been identified including the institution that could act as host. The selection criteria will be based on: • area extent, • land cover, land type use, • climatic conditions, • soil heterogeneity, • and instruments already deployed at the given site. For the candidate sites, existing data on soil, vegetation, and groundwater will be provided by the potential host (UP DE, UNIBO (2 sites), CNR, CTU and INRIM). The data will be compiled and analysed by UP DE, CNR, CTU and INRIM to rank the candidate sites for their suitability.).	**UP DE**, UNIBO, CNR, CTU, DTI, INRIM, PTB
A2.1.2 M24	Based on selection made in A2.1.1, the instrumentation already deployed at these sites and on the metrological requirements identified in A1.1.7, the hosts (UP DE, UNIBO, CNR, CTU and/or INRIM) will install additional instrumentation, e.g., point-scale measurement devices or soil moisture profile probes, at the three high-level test field sites. In the case of point-scale measurement devices, the devices purchased and characterised in A1.2.7, will be provided for this work by DTI. TUBITAK's portable transfer standard for soil moisture measurement, based on visible and near-infrared spectral reflectance measurements (A1.2.8), will be deployed on at least one of the high-level test field sites.	**UP DE**, UNIBO, CNR, CTU, TUBITAK, UFZ, DTI, INRIM

	UFZ will select two of the three high-level test field sites, previously selected in A2.1.1, to apply their mobile version and a point-scale version of the CRNS probe, to support the comparison of soil moisture measurement methods with different sensing volumes. The hosts of the three high-level test field sites (UP DE, UNIBO, CNR, CTU and/or INRIM), together with DTI, TUBITAK and UFZ will document the existing and the newly deployed additional instrumentation. By M18, preliminary data will be collected with the mobile CRNS instruments.	
A2.1.3 M6	For the three high-level field test sites, UFZ, with support from the hosts (UP DE, UNIBO, CNR, CTU and/or INRIM) will establish the soil moisture data retrieval system to enable an automatic feeding of the field data into the project's data management system (A6.1.5). UFZ will document the overall design and the relevant technical details of the retrieval and feeding mechanisms. The functionality of these mechanisms will be regularly monitored to ensure a flawless data stream.	**UFZ,** UP DE, UNIBO, CNR, CTU, INRIM
A2.1.4 M12	UNIBO, with the help of CNR, CTU, UP DE, UKCEH, JV, INRIM and IAPAN will set up links to at least two other test field sites accompanying the three high-level field test sites selected in A2.1.1. This could include candidate sites not selected in A2.1.1 and/or additional sites, such as e.g., the sites operated by JV and UKCEH. The accompanying field sites will be used to investigate individual aspects of the soil moisture measurement methods, possibly for just one out of the three main soil moisture measurement methods targeted, e.g., the point-scale sensors or the CRNS method only.	**UNIBO**, CNR, CTU, UP DE, UKCEH, JV, INRIM, IAPAN
A2.1.5 M24	Using input from A2.1.1 – A2.1.4, UP DE, UNIBO, CNR, CTU and DTI will produce a report about the selection, characterisation, and enhancement of the high-level test sites. The report will also contain information on the additional test sites specified in A2.1.4.	**UP DE**, UNIBO, CNR, CTU, DTI
A2.1.6 M26	To perform field tests, TUBITAK will install its newly developed portable transfer standard for soil moisture measurement system (A1.2.8) on a drone-based system for on-field remote sensing of soil moisture. The obtained results will be compared with the *in-situ* measurements of the soil moisture by means of traditional capacitive type point-scale sensors. In addition, samples from the same test field will be collected and measured in the laboratory by the LoD, TGA, cKF methods established and validated in A1.2.5. The results of this comparative study will be documented in a report. Soil samples from the same test field will be shipped by TUBITAK to CMI and DTI, where they will be analysed by means of soil moisture measurement methods established and validated in A1.2.5. Preliminary results will be made available in M22.	**TUBITAK**, CMI, DTI

C2.b Task 2.2: Validation of existing neutron transport models used to interpret CRNS signals specific to the soil moisture measurand

The aim of this task is to benchmark and validate the existing neutron transport models used to interpret CRNS neutron signals specific to the soil moisture measurand, applying the response functions derived and validated in Task 1.3. These models and their validation are crucial for the improved understanding of the CRNS sensing volume (horizontal and vertical footprint, also for heterogenous conditions) in on-field outdoor conditions. A further aim of this task is to quantify the uncertainties of the various systematic effects affecting the CRNS footprint.

Activity number	Activity description	Participants (Lead in bold)
A2.2.1 M17	On the high-level test sites selected in A2.1.1, and optionally on the accompanying sites specified in A2.1.4, UHEI, CTU, UP DE and UNIBO will systematically compare state-of-the-art procedures for CRNS neutron signal acquisition, data analysis and CRNS footprint estimation. This will be done using input from the report in A1.3.5 and the response functions of the CRNS devices as obtained in A1.3.4.	**UHEI**, CTU, UP DE, UNIBO

A2.2.2 M19	Using input from A2.2.1, UFZ, UHEI, SMU, CTU, DTI, CMI, IRSN, PTB, UNIBO and UP DE will assess (theoretically and experimentally) the systematic effects influencing the CRNS footprint on the high-level test sites specified in A2.1.1. For the experimental approach, DTI and CMI will evaluate the SI-traceable point-scale soil moisture measurements based on A1.2.3 and A1.2.4, in combination with assessment of other soil moisture affecting parameters, such as air humidity, soil density profile, spatial soil heterogeneity as measured by the field site host. Where applicable, preliminary data from A2.1.2 (results from mobile CRNS instruments) will be used to assess spatial patterns within the footprint by UFZ. For the theoretical approach, UHEI and UFZ, with the support from SMU, CMI, IRSN, CIEMAT and PTB, will carry out Monte Carlo neutron transport simulations of the given sites, including sensitivity analysis of various environmental and instrumental effects.	**UFZ**, UHEI, SMU, CTU, DTI, CMI, IRSN, PTB, UNIBO, UP DE, CIEMAT
A2.2.3 M24	PTB and IRSN will perform dedicated neutron measurement campaigns on the hig-level test sites specified in A2.1.1. The measurements will be carried out using Bonner sphere spectrometers (BSS) from PTB and IRSN. PoliMi will select one of the three high-level test field sites, specified in A2.1.1, to apply their large-size wide-range neutron spectrometer. PTB, IRSN, UP DE, UFZ, UHEI, UKCEH, CIEMAT, SMU and PoliMi will use these results to benchmark the Monte Carlo neutron transport calculations from A2.2.2. UHEI, UFZ, UP DE, and UKCEH will also use these results for evaluating approaches for corrections of the incoming cosmic-ray neutron flux, as well as quantifying the uncertainty of these corrections.	**UP DE**, UFZ, UHEI, PTB, IRSN, UKCEH, SMU, CIEMAT, PoliMi
A2.2.4 M27	Based on A2.2.1 – A2.2.3, the different approaches and methods will be systematically compared, validated, and harmonised by UP DE, UFZ, UHEI, PTB, IRSN, CTU, CMI, DTI, SMU, UKCEH and UNIBO, to produce a report on the comparison and validation of existing neutron transport models used to interpret CRNS signals measured under outdoor conditions. A report summarising the findings will be produced. Once the report has been agreed by the consortium, the coordinator on behalf of UP DE, UFZ, UHEI, PTB, IRSN, CTU, CMI, DTI, SMU, UKCEH and UNIBO will send **D3**: "*Report on the comparison and validation of existing neutron transport models used to interpret CRNS signals measured under outdoor conditions*" to EURAMET.	**UP DE**, UFZ, UHEI, PTB, IRSN, CTU, CMI, DTI, SMU, UKCEH, UNIBO

C2.c Task 2.3: Standardisation of the CRNS on-field calibration procedure for soil moisture assessment

The aim of this task is to review and compare approaches for the soil moisture assessment from the neutron count rates measured in the CRNS neutron probes, currently used in the CRNS methodology. The output of this task is a good practice guide on this procedure. This task is strongly correlated with the Task 2.2 as the environmental systematic effects, affecting the CRNS footprint and the resulting soil moisture assessment, play a role here, too.

Activity number	**Activity description**	**Participants (Lead in bold)**
A2.3.1 M32	At the three high-level test field sites selected in A2.1.1, UNIBO, with support from CTU, DTI, UP DE, UFZ, UHEI, PTB, IRSN, CMI and SMU will regularly compare measurement data from the CRNS neutron probes with measurement data using the SI-traceable point-scale soil moisture methods previously established and characterised in A1.2.7. The portable transfer standard developed in A1.2.3 will be initially used, and then at M18 the calibration procedures and model uncertainty budgets developed in A1.2.6 will be used. Using input from A2.2.4, the measurement data from the CRNS neutron probes will be translated into the soil moisture estimates based on the latest findings of A2.2.1 – A2.2.3. UNIBO, UP DE, UFZ and UHEI will agree on and document an optimised soil moisture sampling procedure to enable quality-assured comparison of the data sets between the different experimental sites. At M20, M22 and M30 preliminary time series data will be made available.	**UNIBO**, CTU, DTI, UP DE, UFZ, UHEI, PTB, IRSN, CMI, SMU

A2.3.2 M21	Based on the M20 preliminary data sets from A2.3.1, UNIBO, CTU and UP DE will compare the currently available on-field CRNS calibration procedures against each other in terms of requirements for soil sampling, systematic effects, and uncertainty quantification. The various systematic effects, encountered on the three high-level test field sites, will be regularly documented, and taken into account by UNIBO.	**UNIBO**, CTU, UP DE
A2.3.3 M22	Using input from A2.3.2, UP DE, UNIBO and DTI will develop recommended calibration practices to retrieve a vertically non-weighted mean soil moisture. UP DE, UNIBO and DTI will also investigate the options to obtain a horizontally non-weighted mean soil moisture (e.g., by defining a minimum number of CRNS probes at a site).	**UP DE**, UNIBO, DTI
A2.3.4 M24	Using input from A2.3.3, UP DE, UFZ, UHEI, PTB, IRSN, CTU, TUBITAK, UNIBO, DTI, CMI, SMU and INRIM will produce a good practice guide for calibration practices for CRNS soil moisture data retrieval in outdoor field conditions covering on lateral scales ranging from 10^2 m to 10^3 m and to depths of up to 1 metre. INRIM will provide support by reviewing the good practice guide. Once the good practice guide has been agreed by the consortium, the coordinator on behalf of UP DE, UFZ, UHEI, PTB, IRSN, CTU, TUBITAK, UNIBO, DTI, CMI, SMU and INRIM will send **D4**: "*Good practice guide for calibration practices for CRNS soil moisture data retrieval in outdoor field conditions covering on lateral scales ranging from 10^2 m to 10^3 m and to depths of up to 1 metre*" to EURAMET.	**UP DE**, UFZ, UHEI, PTB, IRSN, CTU, TUBITAK, UNIBO, DTI, CMI, SMU, INRIM

C3 WP3: Comparison and harmonisation of soil moisture observation methods on multiple spatial and temporal scales

The aim of this work package is to compare and harmonise soil moisture observation methods on multiple spatial and temporal scales. In Task 3.1, point-scale, intermediate scale and remote sensing methods will be systematically reviewed and compared in terms of their measurand and its uncertainty, sensing volume, and the systematic effects affecting the process of soil moisture assessment within each method. This comparison will be based on already existing large data sets (historical time series) from established sites, on synthetic time series generated by soil hydrological models (e.g., HYDRUS [20,21]) and on the new data sets obtained on the high-level and accompanying field test sites which have been previously selected and established in WP2. Historical data available within the consortium will be also collected to support the comparison. In Task 3.2, a harmonisation method will be developed to enable a better comparison of the detected signals and to merge the specific strengths of each soil moisture assessment method.

C3.a Task 3.1: Comparison of methods, their constraints and different spatial and temporal characteristics

The aim of this task is to characterise and extract the information content of the soil moisture determined by point-scale, intermediate scale, and remote sensing methods. The information content will then be compared. Specific attention will be paid to spatial and temporal resolution, support volume, accuracy, and reliable uncertainty estimation. This comparison will provide the basis for developing the harmonisation method in Task 3.2 and to further support the development of the data fusion in WP4.

Activity number	Activity description	Participants (Lead in bold)
A3.1.1 M9	UNIBO, with support from UKCEH, CNR and TUBITAK will identify and review at least 3 existing methods for characterising the spatial and temporal soil moisture observations determined by point-scale, intermediate scale, and remote sensing methods. Focus will be paid to the temporal and spatial differences (resolution, support volume and accuracy) of sensing domains of the individual soil moisture measurement methods. The main systematic effects affecting the soil moisture measurand and its uncertainty in each method will also be reviewed and compared and uncertainty limits will be defined. Target traceable relative uncertainties are expected to be in the range of 20 %.	**UNIBO**, UKCEH, CNR, TUBITAK

A3.1.2 M22	CNR, with support from UNIBO, UKCEH, TUBITAK, IAPAN, CTU, UP DE, UFZ, DTI and UHEI, will analyse the M22 preliminary time series data from A2.3.1 (CRNS methods) and A4.2.1 (remote sensing) at the different high-level test field sites. As a further input, the M22 preliminary results of the tests carried out in A2.1.6 will also be used. Historical time series and synthetic numerical modelling data will be analysed in a consistent manner. UNIBO and CNR with support from UKCEH, TUBITAK, CTU and UP DE will develop advanced quality control algorithms for each method and apply them to provide dynamic uncertainty estimates, and to flag data that is not expected to be within the required uncertainty limits defined in A3.1.1. The dynamic uncertainty may be most usefully expressed as a function of soil moisture content, in most cases, but other factors, such as soil type, and biomass dynamics will play a role. UNIBO and CNR with support from UKCEH, DTI, UHEI and UFZ will collect and analyse the QA/QC (quality assurance and quality control) soil moisture time series data obtained by point-scale, intermediate scale, and remote sensing methods.	**CNR**, UNIBO, UKCEH, TUBITAK, IAPAN, CTU, UP DE, UFZ, DTI, UHEI
A3.1.3 M23	UNIBO, with support from CNR, DTI, TUBITAK, UP DE, UFZ and CTU will quantify and compare the information content and assess the strengths and weaknesses of each of the soil moisture measurement method and their sensing domains. The analysis will be performed based on the methods identified in A3.1.1 to quantify the specific characteristics of each method and on the QA/QC time series collected and analysed in A3.1.2. This work will also use the results obtained during the analysis of the individual soil moisture measurement methods in A1.2.5 and A1.3.5. The results of this analysis will identify in which conditions one method is more suitable and effective and they will support the development of field experimental protocols depending on the specific environmental characteristics, e.g., soil type, land use, climate.	**UNIBO**, CNR, DTI, TUBITAK, UP DE, UFZ, CTU
A3.1.4 M24	Using input from A3.1.1 – A3.1.3, UNIBO, with support from IAPAN, UP DE, UKCEH, CNR, TUBITAK, CTU, UFZ, DTI, UHEI and PTB will produce a report on the comparison of soil moisture measurement methods and their different sensing domains (local and remote) including details on the constraints and accuracy of the methods and requirements for harmonisation. Once the report has been agreed by the consortium, the coordinator on behalf of UNIBO, IAPAN, UP DE, UKCEH, CNR, TUBITAK, CTU, UFZ, DTI, UHEI and PTB will send **D5**: "*Report on the comparison of soil moisture measurement methods and their different sensing domains (local and remote) including details on the constraints and accuracy of the methods and requirements for harmonisation."* to EURAMET.	**UNIBO**, IAPAN, UP DE, UKCEH, CNR, TUBITAK, CTU, UFZ, DTI, UHEI, PTB

C3.b Task 3.2: Development of the harmonisation approach

The aim of this task is to develop and test the harmonisation approach. The approach will consider the integration of the specific characteristics identified in Task 3.2 to strengthen the spatial and temporal aggregation of the detected signals, towards the harmonisation of the soil moisture assessments. This task also aims to enable more appropriate comparisons of global remote sensing data with the ground-based data on point and intermediate scale.

Activity number	Activity description	Participants (Lead in bold)
A3.2.1 M12	UNIBO with support from CNR, UKCEH, IAPAN, DTI and CTU will identify and review at least four existing soil moisture harmonisation methods, such as upscaling, downscaling, triple-collocation, and re-analysis. Since the topic is relatively new and not yet established for soil moisture observations, the review will also focus on methods that are applied to other variables in environmental monitoring and in Earth system science. Input and help from the project's Stakeholder Committee (A5.1.1) will be sought.	**UNIBO**, CNR, UKCEH, IAPAN, DTI, CTU

A3.2.2 M28	UNIBO with support from UKCEH, CNR, IAPAN, CTU and UFZ will apply and test the harmonisation approaches identified and reviewed in A3.2.1 on soil moisture QA/QC-processed time series, available for the individual soil moisture measurement methods and collected in A3.1.3. Based on input from A3.1.1 – A3.1.4, UNIBO with support from UKCEH, CNR, IAPAN, CTU and UFZ will investigate the suitability of novel approaches to make the soil moisture retrievals from the different methods better comparable: For example, soil moisture estimates from the depth-sensing method of CRNS will be transformed into the surface soil moisture (SSM) information, which can be compared to the SSM retrieval by remote sensing techniques. And, *vice versa*, the SSM retrieved by remote sensing will be extended to deeper soil layers, to be comparable to the CRNS-based results.	**UNIBO**, UKCEH, CNR, IAPAN, CTU, UFZ
A3.2.3 M30	UKCEH, with support from UNIBO, IAPAN, UP DE, CNR and UHEI will assess the strengths and weaknesses of the different harmonisation procedures applied in A3.2.2. The procedures will be evaluated by comparing the harmonised results, including their uncertainty, as well as the feasibility of the application of the procedures.	**UKCEH,** UNIBO, IAPAN, UP DE, CNR, UHEI
A3.2.4 M32	Using input from A3.2.1 – A3.2.3, UNIBO with support from CNR, UKCEH, IAPAN, DTI, CTU, UFZ, UP DE, UHEI, INRIM and PTB will produce a good practice guide for harmonising soil moisture measurement methods to overcome temporal and spatial differences (lateral scales ranging from point scale to km scale) and the influence of other state variables such as air humidity and soil temperature affecting the measurements. INRIM, CTU, UHEI and IRSN will provide support by reviewing the good practice guide. Once the report has been agreed by the consortium, the coordinator on behalf of UNIBO, CNR, UKCEH, IAPAN, DTI, CTU, UFZ, UP DE, UHEI, INRIM, IRSN and PTB will send **D6**: "*Good practice guide for harmonising soil moisture measurement methods to overcome temporal and spatial differences (lateral scales ranging from point scale to km scale) and the influence of other state variables such as air humidity and soil temperature affecting the measurements*" to EURAMET.	**UNIBO**, CNR, UKCEH, IAPAN, DTI, CTU, UFZ, UP DE, UHEI, INRIM, PTB, IRSN

C4 WP4: Multi-scale and multi-disciplinary soil moisture data fusion

This work package aims at integrating the multi-scale soil moisture measurements to provide new schemes and recommendations to facilitate the generation of high-quality, temporally and spatially consistent soil moisture information useful for land surface sciences and applications, such as climate observations, weather forecasting, hydrology, and agriculture. In Task 4.1, strategies for fusion of the soil moisture data on multiple spatial and temporal scales will be reviewed and compared, and in Task 4.2, the most suited method will be selected and implemented.

C4.a <u>Task 4.1: Definition of data fusion methods for soil moisture measurements on multiple scales</u>

The aim of this task is to review and compare different fusion methods for soil moisture measurements on multiple spatial and temporal scales. On the historical data identified in WP3, different data fusion approaches will be representatively applied and compared. Based on the review of current state-of-the-art practices and implemented test cases, recommendations will be given for a fusion of data including point-scale, CRNS and remote sensing soil moisture measurements. Attention will be paid to the uncertainty model and traceability scheme of each of the utilised soil moisture assessment methods and their relationships.

Activity number	Activity description	Participants (Lead in bold)
A4.1.1 M9	IAPAN, with support from CNR, UNIBO, DTI, TUBITAK, UKCEH, UP DE and PTB, will review and compare at least three current state-of-the-art methods for data fusion of soil moisture assessment on multiple lateral and temporal scales. Based on the review and comparison, a table will be produced by IAPAN with support from CNR, UNIBO, DTI, TUBITAK, UKCEH, UP DE and PTB, comparing the advantages and disadvantages of individual solutions, both in technical and economic terms.	**IAPAN**, CNR, UNIBO, DTI, TUBITAK, UKCEH, UP DE, PTB

A4.1.2 M30	CNR, IAPAN, UNIBO and TUBITAK will apply the soil moisture data fusion methods, reviewed and compared in A4.1.1, on the historical soil moisture time series after their harmonisation in A3.1.3 and A3.2.3. Predominantly, the historical data sets will be used, but the M30 preliminary data from A2.3.1, will be used as well. CNR, IAPAN, UNIBO and TUBITAK will select the most promising method, and will implement the final scheme fusing soil moisture data observed at multiple scales. The data fusion method will be implemented in accordance with the ground-based soil moisture measurement traceability established in A1.1.6, A1.2.6 and A2.3.4.	**CNR**, IAPAN, UNIBO, TUBITAK
A4.1.3 M33	Using input from A4.1.1 and A4.1.2, CNR, with support from IAPAN, UNIBO, TUBITAK, DTI, UKCEH, UP DE and PTB write a report on the comparison of the existing data fusion methods for soil moisture measurements multiple lateral (from 10^{-1} m to 10^{3} m and to depths of up to 1 metre) and temporal (from hours to days) scales to assess the soil moisture with traceable relative uncertainty of 20 % or better. Once the report has been agreed by the consortium, the coordinator on behalf of CNR, IAPAN, UNIBO, TUBITAK, DTI, UKCEH, UP DE and PTB will send **D7**: "*Report on the comparison of the existing data fusion practices for soil moisture measurements on multiple lateral (from 10^{-1} m to 10^{3} m and to depths of up to 1 metre) and temporal (from hours to days) scales to assess the soil moisture with traceable relative uncertainty of 2 % or better*" to EURAMET.	**CNR**, IAPAN, UNIBO, TUBITAK, DTI, UKCEH, UP DE, PTB

C4.b Task 4.2: Implementation of data fusion of soil moisture measurements on multiple scales

The aim of this task is to achieve a cross-disciplinary data fusion of soil moisture measurements across the temporal and spatial scales, ranging from hours to days, and from 10^{-1} m to 10^{3} m, respectively. The lower end of the temporal and spatial scales, respectively, correspond to the *in-situ* soil moisture measurements using the point-scale measuring devices. The upper end of these scales, on the other hand, is linked to the satellite-based remote sensing methods of soil moisture retrieval.

The method selected in Task 4.1 will be applied to fuse the data collected in WP2 and harmonised in WP3. It is expected that the merged soil moisture observations will retain the desirable characteristics of the components at the various spatial and temporal scales. Strengths and weaknesses of the implemented scheme will be critically reviewed, and lessons learnt during this process will be translated into practical recommendations and a good practice guide.

Activity number	Activity description	Participants (Lead in bold)
A4.2.1 M24	CNR will download and process all relevant data series from the Earth Observation data providers to complete the ground-based soil moisture data sets using M22 preliminary data from A2.3.1 and A3.1.2 with corresponding remote sensing data. Data from satellite platforms that support soil moisture retrieval at the spatial scale of 10^{3} m, such as the Copernicus Sentinel-1 constellation, will be used. By M22 preliminary data will be made available.	**CNR**
A4.2.2 M30	CNR, IAPAN and UNIBO will perform the data fusion of multi-scale soil moisture observations collected during the project over the high-level test field sites identified in A2.1.1. The method selected in A4.1.2 will be applied to the data set harmonised in A3.2.2. CNR and IAPAN, with support from UNIBO, will assess the improved spatial and temporal coverage, and prepare examples of multi-scale fused data.	**CNR**, IAPAN, UNIBO
A4.2.3 M34	In addition to the data fusion implementation, CNR, with support from IAPAN, UNIBO, TUBITAK, UP DE, UKCEH, DTI, IRSN, INRIM, UFZ, UHEI and PTB will provide recommendations for calibration/validation procedures of remote sensing soil moisture products, based on lessons learnt in A3.1.4 and A3.2.4. Good practices for integrating the medium-scale observations provided by the CRNS method will be identified.	**CNR**, IAPAN, UNIBO, TUBITAK, UP DE, UKCEH, DTI, IRSN, INRIM, UFZ, UHEI, PTB
A4.2.4 M36	Using input from A4.2.1 – A4.2.3, CNR, with support from IAPAN, UNIBO, DTI, TUBITAK, UKCEH, UP DE, IRSN, PTB, INRIM, UFZ and UHEI will write a good practice guide for interdisciplinary data fusion of soil moisture measurements on multiple scales Once the report has been agreed by the consortium, the coordinator on behalf of CNR, IAPAN, UNIBO, DTI, TUBITAK, UKCEH, UP DE, IRSN, INRIM, UFZ, UHEI and PTB will send **D8**: "*Good practice guide for interdisciplinary data fusion of soil moisture measurements on multiple scales*" to EURAMET.	**CNR**, IAPAN, UNIBO, DTI, TUBITAK, UKCEH, UP DE, IRSN, PTB, INRIM, UFZ, UHEI

C5 WP5: Creating impact

C5.a Task 5.1: Dissemination and communication

Activity number	Activity description	Participants (Lead in bold)
A5.1.1 M2	The project will create a Stakeholder Committee (SC) of at least 5 members from organisations such as agro-meteorological services, national meteorological services, WMO members of expert teams, EMN Climate Ocean members, regional instrument centres, manufacturers etc. The aim of the Stakeholder Committee is to supervise the project advances, be updated on activities and deliverables, directly interact with the metrologists involved to better transfer the user community's vision and needs. The Stakeholder Committee will support by communicating and disseminating the project results. Interaction with the Stakeholder Committee will be achieved via teleconferences and inviting representatives of the stakeholders to project meetings or attending meetings at conferences. Members of the Stakeholder Committee will be identified who could provide help and feedback during the process of development and review of the project's good practice guides. These members will be invited to join the process of good practice guides development and review, and their input and feedback will be sought. In close cooperation with the networking and reviewing activities in A1.1.1 and A1.1.2, UFZ and all participants will also liaise with other projects and networks to disseminate the project e.g., the future ESFRI eLTER RI network (Integrated European Long-Term Ecosystem Critical Zone & Socio-ecological Research Infrastructure), the Global Terrestrial Network – Hydrology (GTN-H) operated by the ICWRGC, the International Soil Moisture Network, the Joint FAO/IAEA Programme "Nuclear Techniques in Food and Agriculture". The project will also liaise with developers, established manufacturers as well as start-up companies, and end-users (e.g., in meteorology, hydrology, agriculture, Earth observation sciences) of commercial devices for soil moisture measurement on the different lateral scales.	**PTB**, all participants
A5.1.2 M2	PTB will create a dedicated project website which is updated at least every 3 months. The website will contain both an open access area and a restricted part for the consortium. The open access area will contain news, project advances, events or technical and scientific information of interest for the project topics. The part of the website with restricted access will be dedicated to exchange information and reports throughout the project. It will also include a digital archive of all presentations, reports and papers from the project.	**PTB,** all participants
A5.1.3 M36	At least 15 presentations will be made in international conferences during the course of the project. The conferences will be selected based on target audience (academia, industry, and measurement supply chain). Relevant scientific meetings include, but are not limited to: • WMO TECO conference • Metrology for Meteorology and Climate • Satellite Soil Moisture and Application Workshop • International Geoscience and Remote Sensing Symposium (IGARSS) • European Geosciences Union General Assembly The dates and locations of these conferences are not yet known. Further relevant conferences will be identified during the project.	**PTB**, all participants
A5.1.4 M36	The participants will submit at least 13 papers in total to peer-reviewed journals during the project. Target journals include, but are not limited to, • Meteorological Applications • Atmospheric Measurement Techniques • Hydrology and Earth System Sciences • Remote Sensing of Environment	**PTB**, all participants

<table>
<tr><td></td><td>The expectations are that at least 7 out the 13 publications will be the result of a collaborative effort from participants from different countries.

The authors of the open access peer reviewed papers will clearly acknowledge the financial support provided through the Partnership as required by EURAMET in accordance with Article 17, Article 18, and Annex 5 of the Grant Agreement with the following text:

“The project (21GRD08 SoMMet) has received funding from the European Partnership on Metrology, co-financed from the European Union’s Horizon Europe Research and Innovation Programme and by the Participating States.”

The authors will ensure that the following meta data is submitted and included for each paper:
• Funder name: European Partnership on Metrology
• Funder ID: 10.13039/100019599
• Grant number: 21GRD08 SoMMet</td><td></td></tr>
<tr><td>A5.1.5
M9</td><td>A project flyer as well as a project poster will be prepared addressing all relevant information about the project and the participants. The texts will be written for non-specialist audience and will be partially based on the publishable summary. Special emphasis will be on promoting the importance of the basic principles of metrology and its implication for TCE measurements. The flyer and poster will be available for download on the project website (A5.1.2). The flyer will mainly be used as a handout during project presentations at conferences and will be added to letters and emails (as a pdf-attachment) for communications with all non-project participants. The project poster will be used to present the general outline of the project during minor conferences and meetings not mentioned below.</td><td>INRIM, all participants</td></tr>
<tr><td>A5.1.6
M36</td><td>To approach the wider public at least two press statements will be released via trade journals: one at the beginning and one at the end of the project and others during the project when results need to be shared with the public. The press release will be disseminated through the participating NMIs and DIs.</td><td>PTB, all participants</td></tr>
<tr><td>A5.1.7
M36</td><td>Information on the results of the project will be disseminated to a range of standards bodies and committees and feedback sought (see details below and in the table in Section B3.c).
<table>
<tr><th>Standards Committee / Technical Committee / Working Group</th><th>Participants involved</th><th>Likely area of impact / activities undertaken by participants related to standard / committee</th></tr>
<tr><td>CEN TC 444 Environmental Characterisation WG5 Physical tests</td><td>DTI</td><td>CEN TC 444 is responsible for providing a platform for the development of European Standards and other technical documents in relation to various kinds of products, materials, services and processes

DTI will prepare a Technical Report incorporating guidelines on recommended procedures for the traceable calibration of soil moisture instruments (A1.1.7) for consideration and adoption by CEN TC 444/WG5.

The committee meets once or twice a year. The project and project results obtained (A1.1.7) will be presented at the first committee meeting after completing the report and guideline in 2024.</td></tr>
<tr><td>ISO TC190 Soil quality

WG1 Soil and Climate Change

SC3 Chemical and physical characterisation</td><td>DTI</td><td>ISO TC 190/WG1 is responsible for Soil and Climate Change and ISO TC 190/WG1 SC3 is responsible for Chemical and physical characterisation.

DTI will work with the representatives to the sub-committees to propose that ISO adopts the project’s Technical Report developed through CEN TC444 as part of ISO 11461:2018 Soil quality — Determination of soil water content as a volume fraction using coring sleeves — Gravimetric method.

The committee meets once a year.</td></tr>
</table>
</td><td>PTB, all participants</td></tr>
</table>

World Meteorological Organisation Standing Committee on Measurements, Instrumentation and Traceability (WMO SC-MINT) (or WMO Commission for Observation, Infrastructure and Information Systems INFCOM Editorial Board)	**INRIM**	The WMO SC-MINT and INFCOM committees are devoted to the periodic revision of the WMO Guide to Instruments and Methods of Observation (Guide No. 8). INRIM will prepare a proposal to include recommendations about soil moisture instruments in an update to the WMO Guide to Instruments and Methods of Observation No. 8. The proposal will be presented at a meeting of the Surface and Sub Surface Expert Team (or similar if during the next intersessional period this expert team will change name or structure). The committee meets at least twice a year.
WMO Global Climate Observing System (GCOS) Surface Reference Network	**INRIM**	INRIM will prepare a proposal for the design of reference grade surface stations, including *in-situ* soil moisture measurements based on demonstrated traceability of this kind of instruments. INRIM will submit this to the GCOS Surface Reference Network, by email or directly attending the GSRN Task Team Meeting for inclusion into the guide on the measurement requirements for Climate Reference Stations taking part to GSRN, in order to include reference grade measurements of soil moisture among the climate reference variables for the GSRN. The network task team meets once a year.
WMO SC-MINT expert team on Measurement Uncertainty (ET-MU)	**INRIM**	INRIM will foster discussions with SC-MINT ET-MU about adopting a uniform procedure for the comparison of different typologies of soil moisture measurements methods and instruments. INRIM will propose by email that the project's recommendations on uncertainty evaluation (A1.2.9) are included in an update to the Guide to Instruments and Methods of Observation No. 8. The expert team meets normally every two months.
EURAMET Technical Committee for Thermometry (TC-T)	**DTI**, INRIM, JV, TUBITAK	At the next meeting in 2023, TC-T will be informed about the activities of the project by DTI, INRIM, JV and TUBITAK. The next meeting will be held alongside COOMET TC 1.10 Thermometry and Thermal Physics, therefore this organisation will also be informed about this project's results. The results from the work on transfer standards for moisture measurements and calibration standards (A1.2.9) will be presented to EURAMET's TC-T's sub-committee for humidity on an ongoing basis. EURAMET TC-T meets annually in April-May.
BIPM Consultative Committee for Thermometry Working Group for Humidity (CCT-WG-Hu)	**TUBITAK,** DTI	BIPM's CCT-WG-Hu will be informed by TUBITAK and DTI about the activities of the project with regards to the project's work on moisture content measurements. BIPM CCT-WG-Hu meets every 2-3 years.
CEN TC 444 Environmental Characterisation WG5 Physical tests	**DTI**	CEN TC 444 is responsible for providing a platform for the development of European Standards and other technical documents in relation to various kinds of products, materials, services and processes DTI will prepare a Technical Report incorporating guidelines on recommended procedures for the traceable calibration of soil moisture instruments (A1.1.7) for consideration and adoption by CEN TC 444/WG5. The committee meets once or twice a year. The project and project results obtained (A1.1.7) will be presented at the first committee meeting after completing the report and guideline in 2024.

	The representatives on the corresponding committee or WG from the participants will jointly ask the chairperson to include a point in the agenda to briefly present the outputs of the project related to the WG activities and ask for comments. Where appropriate a written report will be submitted for consideration by the committee or WG.	
A5.1.8 M27	DTI, with the support of all participants, will organise and hold a one-day conference alongside a one-day training course to disseminate results of the project and promote the uptake of the technology and measurement infrastructure developed, by the end users. The target number of delegates for the conference will be approximately 50. The aim of the conference is to present and discuss the project results, as available by M27, and information to manufacturers and end users of soil moisture measurement devices. Findings from this meeting will also be used to feedback into the project results. The aim of the training course is to train participants from the stakeholder community, specifically targeted to hydro-meteo agencies, agrometeorological consortia and manufacturers. The target number of delegates for the training course is between 10 and 20. The course will include the following topics: a) General metrology principles b) Soil moisture physics, measurand definition and ranges of variability c) Soil moisture instruments typologies and operating principles d) Specific findings on calibration and accuracy of soil moisture instruments The conference and course will be promoted on the project's website (A5.1.2), the participants' websites and professional contacts and through the project's Stakeholder Committee (A5.1.1). DTI will also contact EURAMET-MSU to ask if it can be promoted on the EURAMET website. The project participants will liaise with existing and potential future EMN's e.g., EMN Climate Ocean, any relevant EURAMET TC, to see whether there are any other EURAMET funded projects, EU funded Partnerships or any research/industrial projects, that could be utilised to increase the outreach of this event. A report will be made summarising the conference and course content. The report is published on the projects homepage and communicated through social media such as LinkedIn.	**DTI,** all participants
A5.1.9 M4	Mutual training will be provided between metrology and non-metrology experts of the participants at the project kick-off meeting or as specific event soon after, on the general, technical and metrological principles of interest for the instrumentation and goals of the project.	**DTI**, all participants
A5.1.10 M36	INRIM, with the support of all participants, will organise and hold a one-day "Soil Moisture Workshop". The aim of the workshop is to present and discuss the project results and information to stakeholders, including WMO representatives, national meteorological and agro-meteorological. The three good practice guides (deliverables D4, D6 and D8) will be disseminated via this workshop. The target number of delegates for the workshop will be approximately 20. The workshop will be promoted on the project's website (A5.1.2), the participants' websites and professional contacts and through the project's Stakeholder Committee (A5.1.1). INRIM will also contact EURAMET-MSU to ask if it can be promoted on the EURAMET website. The project participants will liaise with existing and potential future EMN's e.g., EMN Climate Ocean, any relevant EURAMET TC, to see whether there are any other EURAMET funded projects, EU funded Partnerships or any research/industrial projects, that could be utilised to increase the outreach of this event.	**INRIM**, all participants

C5.b Task 5.2: Exploitation and uptake

Activity number	Activity description	Participants (Lead in bold)
A5.2.1 M36	A dissemination, communication and exploitation plan (DCE) will be created at the beginning of the project with support from all participants and submitted to EURAMET at M6. It will be reviewed and updated at least at each project meeting. The DCE plan will provide further details on the following expected results: • Expected result 1: A1.1.7 and A1.2.9 – Input to WMO INFCOM and SC-MINT for the revision of the WMO CIMO Guide to Instruments and Methods of Observation (Guide No. 8). (More information provided in A5.2.2.) • Expected result 2: A1.1.7 – Report detailing (i) the methodologies and approaches needed for traceability for soil moisture measurements by the end-user communities and (ii) for developing a metrological framework for on-site	**PTB**, all participants

	measurements of soil moisture on lateral scales ranging from 10^{-1} m to 10^{2} m. (More information provided in A5.2.3.) • Expected result 3: A1.2.9 – New consultancy and laboratory services to end-users on the traceability of soil moisture measurement using point-scale sensors. (More information provided in A5.2.4.) • Expected result 4: A1.2.8 – New calibration service for soil moisture measurements. (More information provided in A5.2.5.) • Expected result 5: A3.2.4 and A4.2.4 – Good practice guides for harmonising and achieving/performing an interdisciplinary data fusion of soil moisture measurement methods on different temporal scales and on lateral scales ranging from point scale to km scale. (More information provided in A5.2.6.) Further expected results may be identified during the lifetime of the project.	
A5.2.2 M36	Using input from A1.1.7, A1.2.9 and A4.2.4, INRIM will provide input, in the form of a document summarizing the project's relevant results, to WMO INFCOM and SC-MINT for the revision of the WMO CIMO Guide to Instruments and Methods of Observation (Guide No. 8). The process for updating the guide is at WMO-No. 8 website (https://community.wmo.int/activity-areas/imop/wmo-no_8) and will be followed by INRIM with support from all participants.	**INRIM**, all participants
A5.2.3 M36	Using input from A1.1.7, DTI will provide input, in the form of a Technical Report, to CEN TC444 WG5 and ISO TC190 WG1 SC3 for the revision of ISO 11461:2018 Soil quality — Determination of soil water content as a volume fraction using coring sleeves — Gravimetric method.	**DTI**, all participants
A5.2.4 M36	Using input from A1.2.9, DTI will integrate the research results in its existing services related to field trials and plant technology. These services in the division AgroTech are in the following areas: Plants, Environment, Food and Facilities. (https://www.dti.dk/specialists/agrotech/36805). Using input from A1.2.1 – A1.2.7 and A1.2.9, DTI will offer new consultancy and laboratory services to end-users on the traceability of soil moisture measurement using point-scale sensors.	**DTI**
A5.2.5 M36	Using input from A1.2.8 and A1.2.9, TUBITAK will establish a new calibration service for soil moisture measurements. Using input from A1.2.8 and A2.1.6, TUBITAK will start establishing the Turkish Soil Spectral Library.	**TUBITAK**
A5.2.6 M36	The three good practice guides developed in A2.3.4, A3.2.4 and A4.2.4 and will be made available on the project website, and they will be disseminated via the "Soil Moisture Workshop" (A5.1.10) and project-related forums, discussion groups and knowledge sharing channels. A2.3.4 - Good practice guide for calibration practices for CRNS soil moisture data retrieval in outdoor field conditions covering on lateral scales ranging from 10^{2} m to 10^{3} m and to depths of up to 1 metre A3.2.4 - Good practice guide for harmonising soil moisture measurement methods to overcome temporal and spatial differences (lateral scales ranging from point scale to km scale) and the influence of other state variables such as air humidity and soil temperature affecting the measurements A4.2.4 - Good practice guide for interdisciplinary data fusion of soil moisture measurements on multiple scales. In addition, members of the project's Stakeholder Committee will be asked to support the dissemination activities in their respective communities. In addition, the projects dealing with soil moisture, as they have become engaged via A1.1.2, will be informed about the project's results. INRIM will coordinate all project participants in providing input to experts, projects and working committees dealing with soil moisture monitoring, water cycle observations, numerical weather predictions and climate change observations.	**INRIM**, all participants

All IP and potential licencing/exploitation will be handled in accordance with the Grant Agreement and the Consortium Agreement.

C6 WP6: Management and coordination

C6.a Task 6.1: Project management

Activity number	Activity description	Participants (Lead in bold)
A6.1.1 M36	The project will be managed by the coordinator from PTB who will be supported by the project management board (PMB) consisting of one representative from each participant, including the leaders of each work package. The members of the PMB will guide the project, attend the project meetings, organise the progress meetings at their local institutes and call additional meetings if needed to ensure the overall success of the project.	**PTB**, all participants
A6.1.2 M36	The work package leaders will collect information from all participants on the ongoing progress of the work of their respective work package as well as on any issues relevant for the project as a whole and will report to all participants at the regular project meetings. The coordinator and the work package leaders will communicate any important issues by e-mail and telephone.	**PTB**, all participants
A6.1.3 M36	The coordinator from PTB, supported by the work packages leaders and all other participants, will manage the project's risks to ensure timely and effective delivery of the scientific and technical objectives and deliverables. In case of critical issues, the coordinator will invite the involved participants and respective work package leaders to dedicated meetings where problems will be discussed and contingency plans will be agreed.	**PTB**, all participants
A6.1.4 M36	The consortium will ensure that any ethics issues identified are addressed.	**PTB**, all participants
A6.1.5 M36	The overall project relies on an effective, quality-assured and timely storage and exchange of measurement data and processed data from the different soil moisture measurement methods. For this purpose, a concept of a dedicated data management system (DMS), describing the data workflows among the participants, will be discussed at the project's kick-off meeting (A6.2.1) and set up at the beginning of the project. The DMS will be supported by the coordinator, work package leaders and all other participants.	**PTB**, all participants

C6.b Task 6.2: Project meetings

Activity number	Activity description	Participants (Lead in bold)
A6.2.1 M2	The kick-off meeting involving all participants will be held approximately one month after the start of the project, at PTB. A hybrid form of the meeting is foreseen, allowing for on-site and on-line participation.	**PTB**, all participants
A6.2.2 M36	There will be five formal project meetings. These meetings include the kick-off, mid-term (around M18) and final meeting (around M36). In addition, two further meetings will be held around M9 and M27. The meetings will be held prior to reporting. The meetings will review the project progress. In addition, they will be used to ensure participants are clear as to their role for the next period. The location of the meetings will rotate among the participants. Where possible, meetings may be held as satellite meetings to important conferences or committee meetings. All project meetings will be foreseen as hybrid meetings where an on-site as well as on-line participation is possible.	**PTB**, all participants
A6.2.3 M36	In addition to the formal project meetings, technical meetings of work package participants may be held whenever necessary and will be arranged on an ad-hoc basis. Furthermore, project participants may organise meetings in combination with workshops, conferences, intercomparison exercises or other events with the attendance of project participants.	**PTB**, all participants

C6.c Task 6.3: Project reporting

Activity number	Activity description	Participants (Lead in bold)
A6.3.1 M1	One month after the start of the project a publishable summary will be produced and submitted to EURAMET.	**PTB**, all participants
A6.3.2 M6	Six months after the start of the project a data management plan (DMP) and a dissemination, communication, and exploitation plan (DCE) will be produced and submitted to EURAMET.	**PTB**, all participants
A6.3.3 M36 +60 days	Following Articles 19 and 21 and the data sheet of the grant agreement, information will be submitted to EURAMET, in accordance with the procedures issued by them to enable EURAMET to comply with its obligations to report on the programme to the European Commission. o Progress reports will be submitted at months 9, 27 (Jun 2023, Dec 2024 + 45 days), 18, 36 (Mar 2024, Sep 2025 + 60 days). o Impact/Output reports and updated publishable summaries will be submitted at the same times. All participants will provide input to these reports and the coordinator will provide these to EURAMET. Where necessary, additional reports and / or information may be requested to enable EURAMET to comply with its obligations to the European Commission.	**PTB**, all participants
A6.3.4 M36 +60 days	Periodic Reports (including financial reports and questionnaires (if applicable)) will be delivered at months 18 (Mar 2024 + 60 days) and 36 (Sep 2025 + 60 days) in accordance with Articles 19 and 21 and the data sheet of the grant agreement. All participants will provide input to these reports and the coordinator will provide these to EURAMET.	**PTB**, all participants
A6.3.5 M36 +60 days	Final Reports (including updated data management plan, updated dissemination, communication and exploitation plan and results ownership list) will be delivered at month 36 (+ 60 days) in accordance with Articles 19 and 21 and the data sheet of the grant agreement. All participants will provide input to these reports and the coordinator will provide these to EURAMET.	**PTB**, all participants
A6.3.6 M18	The project will be subject to a midterm review in Spring 2024. Reports (project self-assessment, updated publishable summary and presentation) will be delivered prior to the midterm reviews for Call 2021, following the schedule detailed by EURAMET for the specific review. All participants will provide input to these reporting documents and the coordinator will provide the documents to EURAMET.	**PTB**, all participants

Formal reporting will be in line with EURAMET's requirements and will be submitted in accordance with the Reporting Guidelines.

C7 Gantt chart

Month	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36
Activity	Oct-22	Nov-22	Dec-22	Jan-23	Feb-23	Mar-23	Apr-23	May-23	Jun-23	Jul-23	Aug-23	Sep-23	Oct-23	Nov-23	Dec-23	Jan-24	Feb-24	Mar-24	Apr-24	May-24	Jun-24	Jul-24	Aug-24	Sep-24	Oct-24	Nov-24	Dec-24	Jan-25	Feb-25	Mar-25	Apr-25	May-25	Jun-25	Jul-25	Aug-25	Sep-25
															WP 1																					
					Task 1.1																															
A1.1.1																																				
A1.1.2																																				
A1.1.3																																				
A1.1.4																																				
A1.1.5																																				
A1.1.6																																				
A1.1.7																																				
															Task 1.2																					
A1.2.1																																				
A1.2.2																																				
A1.2.3																																				
A1.2.4																																				
A1.2.5																																				
A1.2.6																																				
A1.2.7																																				
A1.2.8																																				
A1.2.9																																				
															Task 1.3																					
A1.3.1																																				
A1.3.2																																				
A1.3.3																																				
A1.3.4																																				
A1.3.5																																				
A1.3.6																																				

Month	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36
Activity	Oct-22	Nov-22	Dec-22	Jan-23	Feb-23	Mar-23	Apr-23	May-23	Jun-23	Jul-23	Aug-23	Sep-23	Oct-23	Nov-23	Dec-23	Jan-24	Feb-24	Mar-24	Apr-24	May-24	Jun-24	Jul-24	Aug-24	Sep-24	Oct-24	Nov-24	Dec-24	Jan-25	Feb-25	Mar-25	Apr-25	May-25	Jun-25	Jul-25	Aug-25	Sep-25
	WP 2																																			
	Task 2.1																																			
A2.1.1																																				
A2.1.2																																				
A2.1.3																																				
A2.1.4																																				
A2.1.5																																				
A2.1.6																																				
				Task 2.2																																
A2.2.1																																				
A2.2.2																																				
A2.2.3																																				
A2.2.4																																				
							Task 2.3																													
A2.3.1																																				
A2.3.2																																				
A2.3.3																																				
A2.3.4																																				

Month	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36
Activity	Oct-22	Nov-22	Dec-22	Jan-23	Feb-23	Mar-23	Apr-23	May-23	Jun-23	Jul-23	Aug-23	Sep-23	Oct-23	Nov-23	Dec-23	Jan-24	Feb-24	Mar-24	Apr-24	May-24	Jun-24	Jul-24	Aug-24	Sep-24	Oct-24	Nov-24	Dec-24	Jan-25	Feb-25	Mar-25	Apr-25	May-25	Jun-25	Jul-25	Aug-25	Sep-25
	WP 3																																			
	Task 3.1																																			
A3.1.1																																				
A3.1.2																																				
A3.1.3																																				
A3.1.4																																				
							Task 3.2																													
A3.2.1																																				
A3.2.2																																				
A3.2.3																																				
A3.2.4																																				

Month	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36
Activity	Oct-22	Nov-22	Dec-22	Jan-23	Feb-23	Mar-23	Apr-23	May-23	Jun-23	Jul-23	Aug-23	Sep-23	Oct-23	Nov-23	Dec-23	Jan-24	Feb-24	Mar-24	Apr-24	May-24	Jun-24	Jul-24	Aug-24	Sep-24	Oct-24	Nov-24	Dec-24	Jan-25	Feb-25	Mar-25	Apr-25	May-25	Jun-25	Jul-25	Aug-25	Sep-25
	WP 4																																			
	Task 4.1																																			
A4.1.1																																				
A4.1.2																																				
A4.1.3																																				
										Task 4.2																										
A4.2.1																																				
A4.2.2																																				
A4.2.3																																				
A4.2.4																																				

Month	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36
Activity	Oct-22	Nov-22	Dec-22	Jan-23	Feb-23	Mar-23	Apr-23	May-23	Jun-23	Jul-23	Aug-23	Sep-23	Oct-23	Nov-23	Dec-23	Jan-24	Feb-24	Mar-24	Apr-24	May-24	Jun-24	Jul-24	Aug-24	Sep-24	Oct-24	Nov-24	Dec-24	Jan-25	Feb-25	Mar-25	Apr-25	May-25	Jun-25	Jul-25	Aug-25	Sep-25
	WP 5																																			
	Task 5.1																																			
A5.1.1																																				
A5.1.2																																				
A5.1.3																																				
A5.1.4																																				
A5.1.5																																				
A5.1.6																																				
A5.1.7																																				
A5.1.8																																				
A5.1.9																																				
A5.1.10																																				
	Task 5.2																																			
A5.2.1																																				
A5.2.2																																				
A5.2.3																																				
A5.2.4																																				
A5.2.5																																				
A5.2.6																																				

Month	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36
Activity	Oct-22	Nov-22	Dec-22	Jan-23	Feb-23	Mar-23	Apr-23	May-23	Jun-23	Jul-23	Aug-23	Sep-23	Oct-23	Nov-23	Dec-23	Jan-24	Feb-24	Mar-24	Apr-24	May-24	Jun-24	Jul-24	Aug-24	Sep-24	Oct-24	Nov-24	Dec-24	Jan-25	Feb-25	Mar-25	Apr-25	May-25	Jun-25	Jul-25	Aug-25	Sep-25
	WP 6																																			
	Task 6.1																																			
A6.1.1																																				
A6.1.2																																				
A6.1.3																																				
A6.1.4																																				
A6.1.5																																				
	Task 6.2																																			
A6.2.1																																				
A6.2.2																																				
A6.2.3																																				
	Task 6.3																																			
A6.3.1																																				
A6.3.2																																				
A6.3.3																																				
A6.3.4																																				
A6.3.5																																				
A6.3.6																																				

Section D: Risk and risk mitigation

D1 Scientific/technical risks

Risk (description)	**Likelihood, impact and severity of occurrence**	**Mitigation** i.e. what the consortium will do to decrease the likelihood of the risk occurring	**Contingency** i.e. what the consortium will do if despite the mitigation the risk still occurs
Task 1.1: Collation of information on stakeholders' needs, and requirements and technical possibilities of the different soil moisture measurement methods is not sufficient, either in the number of obtained responses and/or in the quality or detail of the collected technical information	Likelihood after mitigation: Low Impact: Delay in successive activities in all work packages. Level of severity: High	The active involvement of the Stakeholder Committee in this project minimises this risk. The consortium will ensure that the questionnaire communicates the benefits to those completing it, in addition, the questionnaire will be clear and concise to encourage completion. Finally, the consortium will ensure that the questionnaire is tailored to needs of the individual stakeholders.	The participants will approach the individual stakeholders from the Stakeholder Committee and work with them towards completing the questionnaire and/or providing the required information in other written form. To reduce the impact of delays on the successive activities, continued updates of the required input from the Stakeholder Committee will be sought.
Task 1.1: Failure to define the traceability scheme for soil moisture measurements using the different soil moisture assessment approaches	Likelihood after mitigation: Low Impact: Traceability chain is not set up properly. Level of severity: High	The members of consortium that are experts in soil moisture measurements and SI-traceability will be in close cooperation to ensure the definition and delivery of the required traceability scheme.	The consortium will try to identify the reasons for the failure. To avoid longer delays, larger uncertainties in the traceability scheme could be accepted in the meantime.
Task 1.2: Lack of agreement between the individual measurement facilities and calibration procedures of DTI, CMI and TUBITAK	Likelihood after mitigation: Low Impact: Errors in the traceability chain are observed. Level of severity: High	DTI, CMI and TUBITAK are experienced in metrology relevant for point-scale moisture measurements. Their measurement facilities will be checked to ensure agreement or find problems as soon as possible.	The consortium will try to identify the reasons for the disagreements. To avoid longer delays larger uncertainties could be accepted in the meantime.
Task 1.3: Collation of information on existing neutron metrology facilities and currently available CRNS devices does not include enough technical details to plan the successive activities of characterising the CRNS devices in neutron metrology laboratories, and/or to create the geometrical models of the CRNS devices to be characterised	Likelihood after mitigation: Low Impact: Delay in related activities in WP1 and subsequently in WP2, WP3, WP4. Level of severity: Medium	The consortium includes major institutions that already work in this field and so should have good access to the information required. Furthermore, the availability of detailed technical information on the commercial CRNS devices will be one of the selection criteria for including the CRNS probes into the project. Any issues will be raised at project meetings (if not before) and discussed. The consortia will also ask their Stakeholder Committee for help with the collation of information on existing neutron metrology facilities and currently available CRNS devices.	The participants will approach the individual neutron metrology facilities and CRNS devices manufacturers and work with them towards providing the required information and technical details. To reduce the impact of delays on the successive activities, continued updates of the required input will be sought.
Task 1.3: Failure to experimentally validate the calculated neutron response functions of the CRNS devices	Likelihood after mitigation: Low Impact: The validation of the CRNS neutron measurements is not established. Level of severity: High	The mono-energetic neutron reference fields will be provided in accelerator-based facilities of PTB and IRSN. The neutron reference fields from radionuclide sources will be made available by PTB, IRSN, CIEMAT and CMI.	In case of technical problems of the accelerator-based facilities of one participant, the other participant will act as a backup. In case of technical problems of the facilities of radionuclide neutron sources of one participant, the other participants can act as a backup for this activity.

Task 1.3: Failure to define the traceability scheme for the characterisation of CRNS devices under laboratory conditions	Likelihood after mitigation: Low Impact: Traceability chain is not set up properly. Level of severity: High	The members of the consortium that are experts in metrology of neutron radiation will be in close cooperation to ensure the definition and delivery of the required traceability scheme.	The consortium will try to identify the reasons for the failure. To avoid longer delays, larger uncertainties in the traceability scheme could be accepted in the meantime.
Task 2.1: Failure to select and further enhance (with additional equipment, data retrieval systems and optional links to accompanying test field sites) three high-level test field sites where the comparison of at least two soil moisture measurement methods can be done	Likelihood after mitigation: Low Impact: No data or a reduced set of data is obtained. Level of severity: High	During the pre-selection and final selection phases of the three high-level test field sites, their availability for data taking during this project lifetime will be considered as one of the selection criteria. Moreover, the consortium includes participants that already work in this field and that either operate the experimental field sites themselves and/or have well established links to the field sites providers, possess the required equipment, infrastructure and operational capability to ensure the equipment installation and links to the accompanying field sites. With regards to data retrieval systems, the site host sites (UP DE, UNIBO, CNR, CTU and/or INRIM) and/or the device owner will make efforts to ensure a flawless operation and data provision.	Any issues will be raised at project meetings (if not before) and discussed. The problems will be solved by joint efforts of the participants. To avoid longer delays, the prioritisation of the test field sites and of the additional requirements will take place. In addition, larger uncertainties (for the systematic effects) in the traceability scheme could be accepted in the meantime.
Task 2.2: The SI-traceable point-scale soil moisture measurement procedures, developed in WP1, are not ready to be utilised for the on-field support of the CRNS method	Likelihood after mitigation: Low Impact: Traceability chain is not set up properly. Level of severity: High	DTI, CMI and TUBITAK are experienced in metrology relevant for point-scale moisture measurements. Close cooperation and information exchange will support the joint development of the calibration procedures.	If a delay can be foreseen, the PMB will decide if larger uncertainties can be accepted while the problems are being solved.
Task 2.2: Failure to perform the Monte Carlo neutron transport simulations of the three test field test sites selected in Task 2.1	Likelihood after mitigation: Low Impact: Systematic benchmarking of the Monte Carlo neutron transport calculations cannot be carried out. Level of severity: High	Close cooperation and information exchange between experts will support the simulation work. The simulation codes are well known and available, and the parameters of the test field sites will be known to the required level of details.	Any issues will be raised at project meetings (if not before) and discussed. The problems will be solved by joint efforts of the participants. To avoid longer delays, the prioritisation of the test field sites will take place, to achieve the simulations of the test field sites gradually. Moreover, longer delays could be avoided by lowering the required level of detail in the simulations in the meantime.
Task 2.2: Failure to carry out the neutron measurements with the help of the metrologically traceable Bonner sphere spectrometers (BSS) of PTB and IRSN	Likelihood after mitigation: Low Impact: No data or a reduced set of data is obtained for the benchmarking of the Monte Carlo neutron transport simulations. Level of severity: Medium	The BSS measurement campaigns will be carried out according to a detailed plan in line with PTB, IRSN and the operators of the three high-level test field sites.	The two BSS neutron spectrometers of PTB and IRSN are modular and well characterised systems that proved their operation under various laboratory and outdoor conditions. The systems will act as a backup of each other.

Task 2.3: The procedure developed to retrieve non-weighted mean soil moisture measurand is not harmonised across the three high-level test field sites	Likelihood after mitigation: Medium Impact: Only a weighted-mean soil moisture measurand can be retrieved by CRNS in a unique way, or non-weighted soil moisture retrieval practice will be site-specific. Level of severity: Medium	The Monte Carlo-based neutron transport simulations will be utilised to support and improve the development of the non-weighted retrieval procedure.	The sites for different standardised procedures will be categorised, to be applicable in further activities. The good practice guide on the calibration procedures of CRNS in outdoor conditions will contain site-specific choices.
Task 3.1: Soil moisture time-series cannot be collected in time for the analysis	Likelihood after mitigation: Low Impact: The information content of soil moisture estimates based on different methods will not be assessed. Level of severity: High	The consortium will pre-select test field sites with the best-established observation systems and which are best suited for the integration of additional field activities. The feasibility of the joint soil moisture observations by different methods will be one of the selection criteria in Task 2.1.	Alternative sites and databases will be used, from different networks and freely distributed from e.g., the International Soil Moisture Network. Synthetic soil moisture time-series can be also simulated, based on soil-hydrological models.
Task 3.1: Possible lack or reduced spatial and/or temporal coverage (i.e., lower inflow over a certain area and/or period) of historical soil moisture data sets	Likelihood after mitigation: Low Impact: Limited applicability of the data sets for the harmonisation and data fusion tasks, limited output of results. Level of severity: High	The consortium will pre-select field test sites with the best-established observation systems, and which are best suited for the integration of additional field activities. The availability of historical soil moisture data sets from the test field site will also be considered in the high-level site selection in Task 2.1.	The use of alternative sites and databases deriving from different networks and freely distributed from e.g., the International Soil Moisture Network or through the European Space Agency will be evaluated if necessary.
Tasks 3.2 and 4.1: Possible lack or reduced spatial and/or temporal coverage (i.e., lower inflow over a certain area and/or period) of project ground-based data sets	Likelihood after mitigation: Low Impact: Limited applicability of the data sets for the harmonisation and data fusion tasks, limited output of results. Level of severity: High	The consortium will pre-select field test sites with the best-established observation systems and which are best suited for the integration of additional field activities. The feasibility of the joint soil moisture observations by different methods will be one of the selection criteria in Task 2.1.	The total lack of ground-based data is very unlikely, considering that participants are the developers and providers of the monitored test field sites. Any issues will be raised at project meetings (if not before) and discussed. The problems will be solved by joint efforts of the participants.
Task 4.2: Possible lack or reduced spatial and/or temporal coverage (i.e., lower inflow over a certain area and/or period) of the Earth Observation data sets	Likelihood after mitigation: Low Impact: Impact: Limited applicability of the data sets for the harmonisation and data fusion tasks, limited output of results. Level of severity: High	Sentinel-1 coverage over the European test field sites, used within this project, will be continuously monitored.	The lack of radar-based data is very unlikely, due to the conflict-free Sentinel-1 mission observation scenario and free of charge data policy.

D2 Management risks

Risk (description)	Likelihood, impact and severity of occurrence	Mitigation i.e. what the consortium will do to decrease the likelihood of the risk occurring	Contingency i.e. what the consortium will do if despite the mitigation the risk still occurs
Complexity of managing a large consortium.	Likelihood after mitigation: Low Impact: Disagreement between the participants could delay the progress of technical (in implementing the work) and scientific (in publishing the results) matters. Level of severity: High	At the regular project meetings, the WP leaders will report on the progress of the tasks and activities of the respective WP. In case of any significant delay or other issues, the project coordinator will organise dedicated subgroup meetings with all participants involved. Agreements on how to proceed, in order to solve the problems, will be documented in the minutes of these meetings. In case of severe problems with single participants or delays which may affect the project, the coordinator will consult the Project Management Board (PMB) to discuss and conclude appropriate counter measures in order to hit milestones and time schedules.	The project management board (PMB) will act as the ultimate decision-making body of the project in a constructive way and according to the Consortium Agreement and Grant Agreement.
The onsite facilities of participants, and/or access to public/commercial services or sites is restricted for a period of time during the project due to an extraordinary event or situation that is beyond the participants control e.g. COVID-19	Likelihood after mitigation: High Impact: Activities and deliverables are delayed, or no longer able to be completed. Level of severity: High	In most cases, activities on the critical path have been scheduled to have some overlap in time and thus a delay in the output of one activity will not necessarily cause an immediate delay in another.	Where possible, work will be reassigned to an alternative participant, or rephased, therefore minimising delays and technical deviations that would have a negative impact on the project. If necessary, the consortium will contact EURAMET to discuss options according to the grant agreement.
Key personnel are lost to the project	Likelihood after mitigation: Low Impact: The loss of any team members in any of the WPs would create difficulties in delivering the targeted project results and possibly causing delays to deliverables. Level of severity: High	None of the project members are planning to leave or retire within the duration of this project, although the possible loss of an expert due to severe health problems or accidents cannot be neglected. The grouping of experts within the consortium should minimise the areas where knowledge is held by a single person. All the participants will identify backups for key workers wherever possible to reduce the overall risk to the project. Project plans will be shared within the consortium and results and methodology will be documented. The coordinator, the participants involved and the PMB will try to keep delays and related knock-on effects as low as reasonably achievable.	In case a key member leaves, the project participant concerned will be responsible for appointing an appropriate replacement. If, due to the lack of experienced staff, a participant is not able to replace the lost personnel, other project participants shall take over the responsibility of the respective activities or tasks. The latter may require a re-adjustment of the related budget contributions. However, this may still lead to a delay in delivery.

A participant withdraws from the project	Likelihood after mitigation: Low Impact: Part of the project's deliverables could be affected. Level of severity: Medium	For most of the deliverables of this project several project participants are responsible, although with quite complementary contributions. The loss of one participant would not affect the overall project. Moreover, only for a few deliverables, the loss of one participant could mean that the deliverables cannot be achieved timely and also maybe not in the project lifetime. At the regular project meetings, the coordinator will support an open discussion about any possible issues in communication and/or sharing of expertise, results, equipment etc. among the participants.	In case that a participant should leave the consortium, the tasks related to him will be distributed to one or several other participants, including the re-adjustment of the project's budget. In the worst case a deliverable cannot be provided in the stipulated way. In such a scenario, the consortium will propose alternative deliverables to EURAMET in order to achieve the overall objectives of the project in the most realistic way.
Problems dealing with Intellectual Property (IP) ownership and/or exploitation might occur and could be a source of potential conflict	Likelihood after mitigation: Low Impact: Disagreement between the participants could delay the progress of technical (in implementing the work) and scientific (in publishing the results) matters. Level of severity: Medium	All beneficiaries will sign the grant agreement and all participants will sign the consortium agreement, which includes IP clauses. IP will be handled accordingly. The GA will help the project coordinator and the PMB to manage the project in conformance with the rules defined therein.	In case of any irresolvable IP problem between project participants, independent arbitrators will be used to support the process of finding a balanced problem solving.
Delay in some activities or deliverables of the project	Likelihood after mitigation: Low Impact: An accumulation of delays may cause severe knock-on effects and, without mitigation, may even affect the project as a whole. Level of severity: High	The WPs have been detailed into tasks and activities in such a way that it allows a simple milestone control of the progress. In regular intervals (typically quarterly), each WP leader will review the status of the achievements of his WP. In case of problems identified, WP leaders will inform the project coordinator at the earliest possible date. The progress of tasks and activities of all WPs and, especially, their inter-relationship with the entire project will be discussed at the general project meetings (i.e., every 9 months).	In case of the accumulation of delays with knock-on effects the project coordinator will organise dedicated subgroup meetings with all participants involved. In severe cases, the PMB will be included in the process of developing a corrective action plan.
Interdependencies between technical activities and tasks are too complex	Likelihood after mitigation: Medium Impact: Tasks are delayed, or it is not possible to deliver them. Level of severity: Medium	Technical meetings run by WP leaders have been scheduled to ensure proper sharing of knowledge. The interdependencies between tasks will be considered at meetings to ensure that this is addressed properly in the planning of the work. The technical WPs will be closely managed by their WP leaders to ensure that they deliver their own outputs.	In most cases, activities on the critical path have some overlap in time and thus a delay in the output of one deliverable does not necessarily cause an immediate delay in another.

The lack of interest of the participants to share the required information across community borders e.g., between the point-, intermediate- and large-scale soil moisture observations	Likelihood after mitigation: Low Impact: Inability or lack of accuracy to fulfil the purpose of the tasks. Level of severity: High	The expectations regarding the knowledge and information dissemination will be clarified in advance. A compromise between project participants in this regard will be ensured.	Communication and social effort will counteract such problems as early as possible. The project coordinator and the PMB will act as a moderator to ensure that all required information is shared across the community borders.
The feedback to the project's Good Practice Guides (GPG) from the Stakeholder Committee is missing or the feedback is available only with a considerable delay	Likelihood after mitigation: Medium Impact: Good Practice Guides delayed beyond the schedule. Level of severity: High	The active involvement of the Stakeholder Committee will be sought, which will minimise this risk. For a given GPG, the feedback will be sought predominantly from those members of the Stakeholder Committee who are the experts in the respective fields. The consortium will communicate the deadline for the given GPG well in advance.	A deadline will be set for each of the project's GPGs. In case the invited Stakeholder Committee members will not be available to deliver feedback within the predefined deadline, the project participants will continue to develop and review the given GPG without the Stakeholder Committee input, or with only a limited input from the Stakeholder Committee.

D3 Ethics

The Partnership Ethics Review 2021 has given JRP 21GRD08 SoMMet "Ethics clearance".

Ethical integrity

The participants will ensure that all ethics issues related to activities in the project are addressed in compliance with ethical principles (including the highest standards of research integrity as set out in the ALLEA European Code of Conduct for Research Integrity https://ec.europa.eu/info/funding-tenders/opportunities/docs/2021-2027/horizon/guidance/european-code-of-conduct-for-research-integrity_horizon_en.pdf), the applicable international and national law, and the provisions set out in the grant agreement. This includes the ethics issues identified in the ethics screening and the submitted documents, and any additional ethics issues that may emerge in the course of the project. In the case where any substantial new ethics issues arise, participants will inform the granting authority EURAMET e.V, and for each ethics issue applicable, participants will follow the guidance provided in the Horizon Europe *'How to complete your ethics self-assessment' guide*'.

The consortium will ensure that appropriate procedures, policies and structures (https://ec.europa.eu/info/funding-tenders/opportunities/docs/2021-2027/horizon/guidance/guideline-for-promoting-research-integrity-in-research-performing-organisations_horizon_en.pdf) are in place to foster responsible research practices, to prevent questionable research practices and research misconduct, and to handle allegations of breaches of the principles and standards in the Code of Conduct.

Data protection

By signing or acceding to this grant agreement and / or consortium agreement each participant asserts that the requirements of the General Data Protection Regulation (GDPR) 2016/679 which entered into force on 25 May 2018 will be met. Under the regulation, the data controllers and processors are fully accountable for the data processing operations. Any violation of the data subject rights may lead to sanctions as described in Chapter VIII, art.77-84 of the GDPR.

If personal data are transferred from the EU to a non-EU country or international organisation, such transfers will be in accordance with Chapter V of the GDPR 2016/679. If personal data are transferred from a non-EU country to the EU (or another third state), such transfers will comply with the laws of the country in which the data was collected.

Non-EU countries

The consortium will ensure that participants and collaborators, including those from non-EU countries, fully adhere to Horizon Europe ethics standards and guidelines, no matter where the research or activities are carried out and that research or activities performed outside the European Union are compatible with EU, national and international legislation and can be legally conducted in one of the EU Member States. If applicable, details on the material, samples and/or equipment which will be imported to/exported from EU must be provided and the adequate authorisations granted by the relevant authorities have been or will be obtained and kept on file by the consortium. The consortium will also, in the case of dual use applications, clarify whether any export licence is required for the transfer of knowledge, equipment or material.

Section E: References

[1] Global Climate Observing System, Essential Climate Variable factsheet on Soil Moisture, https://gcos.wmo.int/en/essential-climate-variables/soil-moisture.

[2] European Commission: COMMUNICATION FROM THE COMMISSION TO THE EUROPEAN PARLIAMENT, THE EUROPEAN COUNCIL, THE COUNCIL, THE EUROPEAN ECONOMIC AND SOCIAL COMMITTEE AND THE COMMITTEE OF THE REGIONS The European Green Deal, COM/2019/640 final, CELEX number: 52019DC0640.

[3] European Commission: COMMUNICATION FROM THE COMMISSION TO THE EUROPEAN PARLIAMENT, THE COUNCIL, THE EUROPEAN ECONOMIC AND SOCIAL COMMITTEE AND THE COMMITTEE OF THE REGIONS A Farm to Fork Strategy for a fair, healthy and environmentally-friendly food system, COM/2020/381 final, CELEX number: 52020DC0381.

[4] European Commission: COMMUNICATION FROM THE COMMISSION TO THE EUROPEAN PARLIAMENT, THE COUNCIL, THE EUROPEAN ECONOMIC AND SOCIAL COMMITTEE AND THE COMMITTEE OF THE REGIONS EU Biodiversity Strategy for 2030 Bringing nature back into our lives, COM/2020/380 final, CELEX number: 52020DC0380.

[5] European Commission: Proposal for a REGULATION OF THE EUROPEAN PARLIAMENT AND OF THE COUNCIL establishing the framework for achieving climate neutrality and amending Regulation (EU) 2018/1999 (European Climate Law), COM/2020/80 final, CELEX number: 52020PC0080.

[6] Jackisch, C., et al.: Soil moisture and matric potential–an open field comparison of sensor systems, Earth System Science Data 12.1 (2020): 683-697.

[7] Methods of Soil Analysis: Part 1 Physical and Mineralogical Methods, 5.1, Second Edition. Editor(s): Arnold Klute. First published: 1 January 1986. Print ISBN:9780891180883, Online ISBN:9780891188643, DOI:10.2136/sssabookser5.1.2ed.

[8] Taghizadeh-Toosi, A., et al.: Regulation of N_2O emissions from acid organic soil drained for agriculture, Biogeosciences, 16, 4555–4575.

[9] Ochsner, T.E., et al.: State of the Art in Large-Scale Soil Moisture Monitoring, Soil Sci. Soc. Am. J. 77 (2013) 1888–1919, doi:10.2136/sssaj2013.03.0093.

[10] IAEA YouTube Channel IAEAvideo: Cosmic Ray Neutron Sensor (CRNS): From cosmic rays to soil moisture, https://youtu.be/eZTeQRSmcGY

[11] International Atomic Energy Agency: Field Estimation of Soil Water Content: A Practical Guide to Methods, Instrumentation and Sensor Technology, IAEA-TCS-30 (2008), ISSN 1018–5518.

[12] International Atomic Energy Agency: Cosmic Ray Neutron Sensing: Use, Calibration and Validation for Soil Moisture Estimation, IAEA-TECDOC-1809 (2017), ISBN 978-92-0-101017-9.

[13] Loew, A., et al.: Validation practices for satellite-based Earth observation data across communities, Rev. Geophys. 55 (2017) 779–817, doi:10.1002/2017RG000562.

[14] Peng, J., et al.: A roadmap for high-resolution satellite soil moisture applications – confronting product characteristics with user requirements, Remote Sens. Environ. 252 (2020) 112162, doi:10.1016/j.rse.2020.112162.

[15] Gruber, A., et al.: Validation practices for satellite soil moisture retrievals: What are (the) errors?, Remote Sensing of Environment 244 (2020) 111806.

[16] Montzka, C., et al.: Soil Moisture Product Validation Good Practices Protocol, Land Product Validation Subgroup (WGCV/CEOS), doi:10.5067/doc/ceoswgcv/lpv/sm.001.

[17] EMPIR Project METefnet "Metrology for moisture in materials", Final Publishable JRP Report, 2016.

[18] Østergaard, P., Nielsen, J.: SI-Traceable Water Content Measurements in Solids, Bulks, and Powders, J. Int. J. Thermophys. (2018) 39: 1.

[19] Köhli, M., et al.: Footprint characteristics revised for field-scale soil moisture monitoring with cosmic-ray neutrons, Water Resour. Res. 51 (2015) 5772–5790, doi:10.1002/2015WR017169.

[20] Franz, T.E., et al.: Practical Data Products from Cosmic-Ray Neutron Sensing for Hydrological Applications, Front. Water 2:9 (2020), doi:10.3389/frwa.2020.00009.

[21] Heistermann, M., et al.: Spatio-temporal soil moisture retrieval at the catchment-scale using a dense network of cosmic-ray neutron sensors, Hydrol. Earth Syst. Sci. Discussions, 2021, in review,

doi:10.5194/hess-2021-25.

[22] Wollschläger, U., et al.: The Bode hydrological observatory: a platform for integrated, interdisciplinary hydro-ecological research within the TERENO Harz/Central German Lowland Observatory, Environ. Earth Sci. 76 (2017) 29, doi:10.1007/s12665-016-6327-5.

[23] Evans, J.G., et al.: Soil water content in southern England derived from a cosmic-ray soil moisture observing system – COSMOS-UK, Hydrol. Process. 30 (2016) 4987–4999, doi:10.1002/hyp.10929.

[24] CosmOz: Australian National Cosmic Ray Soil Moisture Monitoring Facility, http://www.ermt.csiro.au/html/cosmoz.html.

[25] Zreda, M., et al.: COSMOS: the COsmic-ray Soil Moisture Observing System, Hydrol. Earth Syst. Sci. 16 (2012) 4079–4099, doi:10.5194/hess-16-4079-2012.

[26] Upadhyaya, D.B., et al.: The Indian COSMOS Network (ICON): Validating L-Band Remote Sensing and Modelled Soil Moisture Data Products, Remote Sens. 13 (2021) 537, doi:10.3390/rs13030537.

[27] Vereecken, H., et al.: On the spatio-temporal dynamics of soil moisture at the field scale, Journal of Hydrology, Volume 516, 2014, Pages 76-96, ISSN 0022-1694, https://doi.org/10.1016/j.jhydrol.2013.11.06..

[28] Colliander, A., et al.: Validation of SMAP surface soil moisture products with core validation sites, Remote Sens. Environ. 191 (2017) 215–231, doi:10.1016/j.rse.2017.01.021.

[29] Crow, W.T., et al.: Upscaling sparse ground-based soil moisture observations for the validation of coarse-resolution satellite soil moisture products, Rev. Geophys. 50 (2012) RG2002, doi:10.1029/2011RG000372.

[30] Straits Research, Automated Weather Station Market: Information by Solution (Software and Hardware), Verticals (Agriculture, Aviation, Oil and Gas, Renewable Energy), and Region–Forecast till 2029, https://straitsresearch.com/report/automated-weather-station-market/.

[31] Thorne, P.W., et al.: Towards a global land surface climate fiducial reference measurements network, International Journal of Climatology, v. 38, 6, pp 2760-2774, 2018.