

Title: Metrology for environmental thermodynamics

Abstract

Improving the metrology associated with global warming and our ability to predict severe weather events relies on accurate measurements of environmental thermodynamics based on rigorous determinations of the water cycle, sea ice and permafrost, soil temperatures with realistic heat flux evaluations. To achieve this improved temperature calibration techniques for air measurements, the development of methods for traceable in-field determination of ecosystem-atmosphere energy fluxes and improved measurements for water cycle and water phase transitions that effect our environment are required. In addition, increasing reliable data input volumes to weather forecasting models is needed to improve prediction accuracy.

Keywords

Metrology for climate, air temperature, water cycle, early warnings in hydrology, sea water and sea ice, permafrost, heat fluxes, eddy covariance

Background to the Metrological Challenges

Measurements of air, water and soil are essential for monitoring climate change, whilst determining ocean-atmosphere heat interchange underpins our understanding of global weather and aids prediction of extreme weather events. These are becoming more frequent as the global temperature rises. Ground-based systems of networked meteorological monitoring stations remotely sample local temperatures and rainfall, relaying data back to remote data collation and monitoring centres, but extreme weather conditions can interrupt data transmission so undermining weather event prediction reliability. Several models for meteorology and hydrology data reconstruction have been developed for flood prediction, but the uncertainty associated with the reconstructed values, is rarely included in model inputs. Increasing the volume of validated data by using dense digital sensor-networks for rain and water level forecasting could be a more cost-efficient approach based on the use of low-cost sensors installed on farms and construction sites for hyperlocal weather insights. For these sensors to be considered for forecasting, data validation based on refining calibration procedures for all sensors and measuring devices, with the development of uncertainty-aware machine learning tools and experimental comparisons are required to improve both data quality and reliability. This approach would require more in-depth technical justifications for current measurement uncertainties, coupled with a review of calibration and maintenance procedures to create cost benefits for all WMO and WMO-sponsored Programmes, as well as improved products and services from the National Meteorological and Hydrological Services (NHMSs).

The ocean-atmosphere heat interchange underpins our understanding of global weather, and enables more reliable predictions of climate trends, whilst also acting as an indicator of extreme weather events. In addition, this interchange provides a robust characterisation of the oceans as CO₂ sink and as a tool for planning rigorous policies for adaptations to climate change.

The sea Ice Surface Temperature (IST) may rise up to 4 °C under the influence of changes to local snow coverage and thermal gradients. The EUMETSAT “TRUSTED” research project is developing a fiducial reference infrastructure, based on a new generation of ocean buoys and aims to link satellite and *in situ* temperature measurements to within 1 mK, whilst support for emerging European infrastructures such as the MINKE RI is also required. The WMO Global Cryosphere Watch (GCW) is about to publish the “permafrost measurement guide”, prescribing breakthrough uncertainty of 0.05 °C and ideal uncertainty of 0.02 °C in permafrost temperature measurements. Such challenging values require accurate on-site sensor calibrations.

Dedicated travelling calibration systems are therefore needed, with metrological grade performance, to achieve the GCW requirements. These are examples of interactions where the NMI community could really make a difference.

At the launch of the GCOS Surface Reference Network (GSRN) pilot phase in September 2023, it was recognised that present knowledge for air temperature measurements in reference networks is not sufficient for completing the uncertainty budget. The BIPM-WMO workshop [1] identified the need for establishing harmonised guidelines with traceable standards for sensor testing and calibration, whilst the WMO Decision INFCOM-2 [2] requests further field experiments and studies to refine and improve the uncertainty evaluation and traceability of measurements in different international climate observation networks. The 2022 GCOS Implementation Plan [3] states that “Understanding and estimating surface fluxes is essential for improving projections of climate change and planning adaptation and response measures”. In addition, the European Metrology Network for Climate and Ocean Observation’s Strategic Research Agenda, [4] identifies the need for metrological support in evaluating sensors characteristics, calibration and measurement uncertainties for future reference-grade ground-based stations.

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.

to the proposal shall focus on improving measurement systems and procedures for climate monitoring, meteorology, and warning reliability by reducing measurement uncertainties in ground-based systems and the development of methods for traceable in-field determination of ecosystem-atmosphere energy fluxes.

The specific objectives are:

1. To improve air temperature measurement and calibration techniques by reducing errors and evaluating uncertainties targeting 0.1 °C and decadal stability of 0.05 °C in reference measurements for meteo-climatological data. This should be based on the development and characterisation of new calibration systems, the evaluation and reduction of sensor response environmental influence factors in field, and the introduction of new data analysis methods.
2. To improve data quality and data reconstructions from ground-based distributed systems used in monitoring environmental thermal quantities to meet the WMO prescribed threshold level for near surface air temperature measurement uncertainties of 1 °C at $k=2$, that also meet the WMO tiered networks concept, from reference to baseline networks. The data quality enhancement should be based on the adaption of existing calibration, validation, and verification procedures, the performance of virtual experiments and the generation of new uncertainty-aware machine learning models.
3. To develop methods for traceable in-field determination of ecosystem-atmosphere energy fluxes (soil and sensible heat fluxes, S-SHF) through improving heat flux plate calibration procedures with a targeted uncertainty of 5 % ($k=2$) and to investigate the use of optical fibre thermometry for large area soil temperature measurements with a target uncertainty of 0.2 °C ($k=2$). In addition to optimise the Eddy Covariance techniques for the determination of S-SHF by the inclusion of the uncertainties and/or corrections associated to the atmospheric parameters involved (e.g. air turbulence, air temperature measurements)
4. To improve the water cycle and phase transition metrology infrastructure by: (i) providing metrology for monitoring water abundance and for improving early flood warning hydrological model input data; (ii) developing laboratory methods and transportable equipment for the traceable measurement of permafrost phase transitions to below 0.05 °C; (iii) reducing the discrepancy between satellite and ground-based measurements of sea ice surface temperature to below 0.1 °C; and (iv) investigating mathematical tools for the extrapolation of marine thermometer ITS-90 functions to achieve target uncertainties below 1 mK.
5. To facilitate the take up of the technology and measurement infrastructure developed in the project by the measurement supply chain (instrument/system manufacturers), standards developing organisations (WMO, BIPM, ICOS), and end users (e.g. meteorological networks, GCOS, GCW, National Meteorological and Hydrological Services, FluxNet, Net Heat Flux).

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 EMRP ENV07 MeteoMet, ENV58 MeteoMet2, EMPIR 17SIP02 SimpleMeteoU, 19SPI03 CRS and 19SIP06 COAT project(s) 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 climate monitoring sector.

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.

The references below were provided by PRT submitters; proposers should therefore establish the relevance of any references.

- [1] *BIPM-WMO workshop on Metrology for climate action report:*
<https://www.bipm.org/documents/20126/27085544/RapportBIPM-2023-03.pdf/57b00234-2bd0-09e1-8d4f-4aaed2ae45fd?version=2.4&t=1687244959519&download=true>
- [2] *INFCOM-2 Commission for Observation, Infrastructure and Information Systems/Doc. 7.4(2), Feb. 2022 WMO-No 1306:*
<https://library.wmo.int/records/item/66287-commission-for-observation-infrastructure-and-information-systems>

- [3] *The 2022 GCOS Implementation Plan:*
<https://gcos.wmo.int/en/publications/gcos-implementation-plan2022>

These references have been provided by EURAMET.

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