

## **Title: Metrology for soil moisture: from ground reference sites towards coherent and traceable global data products**

### **Abstract**

Soil moisture is an essential climate variable and an integral part of the hydrological cycle. It plays a key cross-cutting role at different spatiotemporal scales of weather and climate. There is a need for physically coherent and metrologically traceable global soil moisture data products with reliable uncertainty budgets in many fields ranging from (agro)meteorology and hydrology to land surface and climate modelling. This proposal will develop the infrastructure for long-term, sustainable, and SI-traceable ground-based soil moisture measurements as well as fully characterising and coherently projecting the state dynamics of soil water for climate change adaptation and novel metrologically secured approaches.

### **Keywords**

Soil moisture, soil water state, hydrological cycle, satellite Earth observation, remote sensing, fiducial reference measurements, metrology of temperature and humidity, metrology of ionizing radiation, irrigation strategies

### **Background to the Metrological Challenges**

The Global Climate Observing System (GCOS) of the World Meteorological Organisation (WMO) defines soil moisture as one of the Essential Climate Variables (ECVs) and acknowledges the need for improved measurements in this sector. Global hydrological networks need large numbers of reliable *in-situ* soil moisture observations that must be harmonized, curated, and centralised in the International Soil Moisture Network (ISMN). Specifically, below-ground measurements of soil moisture are one of the key factors in hydrological observations and models. On the global, regional, and local scales, high-resolution and near-real time satellite-based soil moisture data are needed with reliable uncertainties for improved monitoring and modelling of both climate and human-induced changes and extremes. Furthermore, even on the point scale and under well-defined laboratory conditions, open problems persist on the harmonisation of soil water state determination across laboratories. This underlines the need for improved metrological foundation in this sector and the importance of considering not only soil moisture but also complementary parameters defining the soil water state unambiguously.

The global-scale observation of soil moisture faces challenges common to other ECVs. Observation scientists depend on the Committee on Earth Observation Satellites (CEOS) validation framework Fiducial Reference Measurements (FRM) to establish the metrological traceability however, many information gaps remain across spatiotemporal scales. The representativeness uncertainty, quantifying the difference between the true soil moisture on the ground and the soil moisture derived from satellite retrievals, is one of the key factors in the uncertainty budgets that is still poorly characterised. The need for FRM-level reference data for soil moisture directly translates into a need for long-term and trustable data from networks of reference sites. Traceability to SI-standards, reliable uncertainty budgets, harmonised calibration and data interpretation protocols, and revised definitions of measurands and representativeness uncertainties are the currently unresolved problems in assessments of soil moisture.

Within Metrology Partnership project 21GRD08 SoMMet, two SI-traceability chains of a) soil moisture determination under laboratory conditions, and b) neutron measurements via CRNS instruments under laboratory conditions, will be combined and transferred to field conditions to improve the CRNS methodology from metrological perspective. The full quantification of various systematic effects and uncertainty budgets under outdoor conditions, both on point- and intermediate scale, still represents a major challenge that will not

be solved completely by 2025. The European Space Agency (ESA) funded project FRM4SM (Fiducial Reference Measurements for Soil Moisture) is developing quality indicators for *in-situ* measurements and guidelines that qualify ground reference sites as “fiducial”. However, within FRM4SM it was found that no single one of the over 3000 measurement stations contained in the ISMN database can be considered fiducial. This is mainly because none of the sensors used are characterised by an SI-traceable uncertainty budget. Also, virtually no station provides information on calibration procedures or carries out regular sensor maintenance. These open problems need to be addressed by gathering metadata in a harmonised way. Finally, while uncertainties associated with the spatial scale mismatch between point-scale measurements and satellite footprints have been found to be often the greatest source of uncertainty, no ISMN station has been designed specifically to account or even characterize this representativeness uncertainty.

## Objectives

Proposers should address the objectives stated below, which are based on the PRT submissions. Proposers may identify amendments to the objectives or choose to address a subset of them in order to maximise the overall impact, or address budgetary or scientific / technical constraints, but the reasons for this should be clearly stated in the protocol.

The proposal shall focus on the traceable measurement and characterisation of soil moisture measurements.

The specific objectives are:

1. To develop a ground reference operational site and instrumentation for near surface and below-ground traceable, long-term, and sustainable soil moisture measurements on spatial scales from  $10^{-2}$  m to  $10^2$  m in adherence to CEOS FRM validation framework. This should include the implementation of intermediate-scale soil moisture assessment methods (e.g., cosmic-ray neutron sensing (CRNS)) and incorporate state-of-the-art measurements of soil water potential, soil temperature as well as datasets on important physico-chemical properties of soil, groundwater and evapotranspiration dynamics, relevant for hydrological modelling.
2. To develop and validate primary and secondary standards and related methods for traceable point-scale soil moisture measurements under laboratory conditions, with a target relative uncertainty of 1 %, and to expand the traceability chain and uncertainty assessment to the scale transfer to field conditions. This should include i) the development of correction and calibration strategies for sensors applied in situ ii) protocols for point-scale sensors calibration, installation, data treatment and interpretation iii) a review of state-of-the-art methodologies for soil water balance parameters determination under laboratory and outdoor conditions.
3. To quantify the systematic effects and uncertainty budgets of intermediate-(1 m to  $10^2$  m) scale soil moisture assessments under outdoor conditions on the operational site developed in Objective 1. This will also include i) development of inverse modelling methods of different technologies under dynamic and non-stationary outdoor conditions ii) comparison of the point- ( $10^{-2}$  m to 1 m), intermediate- (1 m to  $10^2$  m) and satellite-scale ( $10^2$  m to  $10^3$  m) soil moisture assessments on the operational site to define individual soil moisture measurands and their representativeness in spatiotemporal scales ranging from  $10^{-2}$  m to  $10^3$  m and from minutes to days.
4. To develop new integrated high- and coarse-resolution data products of surface- and below-ground soil moisture based on data assimilation approaches using soil water balance modelling and datasets from Objective 3. The products should i) contain individual soil moisture assessment methodologies ii) consider the coherence of the soil water state, across soil types and across the spatiotemporal scales from  $10^{-2}$  m to  $10^4$  m and from minutes to days iii) contain reliable uncertainty budgets based on SI-traceable ground-based data and sound data-science metrology principles.
5. To facilitate the take up of the technology and measurement infrastructure developed in the project by NMI and DI, the measurement supply chain (instrument manufacturers), standards developing organisations and end users (e.g., ISMN, CEOS Working Group on Calibration and Validation, meteorology industry) and actively engage with EMN Climate and Ocean Observation, EMN Mathmet and EMN Radiation Protection.

These objectives will require large-scale approaches that are beyond the capabilities of single National Metrology Institutes and Designated Institutes. Proposers shall give priority to work that meets documented needs, in particular those supporting the European Green Deal. To enhance the impact of the research, the involvement of the appropriate user community such as industry, standardisation and regulatory bodies is strongly recommended, both prior to and during methodology development.

Proposers should establish the current state of the art and explain how their proposed project goes beyond this. In particular, proposers should outline the achievements of the Metrology Partnership project 21GRD08 SoMMet and how their proposal will build on those.

Proposers should note that the programme funds the activity of researchers to develop the capability, not the required infrastructure and capital equipment, which must be provided from other sources.

EURAMET expects the average EU Contribution for the selected JRPs in this TP to be 2.8 M€ and has defined an upper limit of 3.5 M€ for this proposal.

EURAMET also expects the EU Contribution to the external funded beneficiaries to not exceed 35 % of the total EU Contribution across all selected projects in this TP.

Any industrial beneficiaries that will receive significant benefit from the results of the proposed project are expected to be beneficiaries without receiving funding or associated partners.

## Potential Impact

Proposals must demonstrate adequate and appropriate participation/links to the 'end user' community, describing how the project partners will engage with relevant communities during the project to facilitate knowledge transfer and accelerate the uptake of project outputs. Evidence of support from the "end user" community (e.g., letters of support) is also encouraged.

You should detail how your proposal's results are going to:

- Address the SRT objectives and deliver solutions to the documented needs,
- Feed into the development of urgent documentary standards through appropriate standards bodies,
- Facilitate improved industrial capability, or improved quality of life for European citizens in terms of personal health, protection of the environment and the climate, or energy security,
- Transfer knowledge to the environmental and meteorology sectors.

You should detail other impacts of your proposed JRP as specified in the document "Guide 4: Writing Joint Research Projects (JRPs)"

You should also detail how your approach to realising the objectives will further the aim of the Metrology Partnership to develop a coherent approach at the European level in the field of metrology and include the best available contributions from across the metrology community. Specifically, the opportunities for:

- improvement of the efficiency of use of available resources to better meet metrological needs and to assure the traceability of national standards
- the metrology capacity of EURAMET Member States whose metrology programmes are at an early stage of development to be increased
- organisations other than NMIs and DIs to be involved in the work.

## Timescale

The project should be of up to 3 years duration.

## Additional information

The links provided in this section are only correct at the time of publication up until the end of the Call year.

These references have been provided by EURAMET.

[1] *EMN Climate and Ocean Observation Strategic Research Agenda*  
<https://www.euramet.org/research-innovation/metrology-partnership/strategic-research-and-innovation-agendas>

[2] *EMN MathMet Strategic Research Agenda*  
<https://www.euramet.org/research-innovation/metrology-partnership/strategic-research-and-innovation-agendas>