Metrology for Pressure, Temperature, Humidity and Airspeed in the Atmosphere

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Abstract:

The Joint Research Project METEOMET – "Metrology for Meteorology" realized in the frame of the European Metrology Research Programme (EMRP) is described in the paper. The project is focused on the traceability of measurements involved in the climate changes: surface and upper air measurements of temperature, pressure, humidity, wind speed and direction, solar irradiance and reciprocal influences between measurands. It includes development and testing of novel instruments as well as improved calibration procedures and facilities for ground based observations, including in-situ practical calibrations and best practice dissemination.

The project consortium is based on 18 National Metrology Institutes (NMIs), three un-funded partners and several collaborators, such as universities, research centers, meteorological organization and institutions, from Europe and other non-European countries. Istituto Nazionale di Ricerca Metrologica (INRiM) in Italy is the project coordinator. Three Polish organizations participate in the project: the Central Office of Measure (MG-GUM), the Institute of Low Temperature and Structure Research (INTiBS) and the Wrocław University (UWr).

Keywords: *weather station, temperature, humidity, pressure, environment, climate change*

1. Introduction

The project "Metrology for pressure, temperature, humidity and airspeed in the atmosphere" is realized as the Joint Research Project METEOMET "Metrology for Meteorology" in frame of the European Metrology Research Programme (EMRP). The EMRP is implemented by a Regional Metrology Organisation (RMO) of Europe – EURAMET e.V. (the European Association of National Metrology Institutes) [1].

EURAMET coordinates the cooperation of National Metrology Institutes of Europe in fields like research in metrology, traceability of measurements to the SI units, international recognition of national measurement standards and related Calibration and Measurement Capabilities (CMC) of its members. Through knowledge transfer and cooperation among its members EURAMET facilitates the development of the national metrology infrastructures. As well EURAMET is responsible for the elaboration and execution of the EMRP.

The EMRP is based on Article 185 of the Lisbon Treaty. It provides the opportunity for the user community and other stakeholders to directly suggest topics that the metrology community should address with its resources. The EMRP supports the collaboration of European metrology institutes, industrial organisations and academia through Joint Research Projects (JRPs).

This JRP METEOMET is focused on the traceability of measurements involved in the climate changes: surface and upper air measurements of temperature, pressure, humidity, wind speed and direction, solar irradiance and reciprocal influences between measurands. It responds to the need of new stable and comparable measurement standards, protocols, sensors and calibration procedures, data-fusion and uncertainty-evaluation methods, to enhance data reliability and to reduce uncertainties in climate models. It includes development and testing of novel instruments as well as improved calibration procedures and facilities for ground based observations, including *in-situ* practical calibrations and best practice dissemination. The development of novel instruments for the measurement of water vapour, the most important gas in the atmosphere and a key player in climate change, is a scientifically and technically relevant part of the project.

The project, started on 1 October 2011, is coordinated by Istituto Nazionale di Ricerca Metrologica (INRiM) in Torino (Italy). 18 European National Metrology Institutes and three Universities (un-founded partners) are involved to the project. 29 collaborators from all Europe representing meteorology organizations and other non-European countries, institutes and instrument companies have declared their interest in the JRP participation. Three Polish organizations participate in the project:

– the Central Office of Measure (GUM),

– the Institute of Low Temperature and Structure Research (INTiBS), where the national temperature standard for a low temperature range is maintained,

– the Wrocław University (UWr) – the Department of Climatology and Atmosphere Protection.

2. The project aim

Why the project is needed? Because recent decades have seen notable changes in global and European climate. The World Meteorological Organization (WMO) and the Bureau International des Poids et Mesures (BIPM) have established that many of the principal challenges faced by climate science are indeed measurement challenges. In 2010 the WMO signed a document MRA – "Mutual Recognition Arrangement" elaborated by the BIPM and signed by majority of the NMIs in 1999 [2].

Development of homogeneous climate observations and data sets are basic aims of the project.

This project will respond to some principal needs:

• *Ensuring a defined traceability to the national standards for meteorological observations. Definition of a mea-*

surement protocol in accordance with WMO guidance.

Routine calibration procedures for most of the measurements are not usually adopted but are necessary to maintain a high level of confidence in the quality of the data.

• *Climate measurements uncertainty evaluation.*

The development of more accurate climate models to reduce uncertainties in existing climate change scenarios is a fundamental task.

• *Calibration of weather measurement stations and reference radiosondes.*

Stations must be equipped with calibrated sensors for improving the reliability of measurements.

• *Improved humidity sensors and calibration methods.*

Water vapour is the most important greenhouse gas in the earth's atmosphere and a key component for several physical and chemical processes. Therefore the humidity of air in terms of volume concentration of water is a key parameter to be measured for understanding the climate processes all over the world.

• *Cross-linking of the weather and climate monitoring sites to establishing a well-modelled and cooperating (distributed) European smart monitoring network.*

Metrological cross linking of the weather and climate monitoring sites is an indispensable prerequisite to explore the whole performance in terms of accuracy, reliability, traceability, comparability and cost efficiency. Only a complete, well-modelled and cooperating sensor network allows for low-uncertainty and full-area covering weather and climate-change modelling.

• *Robustness of the historical temperature measurement data.*

Published historical data often lack of a clear statement on the measurement technique and sensors, surrounding environment change, uncertainty budgets and traceability to standards and temperature scales of the different periods.

• *Improve availability of data and promote their use*

Easy and rapid access to information achieved in different European data centres is needed for: modelling, data interpretation, quality control, network selection and network/system performance monitoring.

• *Improve communication and co-operation between scientific community.*

Communication between all the National Institutes or local Agencies interested to climate observations should be improved in order to realize a wide scale monitoring system which overcomes the nowadays braking up.

• Improve measurements program for better geographical and temporal coverage and for near real time monitoring capability.

In Europe the expansion of measurement programmes is necessary to provide adequate global coverage, to increase the number and quality of weather stations with particular attention to areas more sensitive to climate change.

3. The project structure scheme

The project structure scheme is presented in Fig.1. It well reflects those aspects in its work packages (WPs) and tasks organisation.

WP1: Upper air measurements: sensors and techniques

Aim of this work package is to investigate the possibility for traceable absolute humidity sensors based on tunable diode laser absorption spectroscopy (TDLAS). TDLAS hygrometers have big advantages in meteorological humidity measurements. They can be extremely fast but also small and lightweight.

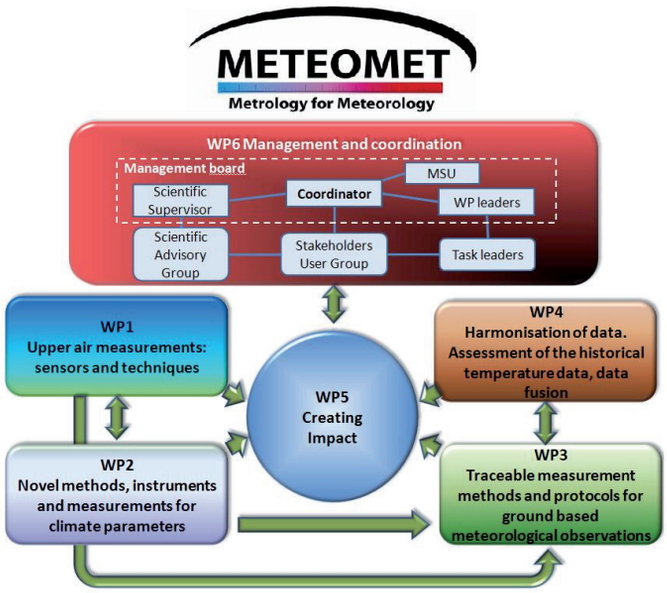

Fig.1. The METEOMET project structure scheme

The objectives of this WP can be summarized in the following list:

• realisation of a traceable TDLAS hygrometer,

• evaluation of the strength and broadening of the spectral absorption lines of the water molecule,

• to improve comparability between existing sensor technologies through:

a) develop special calibration protocols to produce quantitative information about the consistency of data obtained with different sensor technologies,

b) develop a new transportable humidity generator to enable *on-site* calibration of field hygrometers,

c) develop a new "fast humidity calibration system" for establishing traceability to radiosonde based measurements,

d) realize an international field humidity sensor intercomparison campaign with traceable *on-site* calibration using a humidity generator as transfer standard. This intercomparison is jointly organized by institutions involving state of the art as well as recently developed instruments from the major groups active in this field and the German National Standard. This activity will be closely coordinated with the COST – Action ES0604: "Atmospheric Water Vapour in the Climate System (WaVaCS)", the SPARC (Stratospheric Processes And their Role in Climate) water vapour initiative (a project of the World Climate Research Program), and the GRUAN of the GCOS a joint undertaking of the WMO.

The work package is coordinated by the Physikalisch-Technische Bundesanstalt (PTB), Germany.

WP2: Novel methods, instruments and measurements for climate parameters

The aim of this work package is to develop novel methods and instruments for the measurement of temperature, humidity, and pressure in lower and upper atmosphere, and to obtain new data to improve the accuracy of

the saturation water vapour equations in the temperature range between -80 °C and +100 °C

The WP is split into five tasks:

2.1: Water vapour formulae improvement,

2.2: Novel methods and instruments for atmospheric humidity measurement,

2.3: Novel atmospheric multi-sensors,

2.4: GPS and Galileo based measurements,

2.5: Development of accurate laboratory calibration facilities and procedures for air temperature sensors.

The development of novel instruments and measurement methods, in the framework of a metrological research project oriented towards climate and meteorology, is necessary to answer to the needs expressed by the meteorological community, in terms of improvement of the accuracy for the measurement of atmospheric parameters.

CNAM, the National Metrology Institute in France, is a lider of the work package.

In this work package, CNAM, CETIAT (Centre Technique des Industries Aérauliques et Thermiques from France), and MG - GUM from Poland will realize measurements of saturated water vapour pressure over water and ice in the temperature range between -80 °C and +100 °C, where vapour pressures lie between 50 mPa and 101 kPa. Two different devices will be used, to detect and quantify corrections related to possible systematic effects, and define their impact on the final uncertainty budget.

MG – GUM has a water vapour pressure cell made of stainless steel, realized as a compact thick-wall saturator and installed in a thermostat – calibration bath. The system is designed to minimize temperature gradients and water contamination. GUM will carry out measurements of saturated water vapour pressure over water and ice in the temperature range in the whole mentioned temperature range and will perform tests at temperatures down to -90 °C as well.

CETIAT, GUM and INRIM will compare results of water vapour pressure measurements obtained from the three experiments, and, where possible, will merge data and propose a new equation for the water vapour pressure curve.

WP3: Traceable measurement methods and protocols for ground based meteorological observations

The biggest group of participants are involved in realization of the work package since the activities can widely be distributed and carried on separately in order to gain in terms of time and resources. The wide participation of several nations also brings the advantage of establishing or enforcing numerous relationships between NMIs and meteorological services and climate research groups over Europe. The tree Polish organizations are included in the WP as well.

The aim of this work package is to develop traceable measurements methods and protocols for temperature, humidity, pressure and airspeed ground-based measurements needed for climate studies and meteorological long-term and wide scale observations. Weather stations-based measurements are the main subject for this WP.

Six tasks are planned in the WP:

3.1: Definition of state of art in European countries of weather stations performance, use, calibration and traceability,

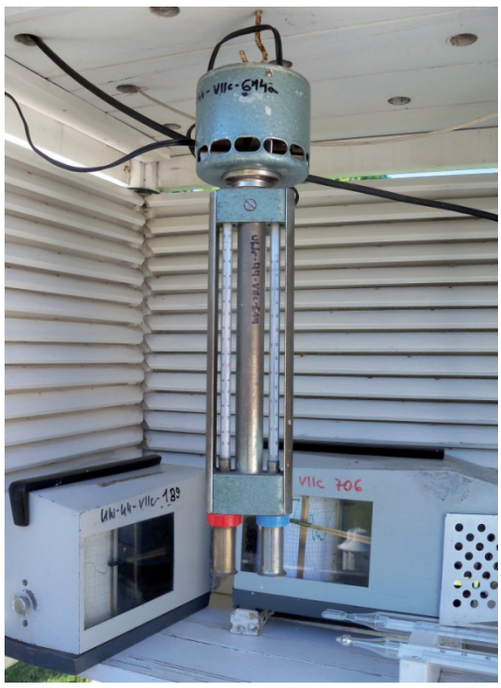

Fig. 2. The Wrocław University weather station apparatus

3.2: Evaluation of the effect of solar radiance and ageing on weather stations,

3.3: Development of a method for establishing traceability in wind speed measurements,

3.4: Development of a laboratory calibration facility and procedures for the combined, simultaneous, calibration of temperature, humidity and pressure sensors in weather stations,

3.5: Construction of a facility for *in situ* traceable calibration of weather stations also for special purposes and under extreme environmental conditions (high mountains, poles),

3.6: Protocols for quality assessment of ground-based measurement and software validation of *in situ* weather stations.

The Polish institutes will collaborate in the majority of these tasks. They will create database of European weather stations: sensors, design, calibration practices, traceability routes and report on the available models.

The aim of the task 3.4 is the development of a facility for the combined, simultaneous, calibration of temperature, humidity and pressure sensors in weather stations. This device will allow the study of the impact of interfering quantities on individual calibration curves of T, H, P sensors. INTiBS and GUM will perform measurements of temperature, humidity and pressure for sensors used on weather stations against appropriate reference standards, in laboratory. The three parameters ranges will be defined according to the real conditions the weather stations can be exposed to, and will be: (-50 50) °C, (10 98) % Rh and (80 110) kPa. Some of general aspects of mutual influences of temperature, humidity and pressure will be investigated. Analysis of achieved results with comparison to routine *in situ* measurements performed by the Wroclaw University. The UWr will provide the basis for the definition of calibration procedures for weather stations.

During the task 3.5 realization INRiM will study and

manufacture a reduced dimension facility for the *in situ* calibration of weather stations. It will allow simultaneous calibration of temperature, humidity and pressure sensors, covering the whole expected range according to the stations locations. It will feature temperature control within 0.05 °C between -20 °C and 50 °C, pressure control within 100 Pa between 75 kPa and 110 kPa, humidity calibration by comparison at 1.5 % uncertainty between 5 % and 95 % Rh. It will be a special chamber made in such reduced dimensions that it can be easy transported. INTiBS and UWr will organise, manage and take a care of the field works for the testing in extreme conditions of weather stations calibrated using the INRiM facility. Two sites are proposed: the research station in the Western Sudetes (Mt. Szrenica, 1365 m being a very moist and windy place with high frequency of rime/icing) and the station on the Spitsbergen (Svalbard) with its logistics and infrastructure that give an easy access to a natural arctic environment.

Fig. 3. The weather station apparatus in the Western Sudetes

The Wrocław University has a permanent access to the Wester Sudets station, by whole year, and to the Spitsbergen station in the period when observation and measurements are possible.

The aim of the task 3.6 is the development of protocols for quality assessment to improve the reliability of ground-based measurement. After an assessment of the needs, the validation of software for *in situ* weather stations will be performed.

The work package is coordinated by INRiM – Italy.

WP4: Harmonisation of data. Assessment of the historical temperature data, data fusion

The work package is coordinated by the Czech Metrology Institute (CMI – Cesky Metrologicky Institut) in Brno.

The aim of this work package is to investigate sources of uncertainty in historical temperature data, include them into the uncertainty budget and correct the input to the climate models thus enhancing climate change detection, prediction and adaptation assessments. A novel software based model for the harmonisation of data under such a metrological approach will be developed.

A further objective of this WP is to enforce the whole relevance of the JRP impact. After the collection of the data and assessment of methods has been performed and when such a metrological analysis will be adopted, the requirement of standardised and traceable methods for collecting temperature data over wide scales and long terms will be strengthened. The main result will be the reduced variability of data made available for similar analysis to be performed also in the future. Harmonization uncertainties, statistical A Type and B Type uncertainties will then be included in the temperature trends evaluations.

WP5: Creating impact

The technical work in this project will deliver advances in measurement and calibration to a highly international science area of critical importance to future global sustainability. Therefore, it is crucial that the outputs are disseminated widely to meteorology organisations, and other stakeholders. The geographical dispersion of users requires suitable dissemination mechanisms: web-based knowledge transfer and training will be used, as will decentralised knowledge transfer mechanisms, with each project participant liaising with local (national) meteorology organisations and practitioners. Presentations during the period of the project will provide short-term high-impact dissemination, while publications and computer-aided learning applications will provide long-term dissemination.

The objectives of the impact work package are to:

• provide links, participation, and knowledge transfer to the "end user" community; including national and international climate and meteorology institutes and organisations, measurement users and instrument companies,

• feed into the development of key standards and protocols through appropriate climate and meteorology bodies,

• develop a coherent approach at the European level in this field of metrology.

The new equipment, facilities, measurement methods and primary standards developed by the project will be disseminated in order to facilitate best practice amongst meteorology organisations, and European NMIs. In all dissemination, there will be an emphasis on promoting measurement traceability and realistic understanding of measurement uncertainty.

The knowledge developed in the project will be transferred *via*:

• website dissemination of project progress and outputs, web-based training material and public access web page containing real time data including measurement uncertainty (T, H, P) from some calibrated weather stations in Europe,

• input into WMO and national working groups developing new best practice and documentary standards in this area,

• stakeholder workshop meetings organized at European and local level, as opportunities for proposal, agreement and adoption of strategies,

• publications – reports, good practice guides, and scientific papers.

Training will be organised, to transfer improved metrological practices and procedures, targeted to meteorological instrument users, and those analyzing meteorological data. Training, using web-based material, and via training courses held in at least 5 countries/regions across

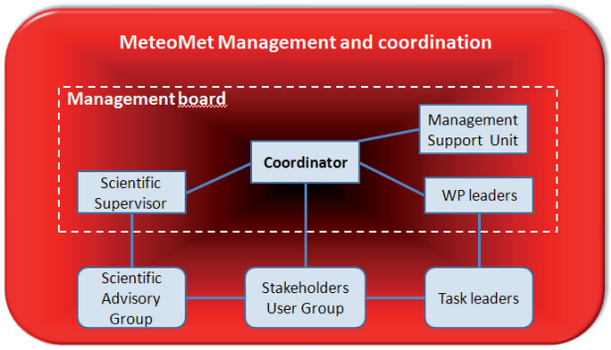

Fig. 4. JRP MeteoMet management structure

Europe will be organized in Poland too.

WP6: JRP management and coordination

The large number of NMIs/DIs (Designated Institute to EURAMET) participating in this JRP together with unfunded JRP-Partners makes the management an important aspect of this project, in order to assure a fruitful coordination of scientific activities and budget control. In addition a number of collaborators are linked to this JRP. The coordination structure for this project will be based on the JRP-Coordinator, a Scientific Advisory Group and the WP leaders. A project Scientific Supervisor will assist the JRP-Coordinator in preparing the reports.

In order to optimize the coordination and the information flux from and to the management and the participants, and to better reflect the main objectives of this JRP, the number of technical work packages has been limited to four only. Work package leadership is assigned to key scientists, experts in the fields of the WP tasks, thus increasing the scientific value to those roles. WP leaders are at the same time responsible of the coordination for progress of the individual work packages and take part in the management and coordination decisions.

The progress of the project will be monitored against the Gantt chart and the deliverable list. All JRP Partners will be required to report their scientific and technical activities, the results achieved, their contributions to deliverable, eventual risks mitigations adopted and problems encountered in respecting the Gantt.

The aim of this task is to provide the scientific and financial reporting to EMRP, according to the guidelines. The first and final periodic reports and financial reporting, the interim reports, the final publishable report are the subject of this task, together with the organisation of JRP meetings.

Reporting, based on information provided by all JRP-Partners, will be provided to EURAMET according to the guidance requirement in terms of content and deadlines.

4. Summary

The need of establishing the road through a uniform approach to the traceability for those measurements involved in climate studies, such as pressure, temperature humidity and airspeed in the atmosphere is a fundamental goal of the project. Weather observations and collection of data are not carried on with similar methods and procedures in the different European countries. A large number of participants from the 18 countries allows a better understanding of the present situations, and constitutes a wide forum for discussing and proposing common procedures. NMIs operating at regional level, in cooperation with meteorological institutes can directly disseminate the results and best practices. The JRP-Consortium brings together the largest European NMIs having broad experience and expertise in metrology for pressure temperature, humidity and airspeed. Expertises have also been acquired in mathematics applied to data harmonisation and software validation. The various tasks are carefully assigned to the corresponding experts of the Consortium.

The development of novel sensors, techniques and facilities can be achieved thanks to the well-established scientific and metrological capabilities and activities of the NMIs involved. Testing in different environmental conditions, moreover, is possible since NMIs operating in several and different areas are included.

The JRP MeteoMET started on 1 October 2011. In the middle of October a kick-off meeting was orginised by the project Coordinator – the INRiM. It was held in the Reale Collegio Carlo Alberto di Moncalieri where is located the Historical Meteorological Observatory of SMI (Società Meteorologica Italiana-Project Partner). About 60 persons from European metrological and meteorological organizations participated in the meeting. The World Meteorological Organization (WMO) was represented on the meeting as well. During the meeting the Scientific Advisory Group and a project Scientific Supervisor were elected.

The JRP MeteoMet is one of the largest projects of the EMRP.

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