A NEW CHALLENGE FOR METEOROLOGICAL MEASUREMENTS: THE "MeteoMet" PROJECT – METROLOGY FOR METEOROLOGY

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Abstract

A joint research project called "MeteoMet - Metrology for Meteorology" (www.meteomet.org) started in October 2011, aiming to respond to the needs for new stable and traceable measurement standards, protocols, sensors and calibration procedures, and uncertainty-evaluation methods, to enhance data reliability and reduce uncertainties in climate models. This project is part of the European Metrology Research Program (EMRP) coordinated by the European Association of National Metrology Institutes (EURAMET).
The big challenge is the propagation of a metrological measurement perspective to meteorological observations in order to better meet the requirement of reliable data and robust datasets over wide scales and long terms.
The project covers several aspects of meteorological observations from upper air to ground based measurements. It includes development and testing of novel instruments as well as improved calibration procedures and facilities, in-situ practical calibrations and best practice dissemination. Historical temperature data series will be validated with respect to uncertainties and the methodology for recalculation of the values will be provided.

The project activities, tasks and deliverables, are here described, with a specific focus on the objectives and the experimental devices that will be assembled for the purpose. The activities advances since the project start are also reported, together with the perspectives of future dissemination and research opportunities.

1. Introduction

Recent decades have seen notable changes in global and European climate, together with an increased desire to both monitor climate change and reduce the impact of human activity on the climate [1, 2]. The consequences of these changes have a deep impact on different aspects of social, political and economic life. Reliable assessment of climate change crucially depends on the robustness of climate data and on the uncertainties associated with measurements. The need to improve data collection and reduce uncertainties in existing climate and impact data and modelling has been expressed by different climate data users such as climatologists, economists and politicians. In particular the World Meteorological Organization (WMO) and the Bureau International des Poids et Mesures (BIPM) have jointly acknowledged that today many of the principal challenges faced by climate science include significant measurement challenges and discussed ways for working together [3, 4]. In this occasion, WMO signed the Mutual Recognition Arrangement (MRA) for national measurement standards and for calibration and measurement certificates issued by National Metrological Institutes (NMIs).
In line with these requirements is the European Joint Research Project (JRP) MeteoMet (www.meteomet.org) which will give the opportunity to the metrological scientific community to give its contribution in support of environmental policies. Traceability and standardisation of climate data will be the principal goal of the cooperation between Metrology and Meteorology, as supported in the project.

Figure 1. The MeteoMet Logo

The activities in the project and the specific subject have brought together a wide consortium of partners: 18 national metrology institutes and 3 universities as partners plus 29 collaborators, including national meteorological organizations, research institutes associations and instruments companies. Such a wide consortium, the biggest in EMRP, together with a strong stakeholder involvement represents a key feature of the project helping to merge and exchange different knowledge aimed at improving the actual climate-science panorama, discussing and proposing common procedures, and allowing wide dissemination of the project results.

Figure 2. NMIs MeteoMet partners

2. *Objectives and Needs for the Project*

The project is focused on the traceability of measurements involved in the climate change evaluation: surface and upper air measurements of temperature (T), pressure (P), humidity (RH), wind speed and direction, solar irradiance and reciprocal influences between measurands. Project main scopes are:

- achievement of robust climate data with measurement uncertainty budget
- novel methods and instruments to improve the measurements and calibration procedure of T, P, RH, and wind speed.
- accurate interpretation of historical temperature data series.

The project aims to strengthen the idea that climate measurements have to be made under standard conditions and in accordance with established practices both for observing methods and for the exposure, selection and use of instruments [5, 6]. For maintaining a high level of confidence in the climate data, it is necessary to use approved instruments with traceability to International System of Units (SI) through the national standards. In this scope, NMIs capabilities in defining procedures, calibration standards and traceability chains are vital for achieving significant advancements.

The work addresses the following topics:

- *Upper air measurements*

During the project a new generation of sensors for upper air measurements will be developed:

- Tuneable diode laser absorption spectroscopy (TDLAS) hygrometers will be investigated to assess their ability to provide consistent atmospheric humidity data. These instruments will be validated against a national standard and their uncertainties analysed. Furthermore, traceable spectral data (line strength and width) of the water molecule will be determined for the first time, including their pressure / temperature and matrix dependence.
- A new generation of compact, robust and high-sensitive hygrometers based on microwave quasi-spherical cavity, suitable for installation in airborne devices, will be developed to measure humidity in the upper atmosphere, where low humidity ratios need to be measured with high accuracy.
- innovative multisensors for free-space non-contact atmospheric measurements of T, P and RH and novel methods for GPS (Global Positioning System) and Galileo-based measurements will be studied.

Moreover, in order to improve comparability between existing sensor technologies this project will carry out:

- improvement of the uncertainty of the water vapour equations to obtain more consistent humidity data from instruments based on different principles of operation.
- development of a new mobile humidity generator to enable onsite calibration of field hygrometers
- development of a new “fast” humidity and temperature sensors calibration system for establishing traceability to radiosonde-based measurements
- the 2nd international intercomparison campaign (Aquavit 2) [7] of airborne field humidity sensors of different types.

- *Ground based measurements*

Three basic aspects related to weather station based measurements will be covered:

- Proposal for novel calibration methods and protocols.

In this context the first metrological intercomparison and testing of weather stations will be organized. The validation of data-logging software used to calculate the indirect measured value from the direct measurement will be performed. Its validation aims to avoid measurement processing errors.

- Evaluation of the effect of solar radiance and wind speed on meteorological parameters measurements.

Based on this information a "standard" radiation shield will be developed in order to improve the accuracy and uncertainty of air temperature measurements. The proposal of procedures for harmonizing measurements with different solar radiation shields will be included. A theoretical model for studying the influence of solar radiation on weather measurements and for uncertainty budget evaluation taking into account aging effects will be developed.
Wind is one of the most measured parameters in weather stations is. However, the measurements performed are difficult to use, primarily due to the influence of the environment. Methods for on-site field calibrations will be developed addressing the influence from the geographical layout. Further the effect of foreign substances (e.g. rain and icing) on ultrasonic anemometers will be optimized using a validated mathematical model.

- Construction of facilities for laboratory and in situ calibration of weather stations also working under extreme environmental conditions.

This project aims to develop dedicated facilities for the combined and simultaneous calibration, in situ and in laboratory, of T, P and RH sensors in weather stations. A laboratory chamber will contain also a wind generator and will be designed to include a solar radiation generator. These facilities allow the analysis of the mutual influences of the monitored parameters. Though, this aspect affects the performance of weather station, generally is not considered in the calibration processes.
The facility developed for in situ calibration will have reduced dimensions in order to be adaptable for the calibration of weather stations and instruments used for the monitoring of environmental parameters also in high altitudes. The new facility is expected to bring benefits to usual weather measurements and high altitude monitoring programs which are important indicators of climate change. The innovative transportable calibration chamber will be used for weather stations operating in the Mount Everest, and at research stations in the Karkonosze Mountains and in the Svalbard Island.

- Assessment of the uncertainties of historical temperature measurement data.

An interesting and controversial theme is the ability to compare historical and modern data series. The surrounding environment conditions, uncertainty budgets and traceability to standards and temperature scales, make it difficult to assess the reliability of the data and to compare the data of the different periods. The project intends to establish criteria for the validation of different spatial and temporal data, investigating the sources of uncertainty affecting the historical temperature data series. A novel software for the harmonisation of data and the inclusion of Type A and Type B uncertainties will be developed.

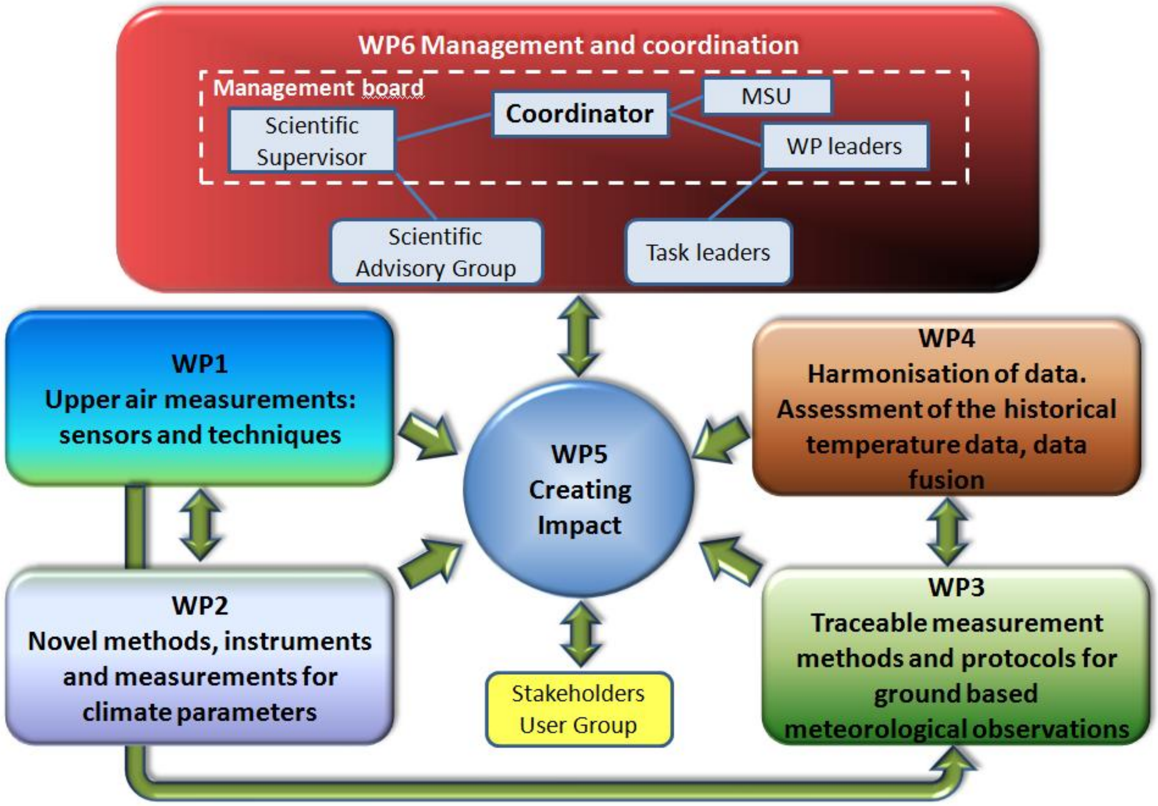


Figure 3. Project structure scheme

3. *Progress up to the present days*

In the first 6 months period two main activities were carried out: the enlargement of the stakeholder community trough liaison with national and international organizations and the starting of the scientific tasks.

At local level, meetings were organized in different countries (Italy, Poland, Sweden, Turkey, Japan) in order to best address the point of view of the meteorological community. At international level, active liaisons were established with WMO, WMO Commission for Instruments and Methods of Observation (CIMO), WMO-GCOS Reference Upper Air Network (GRUAN), International Surface Temperatures Initiative (ISTI), and Slovenian Environment Agency (ARSO).

About the technical outputs almost all activities started. The main results can be summarized as follows:

- A new facility dedicated to the measurement of the saturation vapour pressure and temperature of pure water was built. The apparatus allows performing a static measurement of pressure and temperature of pure water in a closed, temperature-controlled thermostat, conceived like a quasi-adiabatic calorimeter. Preliminary investigations of water vapour pressure were carried out.

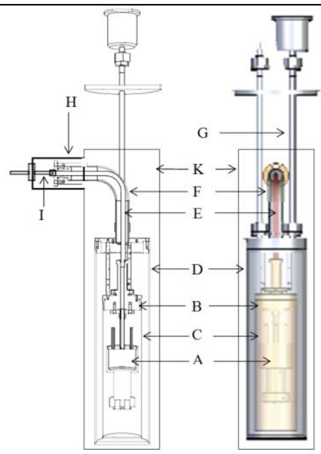


Figure 4a: Water vapour pressure cell and associated adiabatic calorimeter

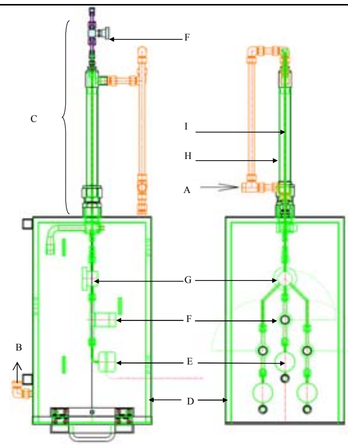


Figure 4b: Thermalization system for pressure sensors

• A stainless steel water vapour pressure cell was built. The cell is dedicated to the research of vapour partial pressure. Preliminary investigations of water vapour pressure were carried out .

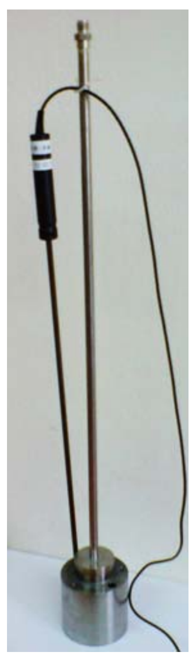
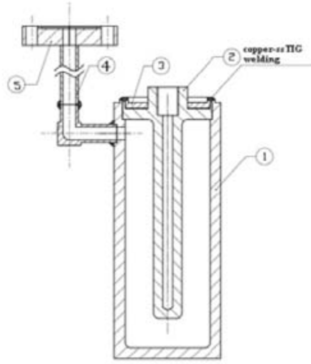


Figure 5: stainless steel cell for water vapour partial pressure measurements

• Investigation of the water vapor–ice equilibrium along the sublimation line was carried out. The measurements were performed in a small gold-plated stainless steel cell using a static method.



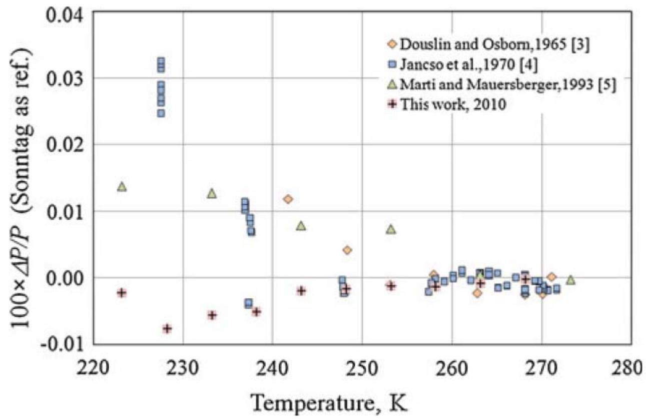


Figure 6: Scale drawing of the sample cell for pure water pressure measurements (left top), picture of the cell that shows the internal (left bottom), and comparison of the carried out measurements of vapor pressure with previously published data: the relative differences with values calculated with Sonntag's formulation as reference are shown in the graph.

- A web questionnaire to collect information about Automatic Weather Station (AWS) from meteorological institutes was produced and made available online. The required information is: type (identification, manufacturer, model), constructive characteristics (dimensions, shield, year of manufacture, year put into operation), sensors (measured parameter, type of sensor, characteristics), owner (country, institute, contact); environment (GPS coordinates, altitude, sea proximity, urban area, polluted area, accessibility) practice (software, equations, calibration method, calibration frequency).
- The survey of AWS diffusion in Europe was reported.
- A reference housing for climate sensors was built. The shield is equipped with a forced aspiration to reduce the influence of heating of the air inside the shield due to direct solar radiation. To test the aspiration efficiency a computational fluid dynamics simulation was performed[1].

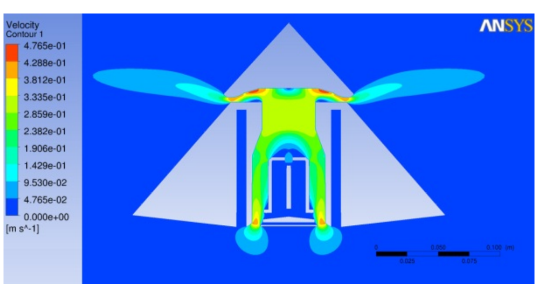


Figure 7. The reference housing modeled in Fluent and photo of first prototype in field.

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[1] Further details are reported in the paper "TRACEABILITY OF GROUND-BASED METEOROLOGICAL SURFACE TEMPERATURE MEASUREMENTS" by C. Garcia Izquierdo et al, presented in this same conference.

• A model for study the effect of the seeding deposition on the ultrasonic anemometer probes was created and the first prototypes assembled.
• The design of a laboratory calibration tunnel purposely studied for the calibration of AWS and the evaluation of wind speed on temperature and pressure sensors was starded by INRiM[1].
• The construction of a transportable AWS calibration facility started and a prototype tested for acquiring useful experience. A further model was manufactured and is under characterization[1].

Figure 8. The transportable chamber for the calibration of AWS made at INRiM.

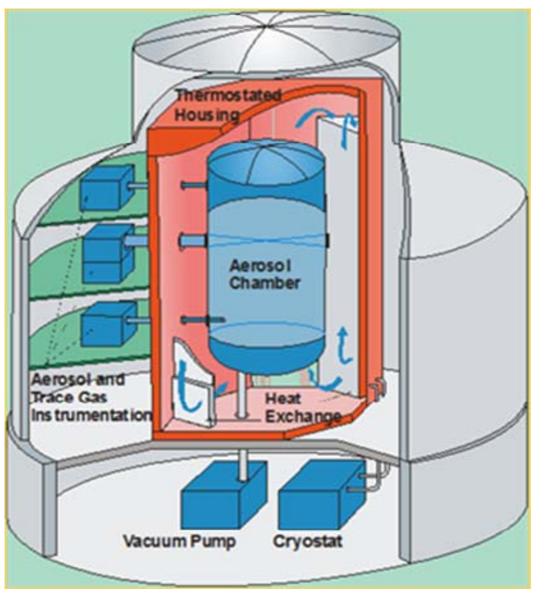
• The MeteoMet website was established and made accessible online. It contains general information about the JRP, guidelines for potential new collaborators, list of JRP related events, documents, and contacts. The web site includes a forum area for discussions for various level of user groups.
• In the frame of the task aiming at assessing the historical air temperature data quality, with respect to measurement protocols, instrumentation and techniques used, and to assess their reliability, a total of 99 series from five different countries have been collected. A database of air temperature series and belonging metadata was designed.

Researchers from non-metrological Institutions will add to the project valuable expertise in fields relevant to the JRP. Five REG (Research Excellence Grants) researchers will work in cooperation with the MeteoMet consortium along the three year. Through the REGs, the Organisations REG will guarantee the JRP-Consortium access to two unique facilities and specific knowledge of complementary importance for the metrological approach.

REG1 The EV-K2-CNR will bring expertise in the measurements of high mountain meteorological measurements by installing in the EV-K2-CNR Pyramid Laboratory/Observatory structure located at 5,050 m altitude at the base of Mount Everest in Nepal instruments calibrated and traceable. A transportable calibration chamber will be studied and adapted for this peculiar environment and application.

Figure 9. The EV-K2-CNR Pyramid Laboratory/Observatory structure located at 5.050 m

REG2 The Karlsruher Institute für Technologie (KIT) in Germany will give access to AIDA (Aerosol Interaction and Dynamics in the Atmosphere) chamber, a unique facility allowing to simulate water vapour in a wide range of amount percent. In the chamber humidity instrument will be tested and a calibration campaign (AQUAVIT2) will take place.



AIDA chamber

Figure 10. Scheme of the AIDA chamber at KIT.

REG3. An environmental wind tunnel facility has recently been constructed at the Mars Simulation Laboratory, at Aarhus University. This climate chamber is capable to simulate temperature, pressure, wind and sand storm expected on the Mars surface. The aim of this REG is to enable this facility to be used for the testing, development, calibration and comparison of meteorological sensors under a wide range of (terrestrial) environmental conditions. This, however, requires extensive modifications (improvements) to the control system, sensor systems and mechanical design of the facility. The REG-Researcher has started the initial detailed measurements of wind flow, temperature, pressure and humidity to determine the performance of the wind tunnel and make recommendations on improvements and modifications. A new laser Doppler anemometry (LDA) / phase doppler anemometry (PDA) system has been installed. Wind flow calibrations have been performed using the 2D LDA system, a pitot tube and the Martian Dust Accumulator (LAMDA) [8]. At present, temperature characterizations of the wind tunnel are underway to provide information on the stability of the chamber.

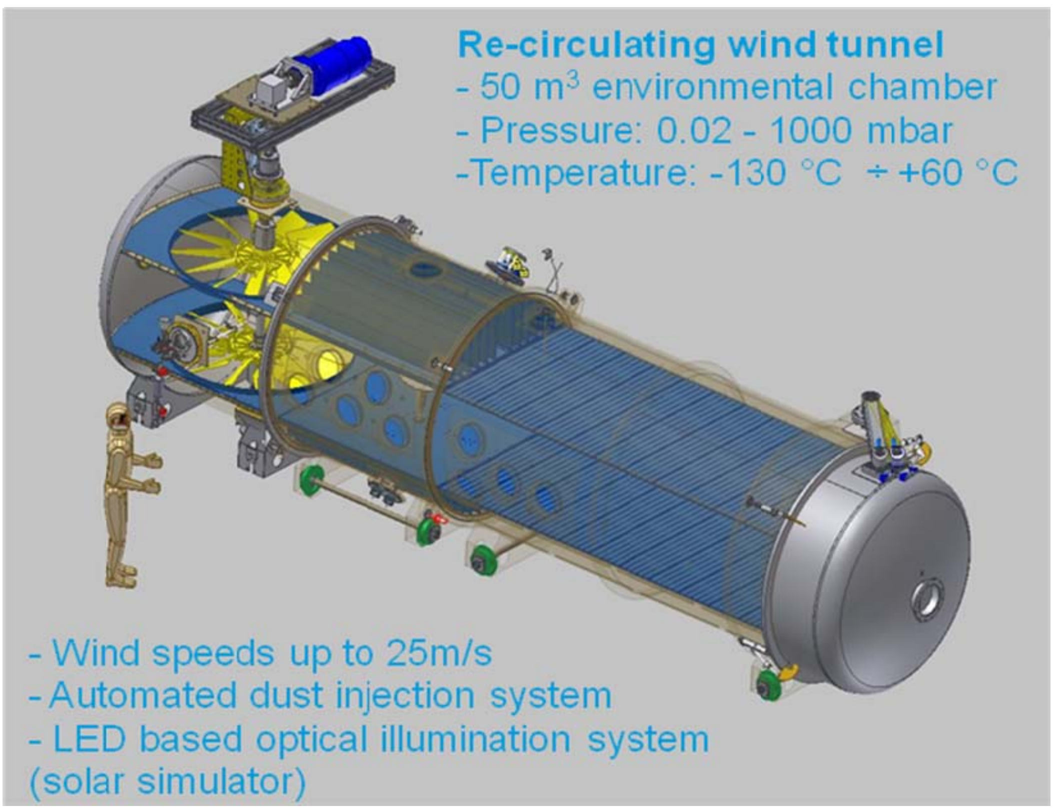


Figure 11. Scheme of the Mars simulator at Aarhus University

REG4 The adversities of plants are influenced by both culture conditions (varietal susceptibility, soil type, fertilization, irrigation, etc.) and by seasonal meteorological trend. The climatic conditions are responsible for advances or delays in the onset of infestations and infections. Metrological investigations are required to evaluate the target uncertainty on temperature and humidity measurements needed to improve the reliability and precision of forecasting models and studies are needed to establish an example of traceable meteorological measurements in sustainable agricultural research sites, and supplement this with a number of validated forecasting models. This O-REG is carried on in cooperation with IMAMOTER-CNR, in Italy, that has a long lasting experience in studies related to the meteorological observation for agricultural purposes. The Organisation has, among its several location, a vineyard equipped with weather and atmospheric instruments. This site will be the subject of the activities of this REG, opening for the first time a metrological approach to agricultural research.

REG5 An Organisation REG has been approved in the call3 of mid 2012 for the Centre for Climate Change (C3) at University Rovira I Virgili. The proposed O-REG aims at estimating the impact of the changeover of traditional observation system to AWS in historical temperature series. The systematic bias (size and shape) introduced in the long temperature series will be calculated and an instrumental calibration strategy and absolute adjustments for minimising this bias will be defined. Paired observations will be carried out in a historical relevant site, equipped with modern and calibrated instrumentation and traditional ones. Instruments change plays a key role in meteorological and climate studies and sometimes is carried out with long lasting procedures and instruments parallel use. This O-REG will also investigate and propose a solution: from a metrological approach, the use of calibrated instrumentation will reduce the parallel period of installation, ideally to zero, if both old and new instruments are calibrated with a traceable procedure.

4. Future opportunities. A follow-up project.

The experience being acquired under the MeteoMet project brings to valuable and unique knowledge both in the meteorological and metrological scenario. People from NMI are studying practical problems of weather observations and atmospheric measurements, meanwhile the several meetings are bringing to the meteorological community the metrological point of view on how to guarantee traceability to the measurements. The apparatuses being built and the procedures implemented for the calibration of different kind of sensors will lead to the availability of new facilities made by the metrological research groups for the meteorology community. Those apparatuses will be fully characterized under the MeteoMet project and after a period of test in cooperation with both scientific communities their routinary use will be possible. The inclusion of instrumental uncertainty, mainly Type-B ones, will be made robust in the years following the first traceability chains definitions achieved during MeteoMet.

In a follow up project, the first tests carried on during MeteoMet REG 4 in terms of the extension of a metrological approach to the agricultural research will be extended, in terms of both traceability for dedicated instruments and inclusion of uncertainties in the models used to predict bacteria growth and consequent treatment. A specific work package including tasks on agricultural metrology, indirect climate indicators, bio systems will be proposed.

MeteoMet full name refers to instruments and methods for atmospheric measurements, thus excluding investigations on water, snow, ice and soil. For the followup project water temperature measurements will be proposed for inclusion. High mountain lakes will be the subject of investigations on how to setup contact thermometry systems, directly linked to temperature standards, in order to reduce the overall measurement uncertainty. Procedures for accurate evaluation of temperature vertical profiles in water of lake and see will be studied. Deep ocean thermometry will also be included and those activities will form an homogeneous workpacaege on water temperature measurement. A study on dedicated devices and measurement best practice and traceability for snow, ice and soil temperature, together with geological investigations, such as temperature of permafrost layers with respect to climate annual conditions will also be possibly included.

The proposal for land reference ground based observing sites will be discussed thanks to the established cooperation between the two communities. For those sites, more robust traceability chain and calibration procedures will be defined for generating accurate data for climate change investigations. The aim is to assist the creation of a possible Surface Ground Based Reference Network. A similar reference site will be proposed under the GRUAN network, in order to link traceable ground based pre-launch data to balloon flight data. This will be a further work package or task.

A GRAUN metrological laboratory, allowing internal calibration cycles and external link to an Institute of Metrology will be proposed as further work package. This will be suggested to be setup in the GRUAN Lead Center and directly linked to PTB, being the German NMI.

This are the first proposal being drafted during the first year of MeteoMet. A follow-up project will be best defined during the process of proposing research topics for the 2013 EMRP Environment II call. A strong support from WMO-CIMO will also be asked in order to better address the several activities that directly involve instruments and methods of meteorological and climate observations.

5. Acknowledgements

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