MMC Torino 2023

METROLOGY FOR METEOROLOGY AND CLIMATE

Book of Abstracts

International Conference on

Metrology for Meteorology and Climate

MMC 2023

Edited by:

Graziano Coppa

September 26 - 30, 2023

Stupinigi Palace, Nichelino (Torino)

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Message from Andrea Merlone
MMC 2023 International Panel Committee
Chairperson

Way beyond any expectation! This can be the summary of MMC 2023, the fourth "Metrology for Meteorology and Climate" International Conference. With more than 150 participants from all the continents, MMC is now confirmed to be one of the world-recognized scientific events on measurements for meteorology, climate and the environment.

Conference sessions and part of the meetings took place in the fantastic "Palazzina di Stupinigi", a seventeen-century royal palace in a natural park close to Torino. Other meetings and trainings were organized at the INRiM campus, with shuttle buses arranged to reach the Conference venue. Regional food and local tastes were also part of the experience: many will remember the variety of coffee breaks offered and the social dinner, also a great moment spent together in a nearby farmhouse, again offering first-hand produced food. Besides the conference sessions, the MMC program included cultural, scientific and natural heritage visits. A guided tour of the palace was the cultural part of side events; on Thursday a scientific even took place in the Palace park: the inauguration and startup of the Climate Research Station managed by INRiM and Società Meteorologica Italiana, at the presence of local authority and the press; on Saturday, a visit to the Bossea caves formally ended the intense week, bringing participants on the underground laboratories, measuring climate thermodynamic parameters.

As usual for the MMC series, several side events and meetings have been organized, starting from the Friday before, where local school pupil met scientists to understand measurement issues in climatology. On Monday 25th a series of meetings took place, among which was the first in-person meeting of the GCOS Surface Reference Network task team and lead center. The very launch of the pilot phase for the GSRN, now being populated by stations and activities. An intense training for marine scientists was organized in the frameworks of the H2020 "MINKE" project, attracting young researchers and qualified teachers. The WMO Expert teams on Quality Traceability and Calibration and on Measurement Uncertainties also met in person to discuss specific topics. A "Mini Expo" was also organized in the palace stables (!) offering the

opportunity to see high quality instrumentation both for calibration laboratories and environmental measurements. Participants to the side meetings and expo all had special offers for attending the MMC days.
The scientific level of the presentations was excellent and is well reported in the abstracts here published. The conference opted for the usual 15 minutes talks and "lightning talks" of 3 minutes, instead of the posters. Keynote speeches from invited speakers completed the scientific content.
The 2023 Metrology for Meteorology and climate was a great success, based first of all on the large participation. A significant support also came from the endorsing Institutions (see next page). But the event could not meet the goal without the constant work of: Daniela Amparore, Alberto Bottacin, Graziano Coppa, Sandro Ferregutti, Elisabetta Melli, Chiara Musacchio, Alberto Sacchetti, Francesca Sanna, Caterina Tassone, and many others who have helped all along the week.

See you at MMC 2025!

Andrea Merlone

Endorsed by

SC-MINT (Standing Committee on Measurements, Instrumentation and Traceability)

Società Meteorologica Italiana

Global Climate Observing System

Associazione Italiana di Scienze dell'Atmosfera e Meteorologia

Centre for Climate Change - Universitat Rovira i Virgili

EPM project 21GRD08 SoMMet (Soil Moisture Metrology)

EPM project 22IEM03 PriSpecTemp (Primary Spectrometric Thermomety for Gases)

European Metrology Network "Climate and Ocean Observation"

MMC Torino 2023

METROLOGY FOR METEOROLOGY AND CLIMATE

Organizing committee

Andrea Merlone (INRiM)
Graziano Coppa (INRiM)
Chiara Musacchio (INRiM)
Alberto Bottacin (PoliTo)
Natalì Aranda (PoliTo)
Elisabetta Melli (INRiM)
Silvia Cavallero (INRiM)
Francesca Sanna (UniTo)

Scientific committee

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Luca Mercalli (SMI)
Yves-Alain Roulet (MeteoSwiss)
Jan Nielsen (DTI)
Peer Hechler (WMO)
Paola Fisicaro (LNE)
Neil Mander (MetOffice)
Drago Groselj (ARSO)
Michela Sega (INRiM)
Manola Brunet (URV)
Angelo Viola (CNR-ISP)
Yong-Gyoo Kim (KRISS)
Graziano Coppa (INRiM)
Krunoslav Premec (WMO)
Stephanie Bell (NPL)
Fabio Madonna (UniSa)
Tilman Holfeder (DWD)
Mareile Astrid Wolff (NMBU)
Dino Zardi (UniTn & AISAM)
Sarah Gallagher (MetEireann)
Gaber Beges (UL-LMK)
Andrew Harper (NIWA)
Javier Garcia Skabar (INTI)
Jane Warne (BoM)

Conference Program

Tuesday 26	Stupinigi Palace – Sala Camini (Fireplaces hall)
13.00 – 14.00	**Registration**
14.00 – 15.15	**MMC Opening**
	Welcome speeches by • Andrea Merlone (MMC chair) • Marta Fusi (Stupinigi Palace director) • Pietro Asinari (INRiM scientific director) • Nichelino high school students • Luca Mercalli (SMI president) • Caterina Tassone (GCOS secretariat) • Krunoslav Premec (WMO secretariat) • Peter Thorne (IPCC lead author, University of Maynooth) • Jane Warne (WMO SC-MINT chair)
15.15 – 16.15	**MMC Opening – Conference Partners** **chair A. Merlone**
15.15 – 15.30	O-99: *The GCOS Surface Reference Network* Tilman Holfelder, Sarah Gallagher, DWD – Met IE
15.30 – 15.45	O-33: *Measurement requirements for a global climate surface reference network* Andrew Harper, NIWA
15.45 – 16.00	O-35: *Project SoMMet – Metrology for multi-scale monitoring of soil moisture* Miroslav Zboril, PTB
16.00 – 16.15	O-97: *The MINKE Project Metrology for Integrated Marine Management and Knowledge-Transfer Network* Rajesh Nair, OGS
16.15 – 16.45	**MMC Exhibitors presentations**
16.45 – 17.30	**Coffee break – Mini Expo opening**
17.30 – 18.30	**Air temperature – CRS workshop** **chair A. Harper**
17.30 – 17.45	O-36: *Air temperature – defining the measurand* Stephanie Bell, NPL
17.45 – 18.00	O-28: *So what is "air temperature"?* Jane Warne, Bureau of Meteorology, Australia
18.00 – 18.15	O-95: *Metrological validation of the 48.8 °C European extreme air temperature record* Chiara Musacchio, INRiM
18.15 – 18.30	O-94: *The Air Temperature Metrology EU Project* Åge Andreas Falnes Olsen, JV
	End of day 1

Wednesday 27	Stupinigi Palace: Sala Camini (Fireplaces Hall)
9.00 – 10.30	**Soil moisture** **chair S. Bell**
9.00 – 9.15	O-10: *Large-footprint evaluation of soil moisture and snow-water equivalent by a single Finapp cosmic-ray neutron sensor* Enrico Gazzola, Finapp s.r.l.
9.15 – 9.30	O-17: *Towards a standardized ground soil moisture network over Italy based on cosmic-ray neutron sensors* Gabriele Baroni, University of Bologna
9.30 – 9.45	O-16: *Comparing remote sensing and cosmic-ray neutron sensing for soil moisture estimation in Northern Italy* Sadra Emamalizadeh*, University of Bologna *Gabriele Baroni presenting
9.45 – 10.00	O-24: *Stakeholder survey on soil moisture measurements – Results from an online questionnaire* Reidun Anita Bergerud, JV
10.00 – 10.15	O-39: *SI-traceable calibration facilities for point-scale soil-moisture sensors* Jan Nielsen, DTI
10.30 – 11.00	Coffee break
11.00 – 12.15	**Radiosondes & Humidity** **chair Y.-A. Roulet**
11.00 – 11.15	O-11: *Recent achievements and current research within the GCOS Reference Upper-Air Network (GRUAN)* Fabio Madonna, University of Salerno
11.15 – 11.30	O-3: *Testing radiosonde humidity sensors by laboratory setups and its application to soundings* Sang-Wook Lee, KRISS
11.30 – 11.45	O-18: *Assessment of the INRiM low frost-point generator and analysis of the uncertainty components between -100 °C and -20 °C* Rugiada Cuccaro*, INRiM *Giulio Beltramino presenting
11.45 – 12.00	O-7: *Improving radiosonde temperature measurements above cloud layers using a dual thermistor radiosonde (DTR)* Yong-Yoo Kim, KRISS
12.00 – 12.15	O-26: *The Hemispherical Blackbody (HSBB), a new reference for pyrgeometer-based measurements of longwave downward radiation* Moritz Feierabend, PTB
12.15 – 12.40	**Interlaboratory comparisons** **chair A. Kowal**
12.15 – 12.30	O-4: *Reference value analysis of interlaboratory comparison in the field of temperature, humidity and pressure* Xuejing Nan, Meteorological Observation Center, China Meteorological Administration
12.30 – 12.40	P-93: *Interlaboratory comparison status comparing laboratory results from WMO regional associations* Gaber Beges, University of Ljubljana
12.40 – 14.00	**Lunch at Stupinigi**
14.00 – 15.00	**Precipitation** **chair H. Dörschel**
14.00 – 14.15	O-40: *Development of calibration facility for non-catching disdrometers*

	Henrik Kjeldsen, DTI
14.15 – 14.30	O-25: *A raindrop simulator for calibration of non-catching precipitation measuring instruments* Enrico Chinchella, University of Genova
14.30 – 14.45	O-19: *The quasi-bicentennial daily rainfall series of the University of Genova: data analysis and accuracy assessment* Arianna Cauteruccio, University of Genova
14.45 – 15.00	O-22: *Measuring the bad weather right – Tales about the measurement challenges in snow storms and the onset of heavy rain events from two sites in Norway* Mareile Wolff, NMBU
15.00 – 15.25	**Short presentations session (1)**
	P-10: *Recent normative developments on the calibration of non-catching precipitation measuring instruments* Luca Lanza, University of Genova
	P-14: *Reference rainfall measurements at the WMO Lead Centre "B. Castelli" in Vigna di Valle (Italy)* Arianna Cauteruccio, University of Genova
	O-27: *The wind-induced bias of non-catching precipitation measurement instruments* Enrico Chinchella, University of Genova
	P-99: *Metrological aspects of a humidity calibrator* Adam Krovina, MicroStep-MIS
	P-98: *Air Temperature Calibration System (ATCS): Development of an ATC-sub chamber for air temperature measurements in climate and environmental chambers* Christina Hofstätter-Mohler, BEV
15.25 – 15.45	**Remote sensing** **chair F. Madonna**
15.25 – 15.40	O-6: *Calibration and validation of FengYun satellite thermal infrared channels using unmanned surface vehicle at CRCS Lake Qinghai* Yong Zhang, National Satellite Meteorological Center, China
15.40 – 15.55	O-34: *Metrological traceability – provided by PTB for remote sensing, atmospheric and ocean measurements* Olav Werhahn, PTB (pre-recorded)
15.55 – 16.30	**Coffee break**
16.30 – 18.00	**Round table** ***Identify open issues and improve cooperation towards the new MeteoMet project***
	End of day 2

Thursday 28	Stupinigi Palace: Sala Camini (Fireplaces hall)
9.00 – 9.30	**Short presentations session (2)**
	P-15: *Measurement of turbulent fluxes over mountainous complex terrain* Alessio Golzio, University of Turin
	P-1: *The importance of using sensors with known measurement uncertainty at high-elevation sites: the freeze-thaw cycles* Guido Nigrelli*, CNR-IRPI *Andrea Merlone presenting
	P-18: *Accuracy evaluation method of meteorological observation data based on measurement uncertainty* Zeqiang Bian, Meteorological Observation Center, China Meteorological Administration

	P-13: *Present state and development perspectives of meteorological network for eastern Poland wetland ecosystem* Kamil Szewczak, Institute of Agrophysics, Polish Academy of Sciences
	P-9: *Study on the uncertainty assessment of the radiosonde meteorological parameters calibration* Xiaozhu Chi, Meteorological Observation Center, China Meteorological Administration
9.30 – 10.30	**Ocean** **chair M. Sega**
9.30 – 9.45	**Invited lecture**: *Uncertainty in Oceanographic measurements* Christoph Waldmann, University of Bremen
9.45 – 10.00	O-37: *Tracking a moving target – sea level* Jane Warne, Bureau of Meteorology, Australia
10.00 – 10.15	O-8: *Characteristics of a drifting buoys reference network for SST measurement* Marc Le Menn, SHOM
10.15 – 10.30	O-29: *Metrological challenges for the monitoring of the partial pressure of CO_2 in the marine environment* Francesca Rolle, INRiM
10.30 – 10.45	**Short presentations session (3)**
	P-11: *Temperature profiles of XBTs and ARGOs intercompared with ship-based CTDs: some further considerations about their metrological comparability in the Mediterranean Sea* Giancarlo Raiteri, ENEA
	P-12: *Updated uncertainties in XBT measurements in Central-Western Mediterranean Sea from in-situ comparisons (2001-2017)* Franco Reseghetti, ENEA
	O-31: *Challenges and strategies for overcoming radiative influence on thermometers in air* Laura Bevilacqua*, NPL *Stephanie Bell presenting
10.45 – 11.15	**Coffee break**
11.15 – 11.40	**Short presentations session (4)**
	P-17: *Analysing the dispersion of air temperature measurements when the thermometers are exposed to ambient conditions* Natalì Aranda, Politecnico of Torino
	P-19: *Low uncertainty calibration method of temperature sensors in air* Miruna Dobre, SMD
	P-4: *Research and application of error calibration methods for HMP155 humidity sensors* Xindi Li, Guangdong Meteorological Data Center
11.40 – 12.10	**Chemistry** **chair F. Durbiano**
11.40 – 11.55	O-9: *Towards the development of atmospheric carbon dioxide Certified Reference Materials at known isotopic composition* Michela Sega, INRiM
11.55 – 12.10	O-41: *EOV O_2 calibration facility: estimation of the incertitude surrounding the data* Laure Chirurgien, Aix Marseille University/University of Toulon
12.10 – 12.35	**Short presentations session (5)**
	P-6: *Evaluation of measurement uncertainty of evaporation sensors in automatic weather stations using Monte Carlo method* Mingming Wei, Meteorological Observation Center of Jiangxi Province, China
	P-3: *Studies on the effect of air ventilation on temperature sensor uncertainty* Sunghun Kim, KRISS
	P-8: *Building influence on air temperature measurements: siting classification* Carmen Garcia Izquierdo, CEM

	P-7: *Amateur weather station compared with operational instrumentation of Meteorological Service on mountain environment* Samuel Buisan, AEMET
	P-2: *Calibration and uncertainty evaluation of radiosonde thermistors in a climate chamber for accurate temperature measurements in upper air* Young-Suk Lee, KRISS
12.35 – 14.00	**Lunch at Stupinigi**
	Introduction to scientific visit
14.00 – 14.30	*A GSRN-affiliated research facility* Andrea Merlone (INRiM) Welcome from hosts • Luigi Chiappero (Ente Parchi Reali president) • Alessandro Azzolina (city of Nichelino councillor to ecology and education)
	Scientific and cultural visit
14.30 – 14.45	Bus to Scientific visit
14.45 – 16.00	INRiM Climate Reference Station Research site (with greetings by city of Nichelino mayor Giampiero Tolardo)
16.00 – 16.15	Bus to Stupinigi Palace
16.30 – 18.00	Guided tours to Stupinigi Palace and Park
18.30	Bus to Cascina Gorgia
19.00 – 22.00	**MMC Social dinner at Cascina Gorgia**
22.00 – 22.15	Bus back to Tram n. 4 final stop
	End of day 3

Friday 29	Stupinigi Palace: Sala Camini (Fireplaces hall)
9.00 – 10.15	**Thermometers** **chair Y.-G. Kim**
9.00 – 9.15	O-30: *Study of radiative effects on thermometers in air in calibration environments* Stephanie Bell, NPL
9.15 – 9.30	O-2: *Climate reference station thermometer characterization* Peter Pavlasek, SMU
9.30 – 9.45	O-5: *A novel method for Callendar-Van Dusen regression of temperature calibration points* Graziano Coppa, INRiM
9.45 – 10.00	O-13: *Intercomparison of thermometers and radiation shields in polar climate. COAT project* Carmen Garcia Izquierdo, CEM
10.00 – 10.15	O-23: *Optimization and characterization of a solar radiation shield design* Davide Botturi, University of Brescia
10.15 – 10.45	**Coffee break**
10.45 – 11.40	**Networks and services** **Chair P. Pavlasek**
10.45 – 11.00	O-32: *Meteonetwork: weather data by citizen-scientists* Alessandro Ceppi, Meteonetwork
11.00 – 11.15	O-15: *Air temperature renewal activities in the Meteorological Service of Canada* Jeffery Hoover, Environment and Climate Change Canada
11.15 – 11.25	O-20: *Evaluation of reliability and use of data from sensors on board of vehicles in meteorology and environmental observations*

	Marcio Santana*, Instituto Nacional de Pesquisas Espaciais (INPE) *Graziano Coppa presenting
	WMO Pre-closing remarks
11.25 – 11.40	*O-90: WMO Rolling Review of Observational Requirements - What role metrology community could play?* Krunoslav Premec, WMO
11.40 – 12.00	**MMC Closing**
	End of day 4

Saturday 30	**Visit to Bossea caves**
8.30	Meeting point at tram n. 4 final stop
8.40 – 10.00	Bus trip to Bossea
10.00 – 10.30	Welcome and coffee – Short introduction to the scientific research and measurements at Bossea caves.
10.30 – 12.30	**Visit to the caves and underground laboratories**
12.30 – 12.50	Bus to Restaurant
13.00 – 14.30	**Lunch**
14.30 – 16.00	Bus back to Torino
	End of day 5

SUMMARY

CONFERENCE PARTNERS

AIR TEMPERATURE

SOIL MOISTURE

RADIOSONDES AND HUMIDITY

INTERLABORATORY COMPARISONS

PRECIPITATION

SHORT PRESENTATIONS SESSION (1)

REMOTE SENSING

SHORT PRESENTATIONS SESSION (2)

OCEAN

SHORT PRESENTATIONS SESSION (3)

SHORT PRESENTATIONS SESSION (4)

CHEMISTRY

SHORT PRESENTATIONS SESSION (5)

THERMOMETERS

NETWORKS AND SERVICES

WMO PRE-CLOSING REMARKS

CONFERENCE PARTNERS

Tuesday 26th 15:15 to 16:15

Session Chair: Andrea Merlone

Papers

O-99 THE GCOS SURFACE REFERENCE NETWORK

O-33 MEASUREMENT REQUIREMENTS FOR A GLOBAL CLIMATE SURFACE REFERENCE NETWORK

O-35 PROJECT SOMMET – METROLOGY FOR MULTI-SCALE MONITORING OF SOIL MOISTURE

O-97 THE MINKE PROJECT – METROLOGY FOR INTEGRATED MARINE MANAGEMENT AND KNOWLEDGE-TRANSFER NETWORK

O-99: THE GCOS SURFACE REFERENCE NETWORK

Tilman Holfelder, Deutscher Wetterdienst (DWD), Germany
Sarah Gallagher, Met Éireann, Ireland

O-33: MEASUREMENT REQUIREMENTS FOR A GLOBAL CLIMATE SURFACE REFERENCE NETWORK

Andrew Harper, National Institute of Water and Atmospheric Research (NIWA), New Zealand

An aim of the GCOS Surface Reference Network (GSRN) is to provide sustained reference quality observations, with full measurement traceability and evaluated uncertainty, on a global scale (on land).
Reference quality observations are based on measurements directly traceable to the International System of Units (SI) standards and include full documentation and evaluation of all uncertainty components.
For the Pilot phase, measurement requirements were defined for the mandatory variables of Air temperature and Precipitation and their associated quantities of influence (AQI) such as solar radiation, relative humidity, and wind. Requirements for additional recommended variables such as Surface radiation budget and pressure including AQIs have also recently been drafted.
There are certain aspects of the science behind some of the technology performing the measurements and components of uncertainty that are well established and well understood. However, there are many others that have been included in the requirements that still require work in terms of studies in the field and laboratory, and theoretical research.
The process for specifying the measurement requirements for the GSRN and components of uncertainty is presented, together with a panorama of open issues still requiring investigations.

O-35: PROJECT SOMMET – METROLOGY FOR MULTI-SCALE MONITORING OF SOIL MOISTURE

Miroslav Zboril, Physikalisch-Technische Bundesanstalt (PTB), Germany

Soil moisture is one of the Essential Climate Variables as defined by the WMO Global Climate Observing System. Soil moisture influences agriculture, forestry, groundwater recharge, flood development, weather, climate, and greenhouse gases emission in the landscape. Several soil moisture observation systems exist on multiple scales, however, poorly harmonized due to the lack of interlinks. There is a need to establish the chain of traceability, the metrological assessment of uncertainties and the harmonisation of soil moisture measurements within the hydrological cycle, on multiple scales ranging from point-scale sensors to satellite remote sensing techniques. In addition, there is an urgent need for real-time, continuous, high-quality, high-resolution and metrologically traceable and harmonised data on soil moisture. Such data are needed to optimise water management strategies as adaptation measures as well as climate change monitoring, modelling and mitigation.

To address these needs, the project SoMMet (Soil Moisture Metrology) has been set up in the framework of the European Partnership on Metrology of EURAMET. The aim of the project is to develop sound metrological tools and establish a metrological foundation for soil moisture measurement methods on multiple scales, ensuring the traceability and harmonisation. On the point scale (10^{-1} m – 10^{1} m), novel primary and secondary standards of humidity measurement will be developed specifically for soil samples, enabling reliable characterization of soil moisture sensors. On the intermediate range (10^{2} m – 10^{3} m), the metrological basis of the cosmic-ray neutron sensing (CRNS) method will be established, in laboratory and outdoor conditions. On the large scale (10^{3} m – 10^{4} m), satellite-based remote sensing techniques will be utilized to derive the soil moisture products. Based on dedicated comparison measurement campaigns, tools for cross-disciplinary harmonisation of the individual methods will be developed. Furthermore, soil moisture data fusion approaches will be researched, aiming 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.

The project consortium consists of nine National and Designated Metrology Institutes and nine research institutions. It will liaise with other projects and networks currently dealing with soil moisture monitoring and open issues of missing soil moisture harmonisation. 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.

O-97: THE MINKE PROJECT – METROLOGY FOR INTEGRATED MARINE MANAGEMENT AND KNOWLEDGE-TRANSFER NETWORK

Rajesh Nair, Istituto Nazionale di Oceanografia e di Geofisica Sperimentale (OGS), Italy
Jaume Piera, Consejo Superior de Investigaciones Científicas (CSIC), Spain

The interaction between Man and the Ocean can be traced to the dawn of human civilization. Today, this ancient link has become a truly existential one, and universally acknowledged as such, as evidenced by the many global initiatives like the UN's "2030 Agenda for Sustainable Development" and "Decade of Ocean Science for Sustainable Development" (2021-2030) as well as innovative socio-economic concepts like the "blue economy" and "blue growth".

Facing the growing challenges posed by a rapidly "transitioning" planet where more than 70% of the surface is covered by oceans will require very reliable measurements with assured long-term usability, traceability, and comparability. Without such measurements, the capacity for qualified and informed decision-making will be severely handicapped, endangering any serious attempts to deal with the rapidly and constantly evolving global environment.

Seeing this need, a new European project called MINKE (Metrology for integrated marine management and knowledge-transfer network; https://minke.eu/) has been launched recently. Its aim is to try to lay down the foundations of a workable framework for making measurements coming from Ocean & Coastal Observing Systems more robust from the metrological perspective. The four-year project, funded under the EU's Horizon 2020 Call entitled "Integrating and opening research infrastructures of European interest" (H2020-INFRAIA-2020-1), began on 01 April 2021 and is set to end on 31 March 2025.

The overall goal of MINKE is to integrate key European marine metrology research infrastructures, and to coordinate their use and development working together with stakeholders such as marine research organisations, instrument manufacturers, the international metrology community, academia, industry, and civil society. The project is proposing an innovative "data quality" scheme for marine data that is multidimensional in character, considering not only "accuracy" but also other data dimensions such as "completeness", for example.

Covering all the relevant scientific fields and a diversity of marine ecosystems, MINKE is trying to build a lasting regional-scale network that will be able to provide the different actors and players involved in marine observing activity with easy access to high quality services and resources for their metrological needs.

Specifically, MINKE is seeking to:

- Build a crosscutting community involving mainstream Metrology and Oceanography to improve the reliability and usability of marine measurements, particularly in the long-term;
- Build a unified platform to help coordinate and promote research and training in marine metrology in Europe;
- Establish common guidelines for developing and/or standardizing measurand definitions, instrument calibration procedures and reference materials for key marine observables (EOVs, ECVs and the like);

- Establish and share recommendations on Best Practice in relation to reference materials and instrument calibration procedures for key marine observables (EOVs, ECVs and the like);
- Explore empirical approaches to assist in the estimation of uncertainty for marine measurements with an emphasis on applications in the field, including the growing sphere of participatory environmental monitoring;
- Establish a specific vocabulary for measuring in the marine environment based on broader existing knowledge (GUM, VIM);
- Establish links to, and engage with, NMIs and the BIPM in the specific domain of measurement in the marine environment.

AIR TEMPERATURE

Monday 15:15 to 16:15

Session Chair: Andrew Harper

Papers

O-36 AIR TEMPERATURE – DEFINING THE MEASURAND

O-05 SO WHAT IS "AIR TEMPERATURE"?

O-07 METROLOGICAL VALIDATION OF THE 48.8 °C EUROPEAN EXTREME AIR TEMPERATURE RECORD

O-19 THE AIR TEMPERATURE METROLOGY EU PROJECT

O-36: AIR TEMPERATURE – DEFINING THE MEASURAND

Stephanie Bell, National Physical Laboratory (NPL), United Kingdom

It is a well-known saying that a thermometer "measures its own temperature". In air, this means that a thermometer with internal self-heating and radiative exchange with wider surroundings will routinely not indicate the true air temperature. This leads us to ask whether we should measure true air temperature; how we can measure true air temperature; and how the measurand "air temperature" can be defined.

In this presentation, the definition of air temperature is discussed in terms of temperature as a general concept, air as a medium, and the idea of the measurand. Practical issues in air temperature measurement are noted, which include radiative effects, instrumental effects such as stem conduction and electrical self-heating, and other problems in real-world observing conditions: for example, condensation. The presentation will touch on the notion of an ideal thermometer, and how the characteristics of real thermometers can approach this. Special consideration will be given to the definition of the air-temperature measurand in meteorology.

O-28: DEVELOPING BEST ESTIMATES OF THE ATMOSPHERIC STATE FROM UPPER AIR MEASUREMENTS

Jane Warne, Bureau of Meteorology (BoM), Australia
Ian Dollery, Bureau of Meteorology (BoM), Australia
Virginia Mazzini, Bureau of Meteorology (BoM), Australia
Dallas Benbow, Bureau of Meteorology (BoM), Australia
Michael Butcher, Bureau of Meteorology (BoM), Australia
Ronald Harwood, Bureau of Meteorology (BoM), Australia

Temperature in the real world is complex. Change a single element in the measurement system from the sensor to the length of grass around the station, sampling method, shielding, algorithms, ventilation or the colour of the screen and you have a different measure of air temperature. Most importantly these impacts are seldom step changes; they often involve dynamic variations correlated with multiple secondary influences. So what is “temperature” in a real world?

The Australian Bureau of Meteorology is amid a large program of work to uplift its observation systems. Of particular importance is changes to the surface network, including replacing 700+ automated weather station logging equipment, screens, and some sensors.

To manage these changes the Bureau is undertaking parallel studies to determine the impacts at the 109 climate sites, in line with WMO Guidance.

This paper presents details of the field and laboratory test design undertaken so far in preparations for this continental scale experiment. A component analysis approach has been undertaken to identify potential sources of impact including algorithms, measurement systems, sensors, and siting. Using this analysis, a range of additional tests; measurements are being incorporated into the study to assist in quantification of the impacts of system changes including siting.

O-95: METROLOGICAL VALIDATION OF THE 48.8 °C EUROPEAN EXTREME AIR TEMPERATURE RECORD

Chiara Musacchio, Istituto Nazionale di Ricerca Metrologica (INRiM), Italy
Andrea Merlone, Istituto Nazionale di Ricerca Metrologica (INRiM), Italy
Graziano Coppa, Istituto Nazionale di Ricerca Metrologica (INRiM), Italy
Luigi Pasotti, Servizio Informativo Agrometeorologico Siciliano (SIAS), Italy
Blair Trewin, Bureau of Meteorology (BoM), Australia
Randall Cerveny, Arizona State University (ASU), United States of America

A maximum temperature of 48.8 °Celsius was purportedly recorded for the automated station in Siracusa Contrada Monasteri, on the island of Sicily, Italy, on 11 August 2021. A World Meteorological Organization ad-hoc evaluation committee was assembled to assess the possibility that the Sicily temperature was the highest recorded temperature in WMO Region VI (Continental only).

Alongside a detailed review of the site considerations and of the regional synoptic weather conditions, in charge of climatologists, the Istituto Nazionale di Ricerca Metrologica was asked to conduct a detailed metrological characterization of the instrument that measured the record.

The study was made at the INRIM Applied Thermodynamics Laboratories. The activities involved testing and calibration of the sensor with specific validation of reading at 48.8 °C. A dedicated analysis was conducted to evaluate quantities of influence on the sensor, solar shield and data-logger with a focus on the solar radiation effect on the instrument's accuracy and the evaluation of the sensor's time constant. Tests were conducted reproducing the same configuration, cabling and recording conditions as those set at the time of the extreme temperature occurrence.

The present work describes the procedures, the equipment involved, the results and evaluation of measurement uncertainty associated to the extreme value recorded.

O-94: ATM EURAMET PROJECT 1459 – INTERLABORATORY COMPARISON OF METHODS OF CALIBRATION

Åge Andreas Falnes Olsen, Justervesenet (JV), Norway

Air temperature measurements are widely used, from industrial applications in precision machining, via environmental laboratory control in precision mass and length metrology, to widespread weather and climate monitoring. Despite their ubiquitous use, air thermometers can be difficult to calibrate precisely. This is in part because many thermometers intended for air use are not amenable to immersion in liquid, which forces the calibration to take place in e.g. climate chambers, with much larger uncertainty. However, the heat exchange between thermometer and air represents a physical challenge, particularly for applications which require high precision.
The Technical committee for thermometry, TC-T, of Euramet launched an interlaboratory comparison (ILC) of methods of air thermometer calibration in 2019. The purpose was to explore further how traceability for air thermometers is best ensured. The ILC had 26 participating institutes in Europe, all of them NMIs or DIs. Two participants reported results for more than one setup and the total number of reports received were 29. The participants measured the electrical resistance of 8 different thermometers at up to 8 different temperatures, ranging from -80 °C to 60 °C. This provided in excess of 1600 data points. Participants reported their measured reference temperature with associated uncertainty, and the measured resistance with associated uncertainty. In addition, they were encouraged to carry out various characterisation experiments to map the influence of environmental variables such as relative humidity and pressure. The circulating probes were carefully characterised and calibrated prior to circulation and afterwards, enabling a direct assessment of altered characteristic curves. Participants used a number of different setups, for instance straightforward climatic chambers, climatic chambers with shields to reduce irradiation effects, subchambers inside climatic chambers, and in some cases liquid bath immersed enclosures.
The results showed that some of the probes drifted substantially during circulation, in the worst case by 1.5 °C, with a more typical drift of a few 100 mK. The thermometers were tested at 0 °C or the triple point of water (0.01 °C) by all participants, but these tests did not reveal systematic trends for any of the probes. Hence it was not possible to evaluate and compensate for drift in the analysis of the data. Instead, a consensus value was computed using the Der-Simonian Laird method, which allows a random and unknown variation between laboratories. The consensus value uncertainty is distinctly temperature dependent, with a minimum around 20 °C. Due to the large instability of the traveling standards it was not surprising that the data was inconsistent in many cases. However, some observations were possible to extract, such as: (i) data were more consistent at temperatures above 0 °C; (ii) the most prominent contribution to uncertainty is uniformity. Despite this, there is no obvious correlation between overall consistency (using a χ^2 assessment) and the magnitude of this contribution.
The full report from the comparison is available on Zenodo at DOI:10.5281/zenodo.8410449, and the data can be accessed from DOI:10.5281/zenodo.8409783.

MMC Torino 2023

METROLOGY FOR METEOROLOGY AND CLIMATE

SOIL MOISTURE

Wednesday 9:00 to 10:30

Session Chair: Stephanie Bell

Papers

O-10 LARGE-FOOTPRINT EVALUATION OF SOIL MOISTURE AND SNOW-WATER EQUIVALENT BY A SINGLE FINAPP COSMIC-RAY NEUTRON SENSOR

O-17 TOWARDS A STANDARDIZED GROUND SOIL MOISTURE NETWORK OVER ITALY BASED ON COSMIC-RAY NEUTRON SENSORS

O-16 COMPARING REMOTE SENSING AND COSMIC-RAY NEUTRON SENSING FOR SOIL SOISTURE ESTIMATION IN NORTHERN ITALY

O-24 STAKEHOLDER SURVEY ON SOIL MOISTURE MEASUREMENTS – RESULTS FROM AN ONLINE QUESTIONNAIRE

O-39 SI-TRACEABLE CALIBRATION FACILITIES FOR POINT-SCALE SOIL-MOISTURE SENSORS

O-10: LARGE-FOOTPRINT EVALUATION OF SOIL MOISTURE AND SNOW-WATER EQUIVALENT BY A SINGLE FINAPP COSMIC-RAY NEUTRON SENSOR

Enrico Gazzola, Finapp Srl, Italy
Luca Stevanato, Finapp Srl, Italy
Stefano Ferraris, Politecnico di Torino / Università di Torino, Italy
Mauro Valt, Agenzia Regionale Protezione Ambiente Veneto (ARPAV), Italy
Alessio Gentile, Politecnico di Torino / Università di Torino, Italy
Davide Gisolo, Politecnico di Torino / Università di Torino, Italy
Luca Morselli, Finapp Srl, Italy
Marcello Lunardon, Finapp Srl, Italy / Università di Padova, Italy
Barbara Biasuzzi, Finapp Srl, Italy
Stefano Gianessi, Finapp Srl, Italy

As droughts periods and extreme weather events become more frequent, it is of paramount importance to expand the ability to monitor water-related environmental parameters like Soil Moisture (SM) and Snow-Water Equivalent (SWE). Cosmic Ray Neutron Sensing (CRNS) is bridging the scale gaps that result from existing technologies: namely point-scale measurements, that are hardly representative of large areas, and space-borne remote sensing, that is hardly representative of the in-depth variability of snow layers or the water content in soil.
CRNS is based on the fact that neutrons coming from space can penetrate tens of cm of soil or hundreds of snow, where they strongly interact with hydrogen, of which water and snow are rich, such as valuable information can be obtained by counting them. Finapp developed and tested a custom scintillator for neutron detection, obtaining a new kind of CRNS probe, light, compact, and easy to install. After proper calibration, our CRNS probe allows to obtain either SM or SWE from the neutron counts, providing a real-time, direct evaluation in a large footprint (up to dozens of hectares), in continuous and autonomous operation regime.
We present the outcome of tests performed across different seasons in 2022 and 2023 at two experimental sites on the Italian Alps: Colle del Nivolet in Piemonte region and Cima Pradazzo in Veneto region, where saturation and footprint effects were observed, respectively, for the measurment of SWE. The possibility of a dual use of a single probe mounted above ground, switching between the evaluation of SWE and SM across the year, is showcased [Fig. 1]. This configuration is suitable for mid-mountain locations and offers to maximize the monitored area (snow at distances up to 200 m was detected around Cima Pradazzo) while maintaining a reasonable SWE saturation level (reached at about 250 mm SWE at the Nivolet site).

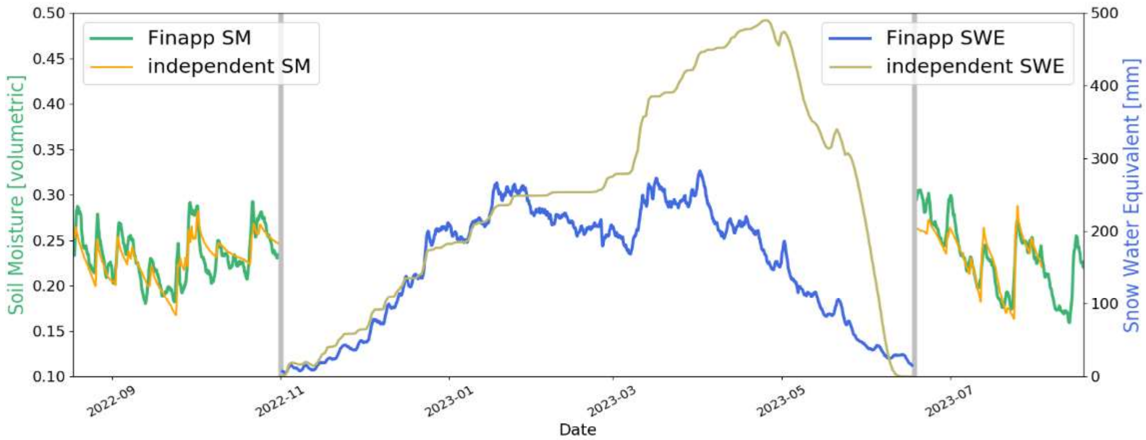


Figure 1. Demonstration of the dual-use of a Finapp probe at the Colle del Nivolet site and the reach of saturation for SWE. Independent trends of SM and SWE provided by TDR measurements and nivometer data + snowpack modelling, respectively.

The above capabilities open to a range of on-field applications related to monitoring climate evolution also in remote areas, possibly evaluating risks correlated to either the SM or SWE amounts (fire, landslides, avalanches, floodings), and strategically assessing water resources for agriculture, industry and hydroelectric power generation.

O-17: TOWARDS A STANDARDIZED GROUND SOIL MOISTURE NETWORK OVER ITALY BASED ON COSMIC-RAY NEUTRON SENSORS

Gabriele Baroni, Università di Bologna, Italy

Soil moisture monitoring has been recognized to play a relevant role for a better understanding of the hydrological processes at the land surface and for supporting water management. To this end, in situ point-scale soil moisture measurements have been promoted and implemented in several areas all around the World. However, the use of different techniques, intercalibration, traceability and maintenance efforts are, among others, some of the aspects that have limited the implementation of ground soil moisture networks in long-term observation systems.

In this contribution we present the activities conducted towards the implementation of ground long-term soil moisture networks addressing some of the challenges described above. Specifically, the use of cosmic-ray neutron sensors for soil moisture estimation will be introduced. Advantages and disadvantages in comparison to other approaches will be highlighted. The sensors available on the markets will be briefly described together with the current laboratory initiatives for their characterization within the project SoMMet (https://www.sommet-project.eu/home). The field activities and the data processing for a standardized soil moisture estimation will be further discussed. Finally, the current development of a regional soil moisture network in collaboration with the Environmental Protection Agency in Italy will be presented and discussed. This network will put the basis for, among others, drought monitoring, improving flood forecasting and risk assessment, comparison with remote sensing and with land surface models.

O-16: COMPARING REMOTE SENSING AND COSMIC-RAY NEUTRON SENSING FOR SOIL SOISTURE ESTIMATION IN NORTHERN ITALY

Sadra Emamalizadeh, Università di Bologna, Italy
Alessandro Pirola, Università di Bologna, Italy
Stefano Gianessi, Università di Bologna, Italy
Luca Stevanato, Università di Bologna, Italy
Cinzia Alessandrini, Università di Bologna, Italy
Gabriele Baroni, Università di Bologna, Italy

Accurate assessment of soil moisture is crucial for understanding hydrological processes and efficient water resource management, particularly in agricultural areas. In this study, we present a comparison between remote sensing techniques, such as the Copernicus Soil Water Index (SWI), with ground non-invasive Cosmic-Ray Neutron Sensors (CRNS). The assessment is conducted across four agricultural sites that reflect different crops and land use in Northern Italy. The data collected spans over the growing season for the year 2021 covering wet and dry periods. Soil moisture is also estimated at various depths using SWI at 1 km resolution. To establish robust comparisons, these products are matched to ground CRNS soil moisture estimation. CRNS sensors provide continuous and non-invasive monitoring capabilities, allowing for accurate and representative soil moisture observations over a footprint of around 5 ha. In addition to soil moisture data, we incorporate the normalized difference vegetation index (NDVI) to investigate its correlation with soil moisture trends. NDVI serves as an indicator of vegetation vigor and biomass, offering insights into the relationship between vegetation dynamics and soil water availability. The presentation will introduce the importance of soil moisture assessment in agricultural contexts, addressing challenges associated with spatial and temporal variability. We will outline the methodology, including the acquisition and preprocessing of remote sensing data, CRNS measurements, and NDVI values. The results will present the comparative analysis between CRNS and SWI at different depths. We will discuss the implications of these findings and explore correlations between NDVI and soil moisture trends, providing insights into vegetation-soil moisture interactions. Conclusions will highlight the performance and reliability of remote sensing data for soil moisture estimation in agricultural areas. We will further discuss the benefits of integrating remote sensing and CRNS techniques for comprehensive soil moisture analysis. Future developments may involve focusing on investigating harmonization and data fusion of ground and remote sensing products to improve soil moisture estimation. The presentation contributes to our understanding of soil-water dynamics in agricultural areas, enabling informed water resource management decisions in Northern Italy and beyond.

O-24: STAKEHOLDER SURVEY ON SOIL MOISTURE MEASUREMENTS – RESULTS FROM AN ONLINE QUESTIONNAIRE

Reidun Anita Bergerud, Justervesenet (JV), Norway
Peter Rothmund, Justervesenet (JV), Norway
Arezoo Taghizadeh-Toosi, Dansk Teknologisk Institut (DTI), Denmark
Henrik Kjeldsen, Dansk Teknologisk Institut (DTI), Denmark
Anna Balenzano, Consiglio Nazionale delle Ricerche – Istituto per il Rilevamento Elettromagnetico nell'Ambiente (CNR-IREA), Italy
Gabriele Baroni, Università di Bologna, Italy
Sebastian Rothermel, Universität Potsdam, Germany

An online questionnaire was established in connection to the research project 21GRD08 SoMMet - Metrology for multi-scale monitoring of soil moisture. The project 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 objectives of the survey were to define the methodologies and approaches needed for different soil moisture measurements by end-user communities. This included parameter range required uncertainties and available measurements, data processing and documentary standards as well as a review of available methods.
The questions were structured in the following themes: general, point scale, intermediate scale, remote sensing from satellite and data fusion, and were online in 2 months in early spring 2023. The questionnaire received 65 answers during this short period of time, and the respondents were mostly from agriculture, water resource management and hydrology communities. All scales received input from the respondents, 2/3 answered both point scale and intermediate scale, while 30 people gave input to the remote sensing part.
Soil moisture observations are not always well defined and the answers from the questionnaire gave good input to proceed in the project. Instrument failure, inhomogeneities in the soil and unknown or inappropriate measurement accuracy are issues the end users have to deal with. Likewise, that clear calibration protocols and standardisation of in situ soil moisture measurements by building a traceability diagram is strongly needed. The respondents asked for more information about satellite product, standardisation of data formats and validation of products.
The survey confirmed that a joint effort among different soil moisture communities is needed for high-quality (metrologically traceable) and harmonised measurements of soil moisture on multiple scales.
Results from the survey will be presented on the project website: https://www.sommet-project.eu/home

O-39: SI-TRACEABLE CALIBRATION FACILITIES FOR POINT-SCALE SOIL-MOISTURE SENSORS

Jan Nielsen, Dansk Teknologisk Institut (DTI), Denmark

SI-traceable metrology for water content in materials has been partly established over the last decade. The Danish Technological Institute (DTI) has established a reference method for measuring the water content of materials based on evolved water vapor detection [1].

Such reference measurement methods are still needed for soil, e.g. in agricultural systems. Traditionally, reference measurements for water determination in soil are based on general Loss-on-Drying (LoD) methods, but the reliability of these methods used with soil is questionable as it detects both water and available volatile organic components.

We will present how in-situ SI-traceable calibration of point-scale soil moisture sensors will be developed and validated in the frame of the project "21GRD08 Metrology for multi-scale monitoring of soil moisture". The presentation will provide details of the reference method for specific soils and discuss the design considerations and requirements for a revised LoD-based measurement standard that can overcome some of the disadvantages of traditional LoD.

RADIOSONDES AND HUMIDITY

Wednesday 11:00 to 12:15

Session Chair: Yves-Alain Roulet

Papers

O-11 RECENT ACHIEVEMENTS AND CURRENT RESEARCH WITHIN THE GCOS REFERENCE UPPER-AIR NETWORK (GRUAN)

O-3 TESTING RADIOSONDE HUMIDITY SENSORS BY LABORATORY SETUPS AND ITS APPLICATION TO SOUNDINGS

O-18 ASSESSMENT OF THE INRIM LOW FROST-POINT GENERATOR AND ANALYSIS OF THE UNCERTAINTY COMPONENTS BETWEEN -100 °C AND -20 °C

O-7 IMPROVING RADIOSONDE TEMPERATURE MEASUREMENTS ABOVE CLOUD LAYERS USING A DUAL THERMISTOR RADIOSONDE (DTR)

O-26 THE HEMISPHERICAL BLACKBODY (HSBB), A NEW REFERENCE FOR PYRGEOMETER-BASED MEASUREMENTS OF LONGWAVE DOWNWARD RADIATION

O-11: RECENT ACHIEVEMENTS AND CURRENT RESEARCH WITHIN THE GCOS REFERENCE UPPER-AIR NETWORK (GRUAN)

Fabio Madonna, Università di Salerno / Consiglio Nazionale delle Ricerche – Istituto di Metodologie per l'Analisi Ambientale (CNR-IMAA), Italy
Ruud Dirksen, Deutscher Wetterdienst (DWD), Germany
Peter Thorne, Maynooth University, Ireland
WG GRUAN

Quality and biases of radiosounding observations strongly vary with sensor type, altitude level, and over time. Many previous studies described the adjustment of historical radiosonde temperature measurements to construct Climate Data Records (CDRs) through applying data homogenization techniques. These studies have used a broad range of approaches enabling the exploration of structural and parametric uncertainties. However, none of these CDRs is fully homogeneous and the estimates are often provided without an estimation of the measurement uncertainties.
To meet the need for homogeneous and fully traceable upper-air measurements with quantified uncertainties, the GCOS Reference Upper-Air Network (GRUAN) was established to provide reference-quality profile measurements of Essential Climate Variables in the upper atmosphere. GRUAN is providing long-term, high-quality radiosounding data at several sites around the world.
GRUAN data processing starts from the raw data and applies corrections for all known measurement errors (e.g. due to solar radiation, sensor time-lag, sonde pendulum motion, etc.), each with a quantified uncertainty contributing to the final uncertainty budget. These corrections are based on extensive characterization under laboratory conditions; full documentation of the corrections and the resulting data product ensures traceability, which is essential for a reference-quality data product.
Several progress have been made in the last few years by GRUAN in providing new reference products for the most recent radiosonde types (RS41, iMS-100, RS-11G) as well as for the GNSS measurements used to retrieve the total column water content. In particular, the GRUAN data products are provided with an improved estimation of the uncertainty budget for the radiosounding products, in terms of characterizing the radiation correction, using laboratory experiments, a radiative transfer model, and ancillary data.
GRUAN research and test activity is also covering the need of continuing measurements of the water vapor profile in the stratosphere using sensitive instruments such as the cryogenic frostpoint hygrometer (CFH). Following the restrictions in several countries on the use of specific cryogens, GRUAN is testing alternative methods to operate chilled mirror instruments which includes alternate coolants or Peltier-based instruments.

O-3: TESTING RADIOSONDE HUMIDITY SENSORS BY LABORATORY SETUPS AND ITS APPLICATION TO SOUNDINGS

Sang-Wok Lee, Korea Research Institute of Standards and Science (KRISS), South Korea

Radiosonde humidity sensors were tested using the upper air simulator (UAS) developed at the Korea Research Institute of Standards and Science (KRISS). To compensate for low-temperature effects, calibration of relative humidity sensors was conducted in the temperature range of -70 °C to +20 °C. The UAS was operated in a two-temperature mode for calibration, where the temperature of the water vapor saturator and that of the test cell containing the radiosondes were independently controlled. In addition, the response time of the sensors was measured to correct for time-lag in the same temperature range. The compensation algorithms obtained by laboratory setups were subsequently applied to the sounding tests. The effects of the calibration and the time-lag correction of humidity sensors in the sounding tests will be discussed. Testing commercial radiosondes by using laboratory setups may enhance the traceability to the International System of Units in the measurement of upper air for meteorology and climate research.

O-18: ASSESSMENT OF THE INRIM LOW FROST-POINT GENERATOR AND ANALYSIS OF THE UNCERTAINTY COMPONENTS BETWEEN -100 °C AND -20 °C

Rugiada Cuccaro, Istituto Nazionale di Ricerca Metrologica (INRiM), Italy
Giulio Beltramino, Istituto Nazionale di Ricerca Metrologica (INRiM), Italy
Rezvaneh Nobakht, Istituto Nazionale di Ricerca Metrologica (INRiM), Italy
Lucia Rosso, Istituto Nazionale di Ricerca Metrologica (INRiM), Italy
Diana Enescu, Istituto Nazionale di Ricerca Metrologica (INRiM), Italy
Vito Fernicola, Istituto Nazionale di Ricerca Metrologica (INRiM), Italy

A low frost-point generator (INRiM 03) operating at sub-atmospheric pressure has been developed at the Istituto Nazionale di Ricerca Metrologica (INRiM) as part of a calibration facility to provide measurement traceability to upper-air sounding instruments. The humidity generator covers the frost-point temperature range from −100 °C to −20 °C and the pressure range from 200 hPa to 1100 hPa. The operating pressure can be adjusted to simulate the atmospheric pressure profile from the ground level to a barometric altitude of more than 12 km. Given the above temperature and pressure range, the generated water vapour amount fraction ranges between $14 \cdot 10^{-9}$ mol mol^{-1} and $5 \cdot 10^{-3}$ mol mol^{-1}.
The system operates with nitrogen as the carrier gas. The gas is first brought to thermal equilibrium by means of a 3-m helically-coiled heat exchanger and then saturated in a single passage through a stainless-steel isothermal saturator. Both the heat exchanger and the saturator are immersed in a high-stability calibration bath. Two calibrated SPRTs, traceable to ITS-90, measure the liquid bath temperature and the frost point temperature as measured in the saturated gas flow, whose difference is less than 5 mK in all working conditions.
Beside an overview of the experimental apparatus, the tests carried out on the generator to evaluate the measurement uncertainty components are discussed. Detailed uncertainty budgets of the generated frost-point temperature and water vapour amount fraction are reported in the whole temperature and pressure range.
The present work has been carried out within the European Metrology Programme for Innovation and Research (EMPIR) project “PROMETH2O - Metrology for trace water in ultra-pure process gases”.
This project (EMPIR 20IND06 PROMETH2O) has received funding from the EMPIR programme co-financed by the Participating States and from the European Union's Horizon 2020 research and innovation programme.

O-7: IMPROVING RADIOSONDE TEMPERATURE MEASUREMENTS ABOVE CLOUD LAYERS USING A DUAL THERMISTOR RADIOSONDE (DTR)

Yong-Gyoo Kim, Korea Research Institute of Standards and Science (KRISS), South Korea

During the daytime, radiosondes deployed above cloud layers may record a temperature reading that is higher than the actual air temperature. This is because the radiosonde is exposed to increased radiation caused by sunlight reflecting off the cloud surface. However, it is difficult to distinguish between the actual temperature increase and this spurious temperature rise when using a single-sensor radiosonde. This is due to the inability to observe the atmospheric conditions above the cloud layer from the ground. One potential solution to this problem is to use a dual temperature sensor radiosonde, known as a DTR, which consists of two thermistors with different emissivity – one white and the other black. The DTR can detect changes in solar radiation in-situ and correct temperature measurements by accounting for the effect of the cloud layer. In this study, we will present experimental results of upper air temperature profiles using a DTR during cloudy daytime and compare them with the irradiance profile measured simultaneously during the same radiosonde sounding test.

O-26: THE HEMISPHERICAL BLACKBODY (HSBB), A NEW REFERENCE FOR PYRGEOMETER-BASED MEASUREMENTS OF LONGWAVE DOWNWARD RADIATION

Moritz Feierabend, Physikalisch-Technische Bundesanstalt (PTB), Germany

The Hemispherical Blackbody (HSBB), which has been developed at the Physikalisch-Technische Bundesanstalt (PTB) in recent years, is a new reference blackbody specifically designed for the calibration of infrared radiometers with a hemispherical acceptance angle such as pyrgeometers, Infrared Integrating Sphere (IRIS) instruments or Absolute Cavity Pyrgeometers (ACP). The HSBB is a transportable reference instrument typically operated in the temperature range from -20 °C to +20 °C. Using the HSBB, it was recently possible to validate the traceability of the established worldwide reference for longwave downward radiation measurements, the Tilted Bottom Cavity BB2007 operated at the Physikalisch-Meteorologisches Observatorium Davos / World Radiation Center (PMOD/WRC) for the World Meteorological Organization (WMO). This comparison underpinned the necessity for a pending scale revision of longwave downward radiation, which was under discussion in the community and which is now on its way following the second session of the Commission for Observation, Infrastructure and Information Systems of the WMO (INFCOM-2).

In order to approve the applicability of the HSBB for upcoming calibration of the above-mentioned radiometer types measuring longwave downward radiation, measurements were performed with varying operating parameters such as different distances between detector and HSBB or different purging rates of the HSBB. These measurements were carried out in cooperation with the German Weather Service (DWD) on site at the DWD Observatory Lindenberg and at PTB. Improved calibration procedures were developed and the results give rise to slightly different acceptance angles of the investigated radiometers which nominally have a hemispherical acceptance angle.

Besides radiometers for measurements of longwave downward radiation, clinical infrared ear thermometers also have large opening angles. As the calibration and testing of these devices is strictly regulated in most countries, high-quality reference blackbodies are required. At PTB, the suitability of the HSBB to act as a reference blackbody for ear thermometer testing has been successfully validated, which is a further critical test for its applicability.

Furthermore, an additional HSBB with an advanced carbon-nanotube-based coating has been put into operation, and direct comparison measurements were successfully performed between both HSBBs. These measurements have rendered both HSBBs suitable for calibration work on site at observatories measuring longwave downward radiation or at PTB.

The mentioned activities were performed within the project Metrology for Earth Observation and Climate 4 (MetEOC4). The project MetEOC4 has received funding from the EMPIR programme co-financed by the Participating States and from the European Union's Horizon 2020 research and innovation programme.

INTERLABORATORY COMPARISONS

Wednesday 12:15 to 12:40

Session Chair: Aleksandra Kowal

Papers

O-4: REFERENCE VALUE ANALYSIS OF INTERLABORATORY COMPARISON IN THE FIELD OF TEMPERATURE, HUMIDITY AND PRESSURE

Xuejing Nan, Meteorological Observation Center, China
Andrea Merlone, Istituto Nazionale di Ricerca Metrologica (INRiM), Italy

Following the Interlaboratory Comparison (ILC) completed in WMO RA VI under the MeteoMet project of Europe, a further ILC focusing on temperature, humidity and pressure of atmosphere of Interlaboratory Comparison was started in WMO RA II, V and VI with the participation of Regional Instrument Center (RIC). The ILC was performed in a round-robin scheme, with a single loop. Every pilot laboratory performed two sets of measurements, at the beginning and at the end of the loop. And the participating laboratories performed their measurements in between. According to the ILC, the reference value for calculation was based on the weighted mean from the pilot laboratories involving two sets of measuring results. In this paper, it is proposed that the reference value for calculation be based on the weighted mean from all laboratories. The two sets of measurement result of pilot laboratories were calculated separately from the larger and smaller values of the claimed uncertainty, named group A and group B. Using the comparison results from each laboratory, two reference values were determined by different algorithms. And the measurement results were evaluated with reference to E_n numbers. Furthermore, the effect of two reference values on the evaluation results were compared to verify the data compatibility between the participating laboratory and the pilot laboratory in terms of the unsatisfying results from some measurement points of the former. The analysis shows that, compared to the calculation method that takes the weighted mean from the pilot laboratories as the reference value, it is more reasonable and equitable to take the weighted mean from all the laboratories as the reference value.

P-93: INTERLABORATORY COMPARISON STATUS COMPARING LABORATORY RESULTS FROM WMO REGIONAL ASSOCIATIONS

Gaber Begeš, Univerza v Ljubljani, Slovenia
Janko Drnovšek, Univerza v Ljubljani, Slovenia
Jovan Bojkovski, Univerza v Ljubljani, Slovenia
Domen Hudoklin, Univerza v Ljubljani, Slovenia
Drago Groselj, Agencija za okolje, Slovenia
Andrea Merlone, Istituto Nazionale di Ricerca Metrologica (INRiM), Italy

This paper presents interlaboratory comparison status comparing laboratory results from WMO regional associations in the field of temperature, humidity and pressure measurements in order to be able to evaluate the proficiency of different national hydrology and meteorology services (NHMS) providing metrology results for climatology observations.
Such ILC concept has already been used in the interlaboratory comparison (ILC), in the field of temperature, humidity and pressure, organized by the WMO Regional Instrument Centre in RA VI (Slovenian Environment Agency) and University of Ljubljana, Faculty of Electrical Engineering, Laboratory of Metrology and Quality, where 18 NHMS's laboratories participated in the ILC including three Regional Instrument Centres (RIC) within METEOMET project. Further on the same concept has been used for region RA II (Asia) and RA V (South-West-Pacific including RIC Tsukuba (Japan), RIC Beijing (China), RIC Melbourne (Australia), RIC Manila (the Philippines)). Currently the same approach is used in RA I (Morocco, Mauritius, Tunisia, Egypt) and RA III (Argentina, Brazil, Colombia, Ecuador, Uruguay).
The interlaboratory comparison is defined by the standard ISO/IEC 17043 as the organization, performance, and evaluation of calibration/test results for the same or similar item by two or more laboratories in accordance with predetermined conditions. In region RA VI laboratories were divided in two loops, in accordance with geographical distribution of participants and in other regions there is only one loop foreseen. Connection between these two loops and thus comparison of the results was evaluated and presented in the WMO Instruments and Observing Methods Report No. 128 and as such present a useful base for comparing also other regionally conduced ILCs. Same procedure and same equipment is used.
The paper presents current status of ILC in other regions. Results from region II and V are already available as WMO IOM report No.134. Measurements in region RA I are finished and report is in preparation. ILC in region RA III is still ongoing and is planned to be finished until April 2024. Results from laboratories around the world will give information on potential influence to climate observations and weather forecast.

PRECIPITATION

Wednesday 14:00 to 15:00

Session Chair: Holger Dörschel

Papers

O-40 DEVELOPMENT OF CALIBRATION FACILITY FOR NON-CATCHING DISDROMETERS

O-25 A RAINDROP SIMULATOR FOR CALIBRATION OF NON-CATCHING PRECIPITATION MEASURING INSTRUMENTS

O-19 THE QUASI-BICENTENNIAL DAILY RAINFALL SERIES OF THE UNIVERSITY OF GENOVA: DATA ANALYSIS AND ACCURACY ASSESSMENT

O-22 MEASURING THE BAD WEATHER RIGHT – TALES ABOUT THE MEASUREMENT CHALLENGES IN SNOW STORMS AND THE ONSET OF HEAVY RAIN EVENTS FROM TWO SITES IN NORWAY

O-40: DEVELOPMENT OF CALIBRATION FACILITY FOR NON-CATCHING DISDROMETERS

Jan Nielsen, Dansk Teknologisk Institut (DTI), Denmark

Precipitation is among the most important meteorological variables for meteorological, hydrological and climate studies. From an operational point of view, non-catching precipitation gauges are attractive, because they require less maintenance compared to the more traditional catching types (e.g. gravimetric or tipping-bucket). Thus, in recent years non-catching precipitation gauges are increasingly adopted in meteorological networks.

Regardless of the growing number of such gauges, calibration procedures and dedicated setups are missing. The result is absence of accuracy, because such devices are not calibrated and consequently their measurements are not traceable to SI units. The reason for this deficiency is probably because non-catching gauges require hydrometeors like those found in real rain for their calibration.

Danish Technological Institute (DTI) is currently developing at setup for test and calibration of non-catching rain gauges. The setup is intended to simulate real rain. That is, it will produce water drops that are similar to those found in real rain in terms of size and velocity. At present, the setup can produce drops with diameters from about 0.2 mm to several mm. Traceability to the SI-unit system is obtained by relating drop size and frequency to water flow and time measurement. As a key feature in this context a volumetric pump is employed and calibrated gravimetrically in the DTI micro-flow laboratory. The drop velocity is determined using a photographic system, and a similar system is employed to map the spatial distribution of the impact points of the drops. A key advantage of the setup is that the non-catching gauges can be calibrated under well-controlled, stable laboratory conditions.

The presentations summarize the initial tests and the validation process of the setup at DTI.

O-25: A RAINDROP SIMULATOR FOR CALIBRATION OF NON-CATCHING PRECIPITATION MEASURING INSTRUMENTS

Enrico Chinchella, Università di Genova, Italy
Arianna Cauteruccio, Università di Genova, Italy
Luca G. Lanza, Università di Genova, Italy

The increasing use of Non-Catching Gauges (NCGs) is driven by the need of high resolution and low maintenance automatic weather stations. The calibration of NCGs is however more challenging than for catching instruments, since hydrometeor characteristics such as particle size and fall velocity must be carefully reproduced to provide the reference precipitation. Currently, no standard calibration procedure for NCGs is available, and manufacturers use internal procedures of which little to no information is often available.

A calibration device has been developed at the University of Genova to generate individual drops and measure them contactless in flight. Drops in the range of 0.5 to 6 mm in diameter are formed at the tip of a calibrated nozzle using a high precision syringe pump. Then, a high voltage power supply creates a large potential difference between the nozzle and a metal ring resulting in the release of the drop. Depending on the drop size and release height, different fractions of the terminal velocity can be achieved. A precision motorised gantry allows for different positions of the gauge sensing area to be sampled. A second gantry aligns the focal plane of a high-resolution camera with the trajectory of the drop. Using speedlights triggered at fixed time intervals, three images of the same drop are captured in a single picture. The shape, size and speed of the drop are determined using photogrammetric techniques once the interval between flashes is known. The instrumental measurement bias is then obtained by comparison with the gauge reading. The drop generation system was validated in a series of laboratory tests against gravimetric cumulative measurements of the released drops.

The rainfall generator was then used to evaluate the performance of different NCGs that use optical principles to sense incoming hydrometeors. Results show significant biases in both the drop size and fall velocity measurements, which propagates on the derivation of the precipitation intensity. Measurements were also found to be affected by the light emitted by the speedlights, requiring dedicated shielding against flashes.

This work was funded as part of the activities of the EURAMET project 18NRM03 “INCIPIT Calibration and Accuracy of Non-Catching Instruments to measure liquid/solid atmospheric precipitation” and was developed as partial fulfilment of the PhD thesis of the first author.

O-19: THE QUASI-BICENTENNIAL DAILY RAINFALL SERIES OF THE UNIVERSITY OF GENOVA: DATA ANALYSIS AND ACCURACY ASSESSMENT

Arianna Cauteruccio, Università di Genova, Italy
Enrico Chinchella, Università di Genova, Italy
Davide Scafidi, Università di Genova, Italy
Gabriele Ferretti, Università di Genova, Italy
Luca G. Lanza, Università di Genova, Italy

The University of Genova maintains a historical series of temperature and rainfall measurements spanning over a period of about two centuries. It was recognised as a long-term observing station by the World Meteorological Organization in June 2021 (Resolution 5 – EC73) for more than 100 years of meteorological observations. The Meteorological Observatory of the University of Genova is operational since January 1st, 1833. The series is uninterrupted, and instruments are positioned, since the starting date of observations, on the terrace of the same University Building, in the historic centre of the town.
The presence of dedicated personnel at the observatory lasted until 1994, when an automatic meteorological station SIAP UM7525 was installed, using the tipping-bucket gravity-based principle with a funnel of 1000 cm^2 and a resolution of 0.2 mm. A tipping-bucket rainfall recorder (SIAP UM8100) had been used before, to write on time charts with daily or weekly duration the sign of each tip. The collector was still of 1000 cm^2 and each step of the pen arm corresponded to 0.2 mm. Each complete up and down stroke of the pen arm therefore sums up to 10 mm of rainfall.
Daily rainfall records are available over the whole observing period, while data are recorded at the temporal resolution of 1 hour from 2002 to July 2021 and 10 minutes since August 2021.
In this work, the quasi-bicentennial daily rainfall series of the University of Genova is analysed to present its main statistical features and observed trends. Although a succession of relatively wet and dry periods out of a significant year-to-year variability is evident, the series does show a quite constant mean value of about 1745 mm/year, at least until the end of the last century. A slight downward trend can be seen, of about 0.24 mm/year, due to a very high value observed in the year 1872 (> 2700 mm). The very last period of observation (about 20 years) shows a significant downward trend with a loss of about 16 mm/year. The observed behaviour is also compared in this work with daily rainfall series from other European locations where a centennial record is available, to show the very local nature of some of the observed features.

O-22: MEASURING THE BAD WEATHER RIGHT – TALES ABOUT THE MEASUREMENT CHALLENGES IN SNOW STORMS AND THE ONSET OF HEAVY RAIN EVENTS FROM TWO SITES IN NORWAY

Mareile Astrid Wolff, Norges Miljø- og Biovitenskapelige Universitet (NMBU), Norway

Facing global change, we do expect changes in the global water cycle. But it's not the global average that will affects people's life. It's the changes in the local water cycle which are important to understand in order to avoid hazards, protect infrastructure, ensure food security and secure access to clean water.
Both numerical weather forecast models and long-term climate models are evolving towards higher resolutions, aiming for more accurate local predictions, but also revealing lots of still unresolved processes, among those, the local water cycle. Accurate measurements with a defined uncertainty are mandatory for improving the physics of those processes in numerical models and for verifying the results.
Measuring a water volume may sound simple. But measuring amounts of water in the pores of a soil or contained in a single rain drop or snow crystal or simply not reaching the measurement bucket due to wind and turbulence are complicated tasks.
In Norway, as a cooperation between the Norwegian University of Life Science and the Norwegian Meteorological institute, two extended measurement sites are operated, focussing on measurement challenges of water related properties in high latitudes:
Haukeliseter – a mountainous location with a WMO approved solid precipitation reference. This site was part of the WMO-solid precipitation intercomparison and data from here contributed to the development of adjustment equations for the wind loss of solid precipitation. Those adjustment functions feature a huge uncertainty, thus the ongoing work is focussing on the role of the precipitation particles microphysics.
Ås - the meteorological field site of Norwegian University of Life Sciences (NMBU) in Ås, about 30 km south of Oslo, was established already 150 years ago, originally to support agricultural education and research. In a current project, the interaction between land and atmosphere were main focus and the field site was extended in 2021 with an eddy covariance tower and a large range of different soil moisture measurements among others to develop a better understanding the water related processes in the ground and lower atmosphere in convective situations.
In this paper, we present the varying measurements from different instruments in challenging weather situations from those two stations and are discussing reasons and plans from our hydrometeorology point of view. We'd like to invite you, the metrology community to join this discussion and plan for projects to work towards to a better description of the uncertainties of our measurements.

SHORT PRESENTATIONS SESSION (1)

Wednesday 15:00 to 15:25

Papers

P-10 RECENT NORMATIVE DEVELOPMENTS ON THE CALIBRATION OF NON-CATCHING PRECIPITATION MEASURING INSTRUMENTS

P-14 REFERENCE RAINFALL MEASUREMENTS AT THE WMO LEAD CENTRE "B. CASTELLI" IN VIGNA DI VALLE (ITALY)

O-27 THE WIND-INDUCED BIAS OF NON-CATCHING PRECIPITATION MEASUREMENT INSTRUMENTS

P-99 METROLOGICAL ASPECTS OF A HUMIDITY CALIBRATOR

P-98 AIR TEMPERATURE CALIBRATION SYSTEM (ATCS): DEVELOPMENT OF AN ATC-SUB CHAMBER FOR AIR TEMPERATURE MEASUREMENTS IN CLIMATE AND ENVIRONMENTAL CHAMBERS

P-10: RECENT NORMATIVE DEVELOPMENTS ON THE CALIBRATION OF NON-CATCHING PRECIPITATION MEASURING INSTRUMENTS

Luca G. Lanza, Università di Genova, Italy
Arianna Cauteruccio, Università di Genova, Italy
Enrico Chinchella, Università di Genova, Italy
Chiara Musacchio, Istituto Nazionale di Ricerca Metrologica (INRiM), Italy
Andrea Merlone, Istituto Nazionale di Ricerca Metrologica (INRiM), Italy

Specific testing and measurement requirements for non-catching instruments used to measure liquid/solid atmospheric precipitation were submitted in October 2017 by CEN TC318 to EURAMET (European Association of National Metrology Institutes) through the cooperation programme between STAIR (the joint CEN-CENELEC strategic Working Group supporting standardization in research and innovation) and EMPIR, the European Metrology Programme for Innovation and Research of EURAMET. The need for research on this subject was also presented at the 3rd STAIR-EMPIR workshop "From metrology research to standardisation", CEN-CENELEC Meeting Centre, Brussels, 10 October 2017.

Indeed, the coverage of the existing EN17277:2019 (still in preparation at that time) is limited to catching gauges, which – due to the presence of the rain collector – can be calibrated using a known flow rate generated in the laboratory as the reference. However, non-catching instruments are increasingly addressed and employed by national weather services, due to the lower maintenance required and unattended operation capabilities. Beyond the new published norm for catching type gauges, traceable instrument calibration methods for non-catching gauges are being developed and could be incorporated into suitable Standards.

The pre-normative joint research project "INCIPIT – Calibration and accuracy of non-catching instruments to measure liquid/solid atmospheric precipitation" (2019-2022) was therefore funded by the European Metrology Programme for Research and Innovation (EMPIR) of EURAMET, including the following partners: INRIM (Italy – coordinator), SMD (Belgium), CEM (Spain), DMI (Denmark), University of Genova (Italy) and MéteoSwiss (Switzerland). The World Meteorological Organization was a partner of this project, acting as "Chief Stakeholder" since the project was addressed to deliver normative proposal and recommendations for calibration of meteorological instruments.

The present work describes the recent development of the process of including results from the INCIPIT project into normative documents at the European scale. Indeed, the technical report including the state-of-the-art in calibration of non-catching instruments was submitted to CEN/TC 318 (Hydrometry) /WG12 (Rainfall Intensity), as a draft Technical Report, and is now in the balloting phase. Also, recommended procedures for the traceable calibration of non-catching precipitation gauges, their testing and maintenance, were submitted to the same committee as a proposal for a new norm, and the text is under preparation at CEN at the time of writing. Guidelines were also submitted to the WMO expert team Surface and sub-surface, Measurement Uncertainties and Quality, Traceability and Calibration.

P-14: REFERENCE RAINFALL MEASUREMENTS AT THE WMO LEAD CENTRE "B. CASTELLI" IN VIGNA DI VALLE (ITALY)

Arianna Cauteruccio, Università di Genova, Italy
Enrico Chinchella, Università di Genova, Italy
Luca G. Lanza, Università di Genova, Italy
Alessandro Turchetti, Centro Tecnico per la Meteorologia, Ministero della Difesa, Italy
Giuseppe Meli, Centro Tecnico per la Meteorologia, Ministero della Difesa, Italy

The Lead Centre (LC) "Benedetto Castelli" on Precipitation Intensity was designated by the WMO/CIMO in September 2010 with the aim of providing specific guidance about instrument calibration and their achievable accuracy, performing laboratory and field tests, and developing research/technical activities about the measurement of precipitation intensity and the related data analysis and interpretation. In July 2022, the LC was confirmed as a WMO Measurement Lead Centre (MLC), as a centre of excellence that will capture the results and provide high-level expertise in the testing of surface-based remote sensing and in situ instruments, and in the standardization of instrument performance.

The MLC is a joint initiative of the Italian Air Force and the University of Genova (Italy) and operates in three different sites: the Field Test site in Vigna di Valle (Rome – I), the Precipitation Laboratory at the University of Genova (Genoa – I), the Mountain site at the top of Mt. Cimone (Modena– I).

The MLC established a reference system for rainfall intensity (RI) observations. This is composed by a set of working reference gauges (WRG) employing a selection of measuring principles tested during the previous WMO Laboratory and Field Intercomparisons of Rainfall Intensity Gauges (in 2004-2005 and 2007-2009, respectively). According to the WMO Guide to Meteorological Instruments and Methods of Observations, the main feature of reference gauge design is to minimize or control the effect of wind on the catch, which is the most serious environmental factor for gauges at low intensity rates. This is achieved by installing the gauges into a pit according to EN 13798:2010.

Four gauges initially composed the working reference group: an OTT Pluvio2 weighing type gauge, a CAE tipping-bucket gauge, a Geonor T200B vibrating wires gauge and a drop counter developed by the Chilbolton Group of RAL Space (UK). Specific data processing protocols have been developed to combine the multiple readings and to provide the best possible estimation of reference RI in the field.

This work describes the instruments nowadays composing the WRG and the accuracy assessment of their performance according to the recently published European norm EN 17277:2019 on the calibration of catching-type gauges. Data are also presented about the comparison of instruments positioned outside the pit with the reference precipitation, including measurements from non-catching instruments.

O-27: THE WIND-INDUCED BIAS OF NON-CATCHING PRECIPITATION MEASUREMENT INSTRUMENTS

Enrico Chinchella, Università di Genova, Italy
Arianna Cauteruccio, Università di Genova, Italy
Luca G. Lanza, Università di Genova, Italy

Non-catching precipitation measurement instruments do not require a funnel to collect hydrometeors and measure the equivalent water flux but detect each of them individually in flight while crossing or impacting the sensing volume or surface. These instruments are being increasingly adopted by users since they provide precipitation microphysical properties (drops size and fall velocity) further to their integral features (rain amount and intensity) and require little maintenance.

Wind is a well-recognised source of environmental bias in precipitation measurements, affecting both catching and non-catching instruments. When immersed in a wind field, indeed, any precipitation measurement instrument behaves like a bluff-body, producing strong velocity gradients and turbulence near its sensing area or volume. These aerodynamic features may significantly divert the trajectories of the approaching hydrometeors away from the sensor.

In this work, we summarise the results of extensive research on the assessment of the wind-induced bias for liquid precipitation measurements using various non-catching instruments. A combination of Computational Fluid Dynamics (CFD) simulation and Lagrangian Particle Tracking (LPT) models is employed to investigate the accuracy of commonly adopted optical, acoustic, and light scattering sensors. Various combinations of wind speed and direction are considered since the instruments are usually not radially symmetric, and the rainfall intensity is also considered by assuming suitable relationships with the drop size distribution.

Results reveal that significant biases occur in the measurement of the microphysical properties of liquid precipitation when obtained in windy conditions. On the one side, drops are deflected by wind from their undisturbed trajectory and may fail to reach the sensing area of the instrument, while on the other side their fall velocity is modified, and they may reach the sensing area with a different velocity than the terminal one. The kinetic energy of individual drops is also affected by the wind, with a significant impact on measurements obtained from e.g., electro-acoustic disdrometers. The measurement biases on the microphysical properties propagate on the derived rainfall intensity and amount.

Although the drop size and velocity measurements are strongly biased in windy conditions, this bias can be quantified using the presented approach for any given instrument shape and measuring principle, and a few examples are given in this work for specific commercial instruments. Adjustment curves can be provided for the correction of the measured data, either in real time or within a suitable post-processing software.

P-99: METROLOGICAL ASPECTS OF A HUMIDITY CALIBRATOR

Adam Krovina, MicroStep-MIS spol. sro, & Slovenská Technická Univerzita (STU), Slovakia
Jaroslav Erdziak, MicroStep-MIS spol. sro
Csaba Ruman, MicroStep-MIS spol. sro

There are several uncertainty sources in a humidity calibrator, such as temperature homogeneity, temperature stability, dew point homogeneity, and stability. These are well known also from a climatic chamber evaluation. The compact humidity calibrator is almost like a small climatic chamber, but there is a different way how the calibrated sensors are normally inserted. While in a climatic chamber, there is enough space to accommodate the sensor along with some cable length, this is not the case for a compact calibrator. Due to the small size of the chamber, the sensors are usually not inserted fully, leaving part of the sensor body and the cable protruding through the chamber door. If the calibrator chamber temperature differs from the ambient, there will be a temperature gradient across the sensor body. The temperature and humidity sensor element will stabilize at a different temperature. This temperature difference is commonly known as the stem effect or lack of immersion.

The compact humidity calibrators normally don't allow for sufficient immersion, which could make the stem effect a big source of uncertainty. We have decided to study this effect experimentally. The experiment goal was to evaluate the stem effect versus insertion depth with the filter mounted and unmounted.

We have used a MicroStep-MIS relative humidity and temperature calibrator Humiwell.

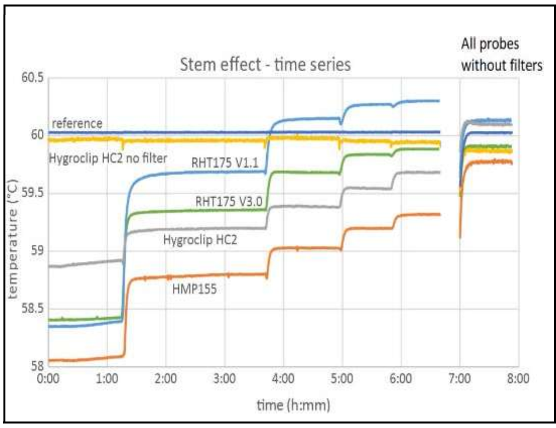
There were four different relative humidity and temperature probe types; HMP155, Hygroclip HC2, RHT175 V1.1, and RHT175 V3.0. These probes have had the sintered plastic filters mounted. There was another Hygroclip HC2 without a filter. We have measured at different immersion depths (2 cm to 6 cm) in 1 cm steps. Then at the maximum immersion, we removed all filters and measured the last data point.

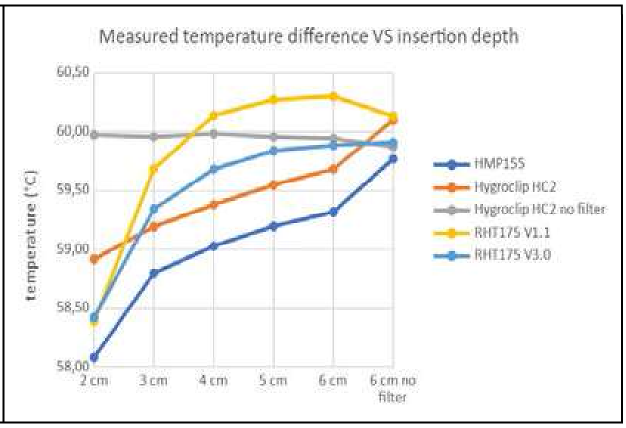
The probe temperature was measured by a built-in passive Pt-100 using a 4-wire, 6.5-digit multimeter with channel multiplexer. The reference temperature was measured by MBW 473. The calibrator was set to the highest possible temperature (60°C) to maximize the stem effect.

The insertion depth was measured from the center of the humidity sensor to the inner side of the chamber door. The stabilization time at each temperature was at least 45 minutes.

The results are depicted in the charts. A difference of approx. (1 to 2) °C was found at the minimum (2 cm) insertion depth. The difference gradually lowered with the increasing insertion depth. At the maximum depth (6 cm) the max. difference was about 0,7°C. After removing all the filters, the temperature differences were less than 0,25°C. The probe that was without filter did perform with a low difference at all depths.

The experiment results show that there is a significant stem effect if a plastic sintered filter is mounted on the probe. Even the maximum possible insertion depth does not help to fully eliminate it at some probe types. The problem could be solved by removing the filters during calibration.


Stem effect - time series
All probes without filters
reference
Hygroclip HC2 no filter
RHT175 V1.1
RHT175 V3.0
Hygroclip HC2
HMP155
temperature (°C)
time (h:mm)
60.5
60
59.5
59
58.5
58
0:00
1:00
2:00
3:00
4:00
5:00
6:00
7:00
8:00


Measured temperature difference VS insertion depth
temperature (°C)
60,50
60,00
59,50
59,00
58,50
58,00
2 cm
3 cm
4 cm
5 cm
6 cm
6 cm no filter
HMP155
Hygroclip HC2
Hygroclip HC2 no filter
RHT175 V1.1
RHT175 V3.0

P-98: AIR TEMPERATURE CALIBRATION SYSTEM (ATCS): DEVELOPMENT OF AN ATC-SUB CHAMBER FOR AIR TEMPERATURE MEASUREMENTS IN CLIMATE AND ENVIRONMENTAL CHAMBERS

Christina Hofstätter-Mohler, Bundesamt für Eich- und Vermessungswesen (BEV), Austria
Peter Pavlasek, Slovenský Metrologický Ústav (SMU), Slovakia

This project includes two main activities:
1. Further development of the BEV prototype of a stabilisation chamber for air temperature measurements, called "Air Temperature Calibration System - sub chamber (ATCS sub chamber)" in climatic and environmental chambers.
2. Development of a unified calibration procedure for industrial temperature sensors with corresponding standard specifications for calculating the measurement uncertainty budget.

Currently, there are no specifications or guidelines for uniformly performing air temperature measurements from industrial temperature sensors. To ensure comparability and proper calibration of industrial sensors, a standard procedure is essential.

This includes, above all, specifications as to how a measuring system for air temperature measurements in climatic and environmental chambers must look and which measured variables must at least be taken into account (temperature, humidity, pressure, wind speed, ...).

The project is to be carried out simultaneously with the submitted and published EURAMET project Reg. No. 1576.

MMC Torino 2023

METROLOGY FOR METEOROLOGY AND CLIMATE

REMOTE SENSING

Wednesday 15:25 to 15:45

Session chair: Fabio Madonna

Papers

O-6: CALIBRATION AND VALIDATION OF FENGYUN SATELLITES THERMAL INFRARED CHANNELS USING UNMANNED SURFACE VEHICLE AT CRCS LAKE QINGHAI

Yong Zhang, National Satellite Meteorological Center, China

Lake Qinghai is one of the main calibration sites of Chinese Radiometric Calibration Sites (CRCS) and also the largest saline of China, which located in the northeast of Tibet Plateau. Lake Qinghai (36°45N, 100°20E) is located 150 km from Xining City, capital of Qinghai Province. Its total area is 4473 km^2 and the perimeter is 360 km. The elevation of the water surface is 3196 m and the cubage of the lake is 105 Gm^3. It is a good place for IR bands' calibrating. The absolute radiometric accuracy of thermal infrared channels of the Advanced Geosynchronous Radiation Imager (AGRI) onboard the FengYun-4A (FY4A) satellite was assessed with field experiment data in a vicarious calibration on 18, 2019, and August 20, 2019, in Lake Qinghai. Continuous water temperature records were collected by an unmanned surface vehicle equipped with a radiometer during the experimental period. We proposed a spectral matching method based on atmospheric transfer code to create consistent equivalent spectral radiance, and the results predicted by atmospheric transfer simulation were convolved with instrument response functions to obtain predicted brightness temperature for comparison with satellite-derived temperature. Our results indicated that AGRI had an average temperature bias of 0.12 K with an RMSE of 0.17 and 0.61 K with an RMSE of 0.22 K in band 12 and band 13 on August 18, while these biases decreased to -0.01 K with an RMSE of 0.13 and -0.48 K with an RMSE of 0.17 K on August 20, respectively. This radiometric accuracy indicated that AGRI TIR bands are well functional compared with their preflight requirement of less than 1 K. The uncertainty analysis also suggested that atmospheric conditions would alter the calibration accuracy by influencing the transmittance and path thermal radiance. Meanwhile, cloud cover also requires more attention to select the appropriate concurrent satellite pixels to reduce the possible cloud edge effects. It is important and necessary for FY4A AGRI to conduct more intense automatic observations and obtain more data to improve the accuracy of radiometric calibration and monitor the operational status of satellite instruments.

O-34: METROLOGICAL TRACEABILITY – PROVIDED BY PTB FOR REMOTE SENSING, ATMOSPHERIC AND OCEAN MEASUREMENTS

Olav Werhahn, Physikalisch-Technische Bundesanstalt (PTB), Germany

In order to provide reliable statements about climate and enviromental change, it is essential to have quantitative, accurate, and reliable measurements, particularly within a highly complex system encompassing a wide range of physical and chemical measurement parameters. Germany's national metrology institute, the Physikalisch-Technische Bundesanstalt (PTB), has taken steps to align its metrology activities on climate actions and environmental protection. This coordination effort extends to global organizations like the International Bureau of Weights and Measures (BIPM) and the European Association of National Metrology Institutes (EURAMET). The so founded Innovation Cluster Environment & Climate (IC-U) has set up strategic actions to address the challenges for metrology on climate and environment. This contribution showcases PTB's engagement on metrology for climate & environment providing metrology solutions and SI traceability to this field.

MMC Torino 2023

METROLOGY FOR METEOROLOGY AND CLIMATE

SHORT PRESENTATIONS SESSION (2)

Thursday 9:00 to 9:30

Papers

P-15: MEASUREMENT OF TURBULENT FLUXES OVER MOUNTAINOUS COMPLEX TERRAIN

Alessio Golzio, Università di Torino, Italy
Valentina Andreoli, Università di Torino, Italy
Silvia Ferrarese, Università di Torino, Italy

The measurement of turbulent fluxes in the atmospheric boundary layer is usually performed using fast anemometers and the Eddy Covariance technique. This methodology has been applied successfully over flat, horizontal and homogeneous terrain in several measurement campaigns. The same method has been used over non-homogeneous and sloped terrains such as in agrometeorological studies, for complex urban and sub-urban terrains, and for mountainous terrain. In the present work Eddy Covariance technique has been applied and investigated in a complex mountainous terrain. A field campaign has recently been conducted at Alpe Veglia (latitude: 46.2751°N, longitude: 8.1457°E at 1746 m a.s.l., in Central-Western Italian Alps at the border between Italy and Switzerland) during three years from September 2018 to August 2021, where both standard and micrometeorological data were collected. The station was made up of a 5 meters high aluminum trellis, and it was equipped with standard meteorological instruments in order to measure: temperature, relative humidity, atmospheric pressure, wind speed and direction, solar radiation, snow height and soil properties. For the measurement of turbulent quantities, a sonic anemometer was installed on top of the same trellis. The measured values obtained from the sonic anemometer were analysed using a filtering procedure consisting in a number of controls and three alternative coordinate rotation procedures: Double Rotation (DR), Triple Rotation (TR) and Planar Fit (PF). The three coordinate rotations were applied on moving temporal windows of 30 and 60 minutes in order to compute the momentum fluxes and the sensible heat flux. A quality assessment was performed on the sensible heat and momentum fluxes considering five quality levels. A comparison of the three coordinate procedures, using quality assessment and sensible heat flux standard deviations, revealed that DR and TR were comparable, with significant differences, mainly under low-wind conditions. The PF method was applied with two approaches: single plane identification and multiple plane sectors. At Alpe Veglia site it was evident that there was a main plane of the flow, with some other secondary planes, and an in-depth analysis showed differences between the seasons.

P-1: THE IMPORTANCE OF USING SENSORS WITH KNOWN MEASUREMENT UNCERTAINTY AT HIGH-ELEVATION SITES: THE FREEZE-THAW CYCLES

Guido Nigrelli, Consiglio Nazionale delle Ricerche, Istituto di Ricerca per la Protezione Idrogeologica (CNR-IRPI), Italy
Marta Chiarle, Consiglio Nazionale delle Ricerche, Istituto di Ricerca per la Protezione Idrogeologica (CNR-IRPI), Italy
Andrea Merlone, Istituto Nazionale di Ricerca Metrologica (INRiM), Italy
Chiara Musacchio, Istituto Nazionale di Ricerca Metrologica (INRiM), Italy
Graziano Coppa, Istituto Nazionale di Ricerca Metrologica (INRiM), Italy

In a context of cryosphere degradation caused by climate warming, rock temperature is one of the main driving factors of rockfalls that occur on high-elevation mountain slopes.
Rock temperature is influenced by the directly solar radiation and by the air temperature, and air temperature controls daily and seasonal freeze-thaw cycles. The daily freeze-thaw cycles play an even more important role in rock instabilities if there is water (solid or liquid) in the rock mass.
In this work we present the 1-year rock temperature data, acquired in the Alps at an elevation above 3000 m, at different depths (10 and 30 cm) and in different aspect conditions (North and Sud).
This work highlights that metrological traceability is fundamental to assess data quality and establish comparability among different measurements; that there are strong differences between air temperature and rock temperature; and that aspect plays a crucial role.

P-18: ACCURACY EVALUATION METHOD OF METEOROLOGICAL OBSERVATION DATA BASED ON MEASUREMENT UNCERTAINTY

Zeqiang Bian, Meteorological Observation Center, China
Shi Qiu, Meteorological Observation Center, China
Xi Chen, Meteorological Observation Center, China
Wei Chong, Meteorological Observation Center, China
Hejun Yu, Meteorological Observation Center, China
Songkui Li, Meteorological Observation Center, China

In ANNEX 1.G. MEASUREMENT QUALITY CLASSIFICATIONS FOR SURFACE OBSERVING STATIONS ON LAND of Guide to Instruments and Methods of Observation WMO-No. 8-2021 edition - Volume I Measurement of Meteorological Variables, A measurement quality classification scheme for automatic weather station is provided. This scheme classifies the observation quality by calculating the overall measurement uncertainty.

The first step in calculating uncertainty is to analyze the sources of uncertainty and establish corresponding mathematical models. Different mathematical models can lead to significant differences in the calculation results of uncertainty.If different uncertainty evaluation mathematical models are used for the same meteorological observation, different results may be obtained, which may lead to different evaluation results for measurement quality classification.It is recommended that WMO provide a globally unified and relatively complete mathematical model for uncertainty assessment for each observation element (including all uncertainty impact components as much as possible), so that the uncertainty values calculated by various countries are consistent and comparable, and the measurement quality classification based on the uncertainty values is also consistent.

Some uncertainty sources are qualitative, for example, Instrument coupling (Radiation screen, Static pressure head, Raingauge fence screen), Maintenance and verification: (Frequency of maintenance, Quality of maintenance, Instrument and system drift with time, Instrument and system aging, Instrument and system faults, Cleanliness of instrument and site), Environment effects: (Sensor mechanical stress during transport and operation, Evaporation of precipitation on screen, Wind effects on measurement, Condensation on temperature instrument, Solar radiation effects on measurement). Due to the calculation of qualitative uncertainty sources, different experiences and evaluation algorithms may lead to different results, which in turn can lead to different results in the calculation of composite uncertainty, thereby affecting the evaluation of observation quality. Therefore, in order to ensure consistency and comparability in global uncertainty assessment, it is best for WMO to provide a unified or standard numerical determination method for these qualitative uncertainty components. In this way, everyone uses the same method to determine the values of these relatively fuzzy qualitative uncertainty components, so that the quality of observation data from different countries can be comparable.

In actual meteorological observations, it is usually a certain observation instrument that directly outputs a measurement value, which is the observation value recorded at that time. Due to the lack of reference values for comparison in actual observations, it is not possible to calculate observation errors in actual observations. Generally, the uncertainty of observation values is evaluated. Among all the sources affected by uncertainty, only the metrological calibration component can there be a correlation between the observation instrument and the reference quantity value. That is only during the metrological calibration process can the observed values of the observation instrument be compared with the reference value, and the observation error of the observation instrument can be obtained. After metrological calibration, the measurement error of the observation instrument meets the error range requirements, and then observation is carried out to ensure the quality of the observation data. Therefore, in order to improve the quality of observation, the importance of the uncertainty component in metrological calibration should be highlighted in measures to control, reduce, and reduce the impact of uncertainty components. Because only strict metrological calibration can ensure that the observation error meets the requirements.

P-13: PRESENT STATE AND DEVELOPMENT PERSPECTIVES OF METEOROLOGICAL NETWORK FOR EASTERN POLAND WETLAND ECOSYSTEMS

Kamil Szewczak, Polska Akademia Nauk (PAN), Poland

Although wetlands cover only about 3% of the land area, they play an important role in stabilizing the climate on Earth. They are a "sink" of one of the main greenhouse gases - carbon dioxide, and, interestingly, they are much more effective in that binding than forests which cover 30% of the land. Moreover, as natural reservoirs, they play important role of water retention. In addition, if we take into account that wetlands are habitat of many endangered animal species, the monitoring of wetlands is becoming a very important aspect in the context of progressive climate changes. On the East of Poland, three main wetland complexes are located, where the most extensive are wetland covered by Biebrza National Park, located on the North-East Poland in the Biebrza river valley. Institute of Agrophysics Polish Academy of Science established and maintains a network of meteorological stations located in Eastern Poland, partially in wetlands areas and in their buffer zones. Currently 12 stations are established. Typically, each station was equipped with sensors for monitoring parameters as: soil moisture, precipitation, air temperature, soil temperature, wind speed and direction, air humidity. In addition, selected stations are able to measure evaporation and solar radiation. As a special attention in the network operation was paid for soil moisture measurements and fusion of soil moisture data for variable spatial scale (research in the framework of SoMMet project) one of the stations was also equipped with L-band remote sensing radiometer ELBARA, providing medium scale measurement data of brightness temperature recalculated for soil moisture. Present operational works are focused for upgrading the network for the unification of data and to provide the additional measuring capabilities for medium scale soil moisture assessment. One of the concepts is to equip the network by Cosmic-Ray Neutron Sensing devices dedicated and calibrated for soil moisture. Presented work shows the current state of the network including long term monitoring results of meteorological data for East Poland wetland ecosystems and describe the short time plans for the network improvement.

Acknowledgements

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

P-9: STUDY ON THE UNCERTAINTY ASSESSMENT OF THE RADIOSONDE METEOROLOGICAL PARAMETERS CALIBRATION

Xiaozhu Chi, Meteorological Observation Center, China
Zeqiang Bian, Meteorological Observation Center, China
Xuejing Nan, Meteorological Observation Center, China

At present, high-altitude meteorological observation is developing rapidly in China. Only the China Meteorological Administration, has set up more than 100 radiosonde stations across the country, and more than 7,000 radiosondes are released every month. It can realize L-band radar service use, Beidou-GPS satellite navigation sounding, and its sounding subsystem can be switched between systems. The sonde is usually equipped with a temperature sensor, humidity sensor, barometer, GPS positioning module, wireless transmission module and other components, with good transient characteristics. It is carried by a balloon with an ascending speed of 5~6 m/s to detect parameters such as temperature and humidity, pressure, wind speed and direction at high altitude. It is very important to calibrate the meteorological element sensors on the radiosonde, and relevant national calibration standards are being issued.

In this paper, based on the calibration and test of the electronic radiosonde sensors, a comprehensive measurement and verification system for multi-parameter climate observe devices is established to realize the integration of atmospheric pressure, temperature, humidity and solar radiation elements. The limitation of calibration of the sonde in the ground environment is overcomed , and the parameters under the working state be reproduced and evaluated. The multi-variable joint control to simulate the atmospheric environment, mainly includes gas preparation subsystem, saturated gas generation subsystem, multi-element experiment chamber subsystem, integrated control and condition monitoring subsystem, solar radiation simulation subsystem and business management subsystem, as well as quantity traceability method.

Calibrating several current popular sondes, the uncertainty factors affecting the calibration results are analyzed, in terms of calibration items, calibration process and main measuring equipment used. Calibration tests are carried out for each calibration item according to the relevant regulations, and the uncertainty of the calibration results is analyzed and evaluated. The calibration results of each calibration item meet the relevant WMO accuracy requirements. The evaluation process and results are applicable to the conditions that basically meet the above conditions. When the measurement conditions are basically the same, the above evaluation process and results can be directly referenced.

OCEAN

Thursday 9:30 to 10:30

Session chair: Michela Sega

Papers

INV. UNCERTAINTY IN OCEANOGRAPHIC MEASUREMENTS

O-37 TRACKING A MOVING TARGET – SEA LEVEL

O-8 CHARACTERISTICS OF A DRIFTING BUOYS REFERENCE NETWORK FOR SST MEASUREMENT

O-29 METROLOGICAL CHALLENGES FOR THE MONITORING OF THE PARTIAL PRESSURE OF CO_2 IN THE MARINE ENVIRONMENT

INVITED: UNCERTAINTY IN OCEANOGRAPHIC MEASUREMENTS

Christoph Waldmann, Universität Bremen, Germany

O-37: TRACKING A MOVING TARGET – SEA LEVEL

Jane Warne, Bureau of Meteorology (BoM), Australia
Lachlan Nicholls, Bureau of Meteorology (BoM), Australia

Sea level is a key measurement in many human endeavours from maritime shipping to climate change impacts. As a field of study, it has captured the interest to people since ancient Greece, through Kepler, Galileo, Kelvin, and Newton to name a few. But it was not until the twentieth century that formal sea level measurements were gathered using tide staffs. Modern sea level measurement is both metrologically complex and multidisciplinary, a collaboration between metrologists, engineers, oceanographers, hydrographers, geodesists, and meteorologists.
Everything in sea level is dynamic while the measurement itself is aiming for better than centimetric accuracy over measurement time frames of seconds to decades in a single observation. This complexity reveals itself in the different types of sea level that people are interested. For example the hydrographic community measure sea level to ensure ships do not run a ground. To do this they have a theorical datum called "Chart Datum". This is a depth on a maritime chart that approximates the depth of water at the lowest astronomical tide. Land surveyors require "relative" sea level. In this case the sea level relative to height of "mean sea level" on land. The third is "absolute" sea level which referenced to the centre of the earth. Climatologists are interesting in this to understand if sea-levels as experience it is a result of the sea rising or the land falling. The problem here is that without a detailed understanding of how each community determined their sea level data you cannot easily compare the different estimates.
This paper presents the work undertaken to connect and quantify this measurement and its uncertainty as a single related set of sea levels. It traces the measurements from laser calibrations in the laboratory, to the water level measurement in the field, the location of the sensors on a moving platform, the local land and continental movement, tidal and geodetic models. We discuss the challenges of creating a single data set that can serve the multitude of users of sea level. Also present the complexity of quantifying the uncertainty of this measurement and the unique challenges of some of the field measurement instruments.

O-8: CHARACTERISTICS OF A DRIFTING BUOYS REFERENCE NETWORK FOR SST MEASUREMENT

Marc Le Menn, Service Hydrographique et Océanographique de la Marine (SHOM), France
Anne O'Carroll, European Organisation for the Exploitation of Meteorological Satellites (EUMETSAT), Europe
Gary Corlett, European Organisation for the Exploitation of Meteorological Satellites (EUMETSAT), Europe
Emma Woolliams, National Physical Laboratory (NPL), United Kingdom
Marc Alexander Lucas, Collecte Localisation Satellites (CLS), France
Carmen Garcia Izquierdo, Centro Español de Metrología (CEM), Spain
Andrea Merlone, Istituto Nazionale di Ricerca Metrologica (INRiM), Italy

Sea-Surface Temperature (SST) plays a key role in the understanding of ocean-atmosphere interactions, in the characterization of the mesoscale variability of the upper ocean, as a boundary condition for numerical weather prediction systems, and in climate monitoring and prediction. SST measured by surface drifters is also used to validate temperatures measured by satellites.
Funded by Copernicus since 2018, the TRUSTED project has made progress towards establishing Fiducial Reference Measurements (FRM) of surface drifting buoys, which are a sub-set of drifting buoys for ensuring the quality of very high accuracy (low uncertainty), climate-quality satellite Sea Surface Temperature (SST) observations. These contain a TRUSTED Reference Sensor for Temperature (TRST) following the specification of HRSST-2 defined by the GHRSST (Group for High Resolution Sea Surface Temperature) and an additional temperature sensor.
What are the characteristics of this sub-set of buoys that allow it to be considered as an FRM network? The concept "FRM" describes independent, fully characterised sensors that are tailored specifically to address the calibration and validation needs of a space-borne sensor. Here we describe how the TRUSTED project has ensured traceability to SI and we focus on why these TRUSTED buoys can be considered as an FRM network with the following elements:

1. sensors are fully characterized and calibrated before deployment.
2. a traceability diagram was established, and full global measurement metadata are associated to buoys.
3. a robust evaluation of uncertainties of the diagram components was made.
4. a model of TRST measurement diagram was built.
5. the knowledge of sensors drift over time was improved for maintaining a good level of confidence in the data collected.

All these elements improve the level of confidence in the data collected and in the comparisons with satellites measurements.

O-29: METROLOGICAL CHALLENGES FOR THE MONITORING OF THE PARTIAL PRESSURE OF CO_2 IN THE MARINE ENVIRONMENT

Francesca Rolle, Istituto Nazionale di Ricerca Metrologica (INRiM), Italy
Francesca Durbiano, Istituto Nazionale di Ricerca Metrologica (INRiM), Italy
Stefano Pavarelli, Istituto Nazionale di Ricerca Metrologica (INRiM), Italy
Francesca Romana Pennecchi, Istituto Nazionale di Ricerca Metrologica (INRiM), Italy
Michela Sega, Istituto Nazionale di Ricerca Metrologica (INRiM), Italy
Rajesh Nair, Istituto Nazionale di Oceanografia e di Geofisica Sperimentale (OGS), Italy

The observed rising levels of carbon dioxide (CO_2) in atmosphere, highly caused by anthropogenic emissions, are responsible for fundamental changes occurring also in seawater carbonate chemistry. The oceans are absorbing more CO_2 from the atmosphere, which is decreasing seawater pH and leading to the acidification of marine waters, with important consequences for the global ecosystem. At present, the partial pressure of CO_2 ($p$$CO_2$) is one of the few variables of the marine carbon cycle directly measurable *in situ*. In order to achieve meaningful and significant measurement results, it is necessary to reach uncertainties small enough to discriminate observed variations due to natural fluctuations, from those due to real trends. In this framework, the development and validation of proper analytical methods and measurement standards is of utmost importance.
Despite the availability of a variety of *in situ* sensors, currently used to monitor $p$$CO_2$ in marine environment, there are several problems to be faced, such as the differences in adopted calibration methodologies and non-validated procedures, or the lack of metrological traceability and of operational harmonization for field measurements. In addition, the scarcity and expensiveness of suitable reference materials to calibrate instrumentation used for $p$$CO_2$ monitoring represents an issue. A promising approach could be the provision, on a larger scale, of appropriate reference standards in gas phase to be used to calibrate $p$$CO_2$ sensors, due to the stability of the CO_2 in the gas mixtures. In addition, intermediate-level standards and working standards, could represent a more affordable and widespread traceability source. Concerning the analytical methods for $p$$CO_2$ monitoring, Non Dispersive Infrared (NDIR) photometry is quite used, but its application could be potentiated.
At INRiM, the Italian Metrology Institute, gaseous reference standards of CO_2 at known amount fraction in synthetic air or nitrogen are produced by the gravimetric method. In the framework of the H2020 Project “MINKE - Metrology for Integrated Marine Management and Knowledge-Transfer Network”, feasibility studies are ongoing to extend the use of these primary mixtures to the calibration of sensors for $p$$CO_2$ in seawater, in cooperation with the National Institute of Oceanography and Applied Geophysics (OGS). In the present work, some preliminary results of this activity will be presented.

MMC Torino 2023

METROLOGY FOR METEOROLOGY AND CLIMATE

SHORT PRESENTATIONS SESSION (3)

Thursday 10:30 to 10:45

Papers

P-11 TEMPERATURE PROFILES OF XBTS AND ARGOS INTERCOMPARED WITH SHIP-BASED CTDS: SOME FURTHER CONSIDERATIONS ABOUT THEIR METROLOGICAL COMPARABILITY IN THE MEDITERRANEAN SEA

P-12 UPDATED UNCERTAINTIES IN XBT MEASUREMENTS IN CENTRAL-WESTERN MEDITERRANEAN SEA FROM IN-SITU COMPARISONS (2001-2017)

O-31 CHALLENGES AND STRATEGIES FOR OVERCOMING RADIATIVE INFLUENCE ON THERMOMETERS IN AIR

P-11: TEMPERATURE PROFILES OF XBTS AND ARGOS INTERCOMPARED WITH SHIP-BASED CTDS: SOME FURTHER CONSIDERATIONS ABOUT THEIR METROLOGICAL COMPARABILITY IN THE MEDITERRANEAN SEA

Giancarlo Raiteri, Agenzia nazionale per le nuove tecnologie, l'energia e lo sviluppo economico sostenibile (ENEA), Italy
Franco Reseghetti, Agenzia nazionale per le nuove tecnologie, l'energia e lo sviluppo economico sostenibile (ENEA), Italy
Lijing Chen, Chinese Academy of Science (CAS), China
Claudia Fratianni, Istituto Nazionale di Geofisica e Vulcanologia (INGV), Italy
Simona Simoncelli, Istituto Nazionale di Geofisica e Vulcanologia (INGV), Italy

Seawater temperature is the longest measured metric and currently more than half a million profiles are collected each year using different instruments. Knowledge of both uncertainties about these measures and their metrological comparability is of great importance in all studies of ocean warming and climate change.
The Expendable Bathythermographs (XBTs) provided a large part of the temperature profiles in the period 1970-2000, after 2000 the Argo Profiling Floats (PFLs) instead ensured a significant part of the measurements. In any case, ship-based Conductivity-Temperature-Depth probes (CTDs) still maintain the role of reference transducers for measurements performed during field activities.
The waters of the Mediterranean Sea (which has become a Hot Spot of planetary climate change in recent years) have peculiar characteristics but there are few dedicated studies in the literature.
The XBT and Argo temperature profiles recorded in the Mediterranean Sea and downloaded from WOD18 (World Ocean Database, October 2022 release) are compared with CTD data (assumed as reference instrument) under strong space-time constraints and differences are estimated. For what concerns the profile matching conditions, following the indications for the first Rossby radius of deformation indicated in literature, XBT, PFL and CTD profiles were matched under the following 3D space-time conditions: ΔLat: ±0.10°, DLon: ±0.13°, Dtime: ±1 day, Ddepth: ±1 m. Rossby radius for mode 1 has a mean value of (10.9±2.6) km, calculated by taking into consideration the variability both in space and in time (along one typical year). The considered spatial window defines a square with a mean side of about ±11.4 km in the region of interest, therefore reasonably circumscribing the circumference whose radius is just the Rossby one.
Comparison of XBTs vs PFLs and CTDs show good results, in particular for depths greater than 100 m, where the water column temperature is more stable and homogeneous: mean differences are in fact quite similar and equal to (0.02±0.11) °C and (0.03±0.12) °C, respectively.
Furthermore, XBT profiles coming from the Ship Of Opportunity Programme (SOOP) monitoring in the western Mediterranean, and recorded in particularly accurate operating conditions, are compared with PFL data (using the previous space-time constraints) evaluating the effects of the application of the following corrections on XBT depth and temperature values, respectively:

1. new coefficients for the XBT Fall Rate Equation (FRE) specific for that basin
2. temperature calculated by resistance measures
3. temperature corrected for drift by tester measurements.

By applying depth and temperature corrections on XBT profiles, a reduction of differences among matched profiles can be observed in comparison with values directly calculated by manufacturer software: mean differences, always for depths greater than 100m, change in fact from 0.033 °C to 0.015 °C, with a distribution of values more similar to a Gaussian one.

P-12: UPDATED UNCERTAINTIES IN XBT MEASUREMENTS IN CENTRAL-WESTERN MEDITERRANEAN SEA FROM IN SITU COMPARISONS (2001-2017)

Franco Reseghetti, Agenzia nazionale per le nuove tecnologie, l'energia e lo sviluppo economico sostenibile (ENEA), Italy
Lijing Chen, Chinese Academy of Science (CAS), China
Andrea Bordone, Agenzia nazionale per le nuove tecnologie, l'energia e lo sviluppo economico sostenibile (ENEA), Italy
Mireno Borghini, Consiglio Nazionale delle Ricerche, Istituto di Scienze Marine (CNR-ISMAR), Italy
Claudia Fratianni, Istituto Nazionale di Geofisica e Vulcanologia (INGV), Italy
Giancarlo Raiteri, Agenzia nazionale per le nuove tecnologie, l'energia e lo sviluppo economico sostenibile (ENEA), Italy
Simona Simoncelli, Istituto Nazionale di Geofisica e Vulcanologia (INGV), Italy

The quality of seawater temperature measurements and a good understanding of the associated uncertainties are of great importance in any study of ocean warming and climate change. Among the various instruments used, the XBT (eXpendable BathyThermograph) probes provided the majority of temperature profiles collected in the period 1970-2000 but uncertainties in their recordings have often created difficulties in oceanographic studies. The main problems are due to the absence of a sensor that measures pressure/depth so that the depth values are only estimated from a fall rate equation with phenomenological coefficients valid for the world ocean, and to the less than excellent performance of the thermistor NTC used.
The waters of the Mediterranean Sea (which in recent years has become a Hot Spot of planetary climate change) have peculiar characteristics in terms of temperature values, profile shape and salinity content but there are few studies in the literature that analyze the uncertainties on instrument measurements used for monitoring in the basin. The accuracies indicated by the XBT manufacturer for the measurements carried out by the XBT probes are rather high for both temperature and depth and do not make them suitable for accurate analyzes of climate change.
This presentation illustrates the preliminary results of in-situ tests carried out between 2001 and 2017 in the western Mediterranean in which nearly simultaneous temperature measurements were recorded from the same vessel with two instruments (XBT and CTD) to try to measure the same measurand. The CTD (e.g. an SBE 911plus) is the standard reference instrument for field measurements of EOVs and has accuracies, sensitivities and uncertainties that are at least one order of magnitude better than those of the XBT probes.
Various XBT models have been launched, in particular the DB version, currently the most used, and of which the sample for the analyzes is robust from a statistical point of view, verifying which was the best fall rate equation describing the movement of the XBT probes , the possible presence of temperature offsets, and the possible influence of the launch height and the calibration of the acquisition system.
New more effective fall rate equations have been determined for each XBT type, but those used so far have been found to work fairly well. A small thermal offset was identified, depending both on the type of probe and, to a lesser extent, on the

acquisition system used. Finally, a depth-dependent correction was calculated (probably linked to a pressure effect on the thermistor) but, unexpectedly, variable with the XBT type.
Analyzes are underway applying these results to the OHC calculations but it can be stated that the new uncertainties calculated for the measurements with XBT probes in the western Mediterranean (which are in good agreement with those shown by G. Raiteri in his presentation) lead us to consider how the evidence of warming of the waters of the Tyrrhenian Sea provided by the latest measurements with XBT probes is statistically robust over the entire measured water column.

O-31: CHALLENGES AND STRATEGIES FOR OVERCOMING RADIATIVE INFLUENCE ON THERMOMETERS IN AIR

Laura Bevilacqua, National Physical Laboratory (NPL), United Kingdom
Stephanie Bell, National Physical Laboratory (NPL), United Kingdom
Dragos Buculei, National Physical Laboratory (NPL), United Kingdom
Jonathan Pearce, National Physical Laboratory (NPL), United Kingdom
Robin Underwood, National Physical Laboratory (NPL), United Kingdom

The influence of the radiative environment on thermometers in air can lead to overestimation or underestimation of the true air temperature by a few tenths of a degree or even, in particularly adverse conditions, a few degrees. These radiative errors can significantly exceed those originating from other causes such as self-heating, drift, and calibration uncertainties; hence it is important to consider and mitigate radiative error.

One factor governing radiative error is the diameter of the sensor, where larger diameters result in larger errors by an amount proportional to the square root of the diameter. The effect can be studied by using sensors with differing diameters and extrapolating the readings to determine the temperature of an effective zero-diameter sensor unaffected by radiative errors. This has the potential to allow evaluation of radiative error, and to enable either correction of error or an appropriate attribution of uncertainty due to radiation.

Whilst this effect has already been examined under close-controlled laboratory conditions, the reality of the dynamic and non-uniform nature of outdoor environments introduces additional challenges such as thermal shadowing and differing response times.

The work aims to investigate the complexities associated with accurate measurement of the true air temperature and proposes initial steps towards overcoming these challenges. This includes an analysis of practical temperature measurements from multiple Pt100 sensors of different sizes compared with measurements from a radiatively immune non-contact acoustic thermometer both in a Stevenson screen and unshielded, as well as modelling of multiple thermometers in a radiative environment.

MMC Torino 2023

METROLOGY FOR METEOROLOGY AND CLIMATE

SHORT PRESENTATIONS SESSION (4)

Thursday 11:15 to 11:40

Papers

P-17 ANALYSING THE DISPERSION OF AIR TEMPERATURE MEASUREMENTS WHEN THE THERMOMETERS ARE EXPOSED TO AMBIENT CONDITIONS

P-19 LOW UNCERTAINTY CALIBRATION METHOD OF TEMPERATURE SENSORS IN AIR

P-4 RESEARCH AND APPLICATION OF ERROR CALIBRATION METHODS FOR HMP155 HUMIDTY SENSORS

P-17: ANALYSING THE DISPERSION OF AIR TEMPERATURE MEASUREMENTS IN THERMOMETERS EXPOSED TO ENVIRONMENTAL CONDITIONS

Natalì Giselle Aranda, Politecnico di Torino, Italy
Andrea Merlone, Istituto Nazionale di Ricerca Metrologica (INRiM), Italy

Meteorological measurements performed with calibrated instruments and traceable to the International System of Units (SI), enhance the quality and value of climate and meteorological observations. However, it is known that the behaviour of the instruments differs when the measurements are done in a controlled laboratory with respect to their exposure to environmental conditions. Regarding air temperature measurements, although many efforts have been made to minimize the effect of influential quantities, such as the optimization of solar shields to reduce radiative errors, the uncertainty contribution due to the environmental influences remains a significant challenge. The present work evaluates the air temperature dispersion, when identical thermometers are exposed to environmental variables, focusing on the relative humidity and solar radiation influence. Tis dispersion is defined as the difference in the lecture of each thermometer with respect to the mean of all the thermometers. For the study, the 10 - s records of several meteorological instruments (thermometers, a hygrometer and a wind sensor) installed in an open field at the Istituto Nationale di Ricerca Metrologica (INRIM), were analysed. Before and after the measurement campaigns, the thermometers were calibrated against reference standards at the INRiM laboratories, guaranteeing the reliability of the data. To analyse the influence of solar radiation, 1- h records from a nearby station "Vallere", 3 km from the INRIM field and with similar environmental conditions, were evaluated. Focusing on the summer 2021 and winter 2022, the study shows that the air temperature dispersion between ± 0.2 °C represents the 98.16 % and 91.64 % of the analysed data in summer and winter, respectively. This result reflects the importance of working with calibrated sensors because otherwise, the difference between thermometer readings would be higher. Moreover, defining outliers to those dispersion values higher than |0.4| °C, most of them were measured with lower humidity, which could be affected by the condensation/evaporation process on the solar shield that protects the thermometers. Analysing the solar radiation, results show that for sunny days, when the radiation starts to rise, the air temperature dispersion is higher. On the other hand, on cloudy days, the radiation effect is decreased and therefore the air temperature dispersion. Finally, considering different ranges of relative humidity and solar radiation, the standard deviation of air temperature dispersion is calculated as an indicator of uncertainty contributions due to these variables. The highest standard deviation, 0.12 °C, is reached when relative humidities vary between 50 % and 75%, and with radiation between 1 W/m^2 and 400 W/m^2. This work is part of the overall efforts aimed at evaluating the uncertainty contribution of the associated quantities of influence, as also prescribed by the World Meteorological Organization Expert Team on Measurement Uncertainty. More study is required to extend the representativeness of the results, for example, the wind effect.

P-19: LOW UNCERTAINTY CALIBRATION METHOD OF TEMPERATURE SENSORS IN AIR

Miruna Dobre, FPS Economy, DG Quality and Safety, Metrology Division (SMD), Belgium
Justyna Dobosz, Instytut Niskich Temperatur i Badań Strukturalnych (INTiBS), Poland
Aleksandra Kowal, Instytut Niskich Temperatur i Badań Strukturalnych (INTiBS), Poland

Air temperature sensors are either calibrated in liquid baths with low uncertainties but in different conditions than daily use or in air (inside climatic chambers) with higher uncertainties. An intermediate method, calibration in a small air chamber immersed into a liquid bath was developed by two national metrology institutes (INTIBS and SMD). Shape and dimensions of chamber was adjusted to length and diameter of air sensors as well as the liquid baths geometry commonly used in metrology laboratories. The performance of the chamber was tested during the calibration of the several types of air temperature sensors. Obtained measurements were compared with calibration in fixed point and liquid bath. An average difference of 4 mK was found between calibration in liquid bath with or without inner chamber.

P-4: RESEARCH AND APPLICATION OF ERROR CALIBRATION METHODS FOR HMP155 HUMIDITY SENSOR

Xindi Li, Guangdong Meteorological Data Center, China

According to the requirements of Guangdong Meteorological Station for HMP155 humidity sensor, this paper summarizes the laboratory calibration experience, and obtains three calibration methods of the sensor under the condition of common indication value error. According to the single point deviation, linear fitting and high humidity increased density, the indication error of the sensor is effectively reduced by means of key adjustment and serial port commands input. The adjusted sensor calibration data meet the needs of the regulations and the observation requirements.

CHEMISTRY

Thursday 11:40 to 12:10

Session chair: Francesca Durbiano

Papers

O-9 TOWARDS THE DEVELOPMENT OF ATMOSPHERIC CARBON DIOXIDE CERTIFIED REFERENCE MATERIALS AT KNOWN ISOTOPIC COMPOSITION

O-41 EOV O2 CALIBRATION FACILTY: ESTIMATION OF THE INCERTITUDE SURROUNDING THE DATA

O-9: TOWARDS THE DEVELOPMENT OF ATMOSPHERIC CARBON DIOXIDE CERTIFIED REFERENCE MATERIALS AT KNOWN ISOTOPIC COMPOSITION

Michela Sega, Istituto Nazionale di Ricerca Metrologica (INRiM), Italy

From provisional data, global mean temperature in 2022 was estimated to be 1.15 ± 0.13 °C above the pre-industrial average level, thus making this year one of the warmest years on record. The increased levels of greenhouse gases (GHGs) in the atmosphere represent the main cause for such an increasing and carbon dioxide (CO_2) is the single most important anthropogenic GHG. Immediate action on GHG emissions mitigation is required to limit dangerous changes to Earth's climate. To support governments verifying emissions and demonstrating national reduction targets, it is necessary to discriminate between the natural and various man-made sources of GHGs. Discriminating man-made emissions in the measured CO_2 amount fraction is challenging and requires information on the isotopic composition, especially if reduced man-made emissions start to play a role.

INRiM, in the framework of the EMPIR Joint Research Project 19ENV05 "Stable isotope metrology to enable climate action and regulation (STELLAR)", uses its expertise in the preparation of gas standards by gravimetry for the realisation of Certified Reference Materials (CRMs) of CO_2 at known amount fraction and isotopic composition. The verification of the mixtures is carried out with different spectroscopic techniques, non-dispersive infrared photometry for amount fraction determination and Fourier-transform infrared spectroscopy for the assignment of the isotopic composition.

Starting from the development of new RMs of pure CO_2 in high pressure cylinders with different isotopic compositions carried out in the previous EMPIR Joint Research Project 16ENV06 "Metrology for Stable Isotope Reference Standards (SIRS)", diluted RMs at 410 $\mu mol \cdot mol^{-1}$ in synthetic air were prepared, in the range from +1.2 ‰VPDB to -42 ‰VPDB for δ13C, with a target uncertainty of 0.05 ‰ for δ13C-CO_2.

The prepared mixtures were then sampled in glass flasks by using an ad hoc system based on calibrated MFCs, and sent to the Max Planck Institute for Biogeochemistry (MPI-BGC), partner of both SIRS and STELLAR projects, for the validation of their isotopic composition.

An appropriate uncertainty budget was prepared for the developed RMs, taking into account the relevant uncertainty sources, such as the contributions pertaining to parent materials, to sampling and to possible contaminations from the matrix gas.

The final goal of this activity is the production of CRMs of atmospheric CO_2, and will be carried out after completing the ongoing stability study of the gaseous mixtures. The participation in an international comparison organised by CCQM will also support the production of these CRMs.

O-41: EOV O_2 CALIBRATION FACILITY: ESTIMATION OF THE INCERTITUDE SURROUNDING THE DATA

Laure Chirurgien, Aix-Marseille Université & Université de Toulon, France

One of the EMSO-ERIC objective is to collect, deliver and promote the use of high-quality data from long-term, high-frequency observations at fixed locations in the open ocean. Time series observations at critical or representative locations are one essential element of a global ocean observing system. They provide a unique view of the full temporal behaviour of a system; an accurate reference and long-time baseline data. Sensors are deployed at sea for different amounts of time. Sensor calibration ensures measurement accuracy and allows for the inter-comparability of long-term data observation of all the infrastructure. Estimating the associated uncertainties of these calibrations for each sensor, is essential for guaranteeing the data quality. This quality brings coherence to the datasets over time and between different observatories, ultimately enabling their use in a more global context. To achieve this aim, the EMSO-ERIC consortium has developed a calibration bench dedicated to dissolved oxygen sensors. This work will present the uncertainty estimation associated with this calibration facility to provide a reliable service to the observing community.

MMC Torino 2023

METROLOGY FOR METEOROLOGY AND CLIMATE

SHORT PRESENTATIONS SESSION (5)

Thursday 12:10 to 12:35

Papers

P-6: EVALUATION OF MEASUREMENT UNCERTAINTY OF EVAPORATION SENSORS IN AUTOMATIC WEATHER STATIONS USING MONTE CARLO METHOD

Mingming Wei, Meteorological Observation Center of Jiangxi Province, China

Due to the fact that the evaporation sensor of the automatic weather station does not fully meet the applicability conditions for GUM（Guide to the Expression Uncertainty in Measurement）evaluation, there is a certain deviation in the results of GUM method evaluation. Existing research has shown that the measurement uncertainty results evaluated by Monte Carlo method (MCM) are more authentic and effective. In order to effectively improve the accuracy of the evaporation sensor measurement data, this study plans to use the MCM method to evaluate the uncertainty of its measurement results, Firstly, based on the basic principle of MCM evaluation, the working principle and calibration process of the evaporation sensor are analyzed, and a corresponding measurement model is established. Then, taking the measurement results of a 60mm calibration point as an example, the uncertain reading sources generated during the experiment are analyzed and simulated, and propagated and output through MCM. The measurement uncertainty results are obtained as follows: the best estimated value of measurement error y=0.11066 mm, and the standard uncertainty u(y)=0.06843 mm, The left and right endpoints containing 95% intervals are ylow=-0.0234 mm, yhigh=0.244958967 mm. Finally, the MCM evaluation results were compared with the GUM results, and the results showed a corresponding 95% inclusion interval. The deviation values of the left and right endpoints of GUM and MCM were 0.009 mm and 0.0087mm, respectively, with a corresponding numerical tolerance of 0.005 mm. Since the Joint Committee for Guides in Metrology (JCGM) proposed in JCGM 101: ISO/IEC Guide 98-3"2008 GUM supplement1" that when the deviation value is greater than the numerical tolerance, the GUM method is no longer applicable. Therefore, when evaluating uncertainty in this field, GUM is no longer applicable and it is recommended to use the MCM method.

P-3: STUDIES ON THE EFFECT OF AIR VENTILATION ON TEMPERATURE SENSOR UNCERTAINTY

Sunghun Kim, Korea Research Institute of Standards and Science (KRISS), South Korea

Accurate and reliable air temperature measurements are crucial for many scientific and industrial applications. One commonly used method to ensure temperature measurement accuracy is by calibrating temperature sensors in a climatic chamber. In this presentation, we discuss an experimental study aimed at evaluating the effects of air ventilation on the uncertainty of air temperature thermometers in a climate chamber. To increase the thermal stability inside the chamber, we designed a cylindrical cap with several small ventilation holes to control air ventilation. We used three types of PRT sensors with a nominal resistance of 100 Ω and varying thicknesses of 0.5 mm, 3 mm, and 6 mm. We measured the stability of each thermometer at six temperatures ranging from -40 °C to 60 °C. We then analyzed the changes in calibration uncertainty with and without the cap. The results of our study will provide valuable insights into the impact of air ventilation on the accuracy and reliability of air temperature measurements in a climate chamber. This information will be useful for researchers and practitioners in a variety of fields, including environmental monitoring, materials science, and manufacturing.

P-8: BUILDING INFLUENCE ON AIR TEMPERATURE MEASUREMENTS: SITING CLASSIFICATION

Carmen Garcia Izquierdo, Centro Español de Metrología (CEM), Spain

The proposed contribution describes the metrological procedure carried out for the evaluation of the influence of buildings in the vicinity of meteorological stations, on air temperature measurements. This evaluation aims at producing reliable conclusions, information and data to contribute to the WMO siting classification schemes for air temperature measurements. For this purpose, a field experiment was designed, deployed, and one-year lasting air temperature measurements were taken and analysed.

In this field experiment, eight calibrated thermometers, equipped with the same model of artificially ventilated radiation shields, were installed at 1.5 m from the ground and at different distances from a 200 m wide building. This building was the unique artificial heat source and the unique object projecting shades over a flat surface (no discernible slope) in an open space larger than 40 000 m^2, covered by natural short grass. This configuration provides the observation of the horizontal distribution of air temperature radially from the building and, as a conclusion, it enables the quantification of the building influences on air temperature measurements at different distances from the building.

The field experiment, the analysis procedure, the temporal evolution of the building influence on air temperature measurements along the day also with respect to other meteorological parameters, were considered.

Two different building effects were found, positive building effect in the mornings and negative building effect in the afternoons. It was found that the maximum values of these two building effects are strongly linked with the human activity performed inside the building, mainly at the closest distances to the building. Only the data with the lowest human activity impact was considered for the conclusions of this study. It was also observed that the building influence is higher in clear days and the maximum building influence value is directly linked with the maximum solar irradiance at that day. The influence of wind on building influence was also analysed, reaching the conclusion that due to characteristic of local winds, in terms of low speed and direction, the wind impact could be considered as negligible.

The maximum values of building influence on air temperature measurements, the associated uncertainty values and the conclusions are presented in this proposal. All these points have been addressed using metrological principles with the purpose to give consistency and robustness to the evidence here presented.

P-7: AMATEUR WEATHER STATION COMPARED WITH OPERATIONAL INSTRUMENTATION OF METEOROLOGICAL SERVICE ON MOUNTAIN ENVIRONMENT

Samuel Buisan, Agencia Estatal de Meteorología (AEMET), Spain

Amateur weather stations networks have grown considerably providing new sources of information. One of the most popular types of weather station used by amateurs, especially in Spain, is the Davis Vantage Pro2.

This station was installed in AEMET Formigal test site located in a mountain environment at 1800 m a.s.l with the primary objective of performing an intercomparison in precipitation against the solid precipitation reference, the Double Fence Automated Reference (DFAR) and the precipitation gauge used operationally in AEMET. As secondary objective we compared the temperature and relative humidity from Davis station with a previously calibrated temperature and humidity probe used operationally in AEMET network located in an appropriate radiation shield also used in AEMET network.

After a quality control of data, 392 days of data for precipitation and 435 days of data for temperature and relative humidity were used for analysis, covering all seasons and also extreme weather episodes.

A preliminary analysis showed that Davis station liquid precipitation measurements accumulated over the study period was 11 % greater than DFAR and AEMET operational precipitation gauge measurements. For solid precipitation, as it was expected, the underestimation of precipitation was quite significant (44%), with total accumulation slightly greater than AEMET operational gauge accumulation.

Despite average temperature difference between calibrated probe and Davis station was 0.11 °C, after corrections due to results on AEMET calibration probe, the number of cases where maximum temperature was not compliant with AEMET requirements (0.6 °C) was significant, 19 % of cases, which increased to 28% of cases with snow on the ground. However, for minimum temperature, the number of cases where temperature was greater or lower than 0.6 ºC decreased considerably to 5% (6% for cases with snow on the ground).

When analysing relative humidity, the performance decreased with a high number of cases not compliant (difference in relative humidity higher than 5%). For daily maximum relative humidity 11% of cases (14% with snow on the ground) were out of the acceptance limit, whereas for daily minimum relative humidity the number of cases was very high, 66% (75% with snow on the ground)

The Davis station was, overall, robust in this harsh environment and there was not significant problems of communications or false records.

This work is therefore useful to assess the performance and limitations of this station when compared with operational instrumentation and their metrological requirements.

P-2: CALIBRATION AND UNCERTAINTY EVALUATION OF RADIOSONDE THERMISTORS IN A CLIMATE CHAMBER FOR ACCURATE TEMPERATURE MEASUREMENTS IN UPPER AIR

Young-Suk Lee, Korea Research Institute of Standards and Science (KRISS), South Korea

Temperature measurements in the free atmosphere using radiosondes are affected by various factors such as solar radiation, air pressure, and wind speed. Therefore, a prerequisite for accurate measurement is the calibration of sensors in laboratory setups. Calibration provides a measurement uncertainty of the raw temperature of radiosondes with traceability to the International System of Units (SI). To calibrate many sensors simultaneously, a climate chamber can be used. In this study, we present the calibration and uncertainty evaluation of 35 radiosonde thermistors from -70 to 30 °C in a climate chamber. The spatial temperature deviation (STD) of the calibration space of 35 thermistors was measured by five calibrated platinum resistance thermometers (PRTs) with an uncertainty of 50 mK. Interestingly, the temperature on the front door side was generally higher than the rear fan side in the climate chamber. To reduce the STD, we moved the calibration setup to the bottom of the climate chamber, which significantly improved the calibration uncertainty of 35 radiosonde thermistors, especially at -70 °C. The total calibration uncertainty of radiosonde thermistors was about 0.1 °C with a coverage factor k = 2. To confirm the validity of the calibration, we performed a dual sounding test of these radiosondes at nighttime, and the temperature difference among radiosondes was within the calibration uncertainty.

MMC Torino 2023

METROLOGY FOR METEOROLOGY AND CLIMATE

THERMOMETERS

Friday 9:00 to 10:15

Session chair: Yong-Gyoo Kim

Papers

O-30: STUDY OF RADIATIVE EFFECTS ON THERMOMETERS IN AIR IN CALIBRATION ENVIRONMENTS

Paul Carroll, National Physical Laboratory (NPL), United Kingdom
Sarah Beardmore, National Physical Laboratory (NPL), United Kingdom
Dragos Buculei, National Physical Laboratory (NPL), United Kingdom
Olivia Whiteside, National Physical Laboratory (NPL), United Kingdom
Stephanie Bell, National Physical Laboratory (NPL), United Kingdom

It is often recommended that thermometers for use in air should be calibrated in air, to take account of aspects of performance that depend on the thermal medium of use, such as electrical self-heating. This also allows the calibration laboratory to assign uncertainties that relate to operation in air, which are typically larger than uncertainties of calibration in a liquid bath. However, there is growing awareness of radiative influence on thermometers operating in chamber environments that are not radiatively uniform. This radiative effect is a function of thermometer cross-section as well as of the radiative field and air flow. Because of this, even in calibration or in ideal laboratory conditions, a 6 mm thermometer in air can sometimes differ from true air temperature by 0.05 K to 0.1 K. In real-world conditions, such as in meteorological screens, the effect can be significantly greater.
This presentation shows results of thermometer measurements in air, carried out in test chambers using different layouts and sub-chamber arrangements, aimed at demonstrating radiative influence and quantifying its contribution to uncertainty under different calibration conditions. Some conclusions will be proposed for how to mitigate radiative influence during calibration.

O-2: CLIMATE REFERENCE STATION THERMOMETERS CHARACTERIZATION

Peter Pavlasek, Slovenský Metrologický Ústav (SMU), Slovakia

Ground-based stations are an essential part of a complex climate observing systems which purpose is to generate data for evaluating local and global climate trends. Measurement traceability in these types of stations is fundamental for generating a robust climate understanding based on comparable data in space and time, both within networked stations and between networks. This importance was expressed by the Global Climate Observing System (GCOS) of the United Nations Environment Programme and WMO (World Meteorological Organization), in its published report 226 that highlights the need for available reference grade observations for accurately detecting of local and global climate trends [1]. As a following action, the GCOS launched in 2022 the implementation plan of its Surface Reference Network (GSRN) where an essential part of the effort is the understanding of instruments performance in field monitoring of temperature, humidity, and pressure. We focused the work here presented on the characterization of resistance thermometers of various types that are candidates to be installed in future prototype reference station. The selection of sensors using resistance measurement principle was motivated by their overall frequent in field use and general superior performance in comparison to other commonly used temperature sensors. The measurements took place under controlled laboratory conditions simulating as close as possible conditions in the field, leading to recommendations on the requirements of instrumentation for a climate reference station. In order to properly determine sensor performance and the components of the measurement uncertainty budget for climate reference stations the metrological parameters as stability, hysteresis and self-heating were determined. These essential parameters were measured in a temperature range typical for air temperature measurements for climate which is from -40 °C up to +60 °C. The characterization of temperature sensors from multiple manufacturers has shown diverging results in all measured parameters which were measured over the whole temperature range. In general, the measurements indicate that from the point of sensor stability the critical temperatures were 20 °C and -40 °C, with indicated highest temperature instability on the level of 0.02 °C. The highest hysteresis effect has been observed at temperatures of 0 °C and -40 °C with a maximum of 0.05 °C. Sensor self-heating exhibits multiple dependencies of the level of supply current that vary with tested sensor and temperature point. This research was made possible thanks to the project (19SIP03-Climate Reference Station) which has received funding from the EMPIR programme co-financed by the Participating States and from the European Union's Horizon 2020 research and innovation programme. This work is part of the opening activities for a future GSRN affiliated research facility.

O-5: A NOVEL METHOD FOR CALLENDAR-VAN DUSEN REGRESSION OF TEMPERATURE CALIBRATION POINTS

Graziano Coppa, Istituto Nazionale di Ricerca Metrologica (INRiM), Italy
Peter Pavlasek, Slovenský Metrologický Ústav (SMU), Slovakia
Francesca Romana Pennecchi, Istituto Nazionale di Ricerca Metrologica (INRiM), Italy

The Callendar-Van Dusen equations describe the relationship between the electrical resistance R of a metal resistor (usually platinum, for Platinum Resistance Thermometers or PRTs) crossed by current, and the temperature T of the environment to which the resistor is exposed. This equation is used to perform regressions on temperature calibration points for Resistance Temperature Detectors across a wide range of temperatures, for industrial applications as well as for environmental (atmospheric, marine and cryospheric) thermometers. Currently there are no internationally agreed prescriptions on the mathematical regression method for the Callendar-Van Dusen: most methods rely on classical Ordinary Least Squares approach, which is simple and widespread, but can lead to numerical inaccuracies on computer software, especially when calculating the inverse Gram matrix. This work presents a mathematical method of regression, called Piecewise Constrained Least Squares (PCLS), which preserves the peculiar structure of the Callendar-Van Dusen equation, applying continuity and linear dependence conditions in order to find the best fit coefficients of the equations. Mathematical derivation of the equations will be provided, including — for the first time in literature — variance-covariance matrices of the coefficients and of the fitted values, residuals and estimator of variance. Performances will be compared against currently used regression methods in terms of fit residuals and uncertainty propagation. Formulas for Weighted Piecewise Constrained Least Squares (WPCLS) will be provided as well.

O-13: INTERCOMPARISON OF THERMOMETERS AND RADIATION SHIELDS IN POLAR CLIMATE. COAT PROJECT

Carmen Garcia Izquierdo, Centro Español de Metrología (CEM), Spain

Air temperature measurements are performed by different combinations of thermometers and radiation shields. The response of each system (thermometer + radiation shield) to air temperature changes, residual sun radiation, wind, humidity, etc. depends on the system itself, i.e. on the model of both components, shield and thermometer. This makes the worldwide comparability of air temperature measurements limited, creates inconsistencies in climate data series and reduces the accuracy and reliability of long-term air temperature data. Field intercomparisons of instruments have been identified by WMO as a useful tool to increase the comparability of measurements taken at different times, in different places, and with different equipment.

In particular, no intercomparison of thermometers and radiation shields in polar climate was performed so far. In this frame, the project COAT - Increasing the comparability of extreme air temperature measurements for meteorology and climate studies - was selected and funded by the European Metrology Research Program, EMPIR, as a prosecution of the MeteoMet activities.

COAT project has WMO as the main supporter and it aims at organizing, conducting and analysing the results of an intercomparison of thermometers and radiation shields in the arctic research area of Ny-Ålesund – Svalbard. The project started in October 2020 and it ends in April 2024. Its consortium is composed of an international multidisciplinary team, including meteorologists, Earth science researchers and metrologists.

The progress of the project to date is as follow:

1. The comparison protocol covering the planning, initiating and conducting of field intercomparisons of thermometers and radiations shields was written, and reviewed by the WMO-INFCOM/SC-MINT-ET on Surface and Subsurface Measurements and other stakeholders. This intercomparison protocol includes the implementation of metrological concepts and procedures on how to conduct the intercomparison.
2. The collection of the instrumentation was completed and all the systems were initially characterized at CEM. Then, this instrumentation was transported to the Arctic area in Ny-Ålesund. The deployment of all instrumentation was performed in July 2022 and air temperature data has been collected since then from the different sensors and radiation shields involved in the comparison.

This contribution presents the project, explains the comparison procedure, the selection of the instruments, the description of the preliminary calibration of the involved instrumentation, their deployment in Ny-Ålesund and the preliminary analysis of the collected data.

O-23: OPTIMIZATION AND CHARACTERIZATION OF A SOLAR RADIATION SHIELD DESIGN

Davide Botturi, Università di Brescia, Italy
Simone Pasinetti, Università di Brescia, Italy

The authors propose the design of a helicoidal solar screen to protect in-field temperature sensors from solar radiation while facilitating air flow for heat removal. The aim of this work is to optimize the design of the solar screen and to characterize its performances by the means of fluid-dynamic simulations and in-field testing.
At first different geometries have been obtained revolving a blade profile around helicoids with different pitches and internal diameters.
The blade profile has been designed by the means of minimizing the amount of solar radiation which reaches the internal area of the screen while satisfying some fluid dynamics constraints. This has been obtained by ensuring that the upper profile of the blade has a constant inclination which is always greater than the inclination of the lower profile of the blade. The lower profile of the blade is designed as a parable (allowing the inclination of the blade to vary linearly). This expedient causes the light rays bouncing between the upper profile of the blade to the lower profile of the next blade to gradually straighten until they leave the screen.
The pitch of the helicoid has been varied to ensure that a percentage of air (ranging from 25% to 50%) unaffected by the thermal boundary layer reaches the temperature sensor while the internal diameter has been designed to be one or two times the blade profile.
The generated geometries have been simulated with OpenFoam (software for fluid dynamic simulations) and four of the most promising solar shields have been 3D printed.
The authors plan to test and characterize the four prototypes in real conditions trough in field experiments to determine the best-performing design in various climatic conditions.

MMC Torino 2023

METROLOGY FOR METEOROLOGY AND CLIMATE

NETWORKS AND SERVICES

Friday 10:45 to 11:25

Session chair: Peter Pavlasek

Papers

O-32 METEONETWORK: WEATHER DATA BY CITIZEN-SCIENTISTS

O-15 AIR TEMPERATURE RENEWAL ACTIVITIES IN THE METEOROLOGICAL SERVICE OF CANADA

O-23 EVALUATION OF RELIABILITY AND USE OF DATA FROM SENSORS ON BOARD OF VEHICLES IN METEOROLOGY AND ENVIRONMENTAL OBSERVATIONS

O-32: METEONETWORK: WEATHER DATA BY CITIZEN-SCIENTISTS

Alessandro Ceppi, Associazione Meteonetwork OdV & Politecnico di Milano, Italy
Gianandrea Peressutti, Associazione Meteonetwork OdV, Italy
Luca Cerri, Associazione Meteonetwork OdV & Hortus srl, Italy
Matteo Fumi, Associazione Meteonetwork OdV, Italy
Mauro Serenello, Associazione Meteonetwork OdV, Italy
Guido Cioni, Associazione Meteonetwork OdV, Italy
Gabriele Franch, Associazione Meteonetwork OdV & Fondazione Bruno Kessler, Italy
Marco Giazzi, Associazione Meteonetwork OdV, Italy

The potentiality of citizen science in bringing together large groups of people and science has been recently strengthened thanks in part to collaborations with universities and research centres. Over the past few decades, amateur weather networks have played a significant role, benefiting from advancements in technology. A notable example is the Meteonetwork (MNW) association, which was established in 2002, and primarily consists of passionate individuals interested in atmospheric science. MNW is a non-profit organization with the task to "promote and disseminate for the benefit of community the knowledge of meteorological, climatological, environmental, hydrological and glaciological sciences, and their multiple expressions on the territory".

Over time, MNW has successfully established an extensive network of weather stations throughout Italy, and in recent years, they have expanded their horizons including European networks as well. The MNW operational area includes the whole European region, with a particular focus over Italy. Currently, the network consisted of more than 6500 weather stations from 42 countries around the world. A detailed overview of the MNW network can be seen at this web site https://meteonetwork.eu/en. Among these 6500 stations, 4780 upload their data on the MNW database at least once every 24 h, and around 3400 are constantly on-line during the day.

More than 2100 weather stations are owned by citizen scientists of the MNW association whose admission procedure ensures a certain level of data quality for each sensor, since erroneous data reading caused by sensor malfunctions, hardware, or power supply error or changed environmental conditions can still occur. In addition, MNW data are subjected to automatic validation and quality control procedures in order to reduce this possibility of measurement errors entering in the MNW production chain. Once a weather station proceeds through the validation phase and finally joins the database, data are freely published in real-time on the MNW web sites and app.

Data are used to generate various services, such as real-time charts or daily extremes maps. Moreover, through single call or even bulk APIs, MNW data are accessible for users' researches and studies. The plotted variables are the following: air temperature and relative humidity, dew point, precipitation, wind speed and direction, sea level pressure, and UV and global solar radiations.

The open-source policy adopted by MNW has allowed to sign scientific agreements with different bodies, such as universities and Regional Environmental Protection Agencies. In fact, the network data are licensed under Creative Commons BY (CCBY) 4.0, and we have active Application Programming Interface (API) services available to users. During

the last decade, MNW stipulated official agreements to supply long data series for universities, private companies, institutions, students, and researchers.
From the MNW experience, crowdsourcing is now an appreciated tool for engaging the public and scientific research. If appropriate validation and quality control procedures are adopted and implemented, it has enormous potential for providing an integrative valuable source of high temporal and spatial resolution real-time data, especially in regions where few observations currently exist, thereby adding value to science, technology, and society.

O-15: AIR TEMPERATURE RENEWAL ACTIVITIES IN THE METEOROLOGICAL SERVICE OF CANADA

Jeffery Hoover, Environment and Climate Change Canada

The Meteorological Service of Canada (MSC) operates Automatic Weather Stations (AWS) across Canada which measure air temperature and other meteorological parameters including air pressure, relative humidity, wind speed, precipitation accumulation, and snow depth. These measurements are critical for weather, climate, hydrology, transportation and validation of remote sensing products. The measurement uncertainty and traceability of these measurements to the international system of units (SI) is essential to ensure measurements are reliable and meet climate and other user needs. As part of its air temperature renewal activities MSC intends to investigate: (1) alternative radiation shields with the potential to replace its current aspirated wooden Stevenson screen, (2) alternative temperature sensors to replace its current discontinued YSI44212 thermilinear sensor, (3) a new field verification procedure for improved comparability between reference and operational thermometers, (4) calibration program updates including calibration and adjustment of operational thermometers, and (5) quantifying measurement system uncertainties following the World Meteorological Organization (WMO) measurement uncertainty classification system. These activities are intended to inform the MSC's next generation of air temperature measurements in Canada into the future.

O-20: EVALUATION OF RELIABILITY AND USE OF DATA FROM SENSORS ON BOARD OF VEHICLES IN METEOROLOGYAND ENVIRONMENTAL OBSERVATIONS

Marcio A. A. Santana, Instituto Nacional de Pesquisas Espacias (INPE), Brazil
E. E. Almeida, Instituto Nacional de Pesquisas Espacias (INPE), Brazil
Patricia .L. O. Guimarães, Instituto Nacional de Pesquisas Espacias (INPE), Brazil
Luciana M. Sugawara, Instituto Nacional de Pesquisas Espacias (INPE), Brazil
Andrea Merlone, Istituto Nazionale di Ricerca Metrologica (INRiM), Italy
Chiara Musacchio, Istituto Nazionale di Ricerca Metrologica (INRiM), Italy
Graziano Coppa, Istituto Nazionale di Ricerca Metrologica (INRiM), Italy

The implementation of meteorological databases from new data sources, including previously disregarded metadata, comes to fill some spatial, temporal and informational gaps in several applications involvingenvironmental monitoring. Currently there is the WMO Integrated Global Observing System (WIGOS), which is a global network that provides essential data for meteorology and climatology. Among these observation systems are recommendations for mounting sensors in an Automatic Weather Station (AWS), including ideal conditions formeasurements and how obstacles, such as trees and buildings can affect sensor readings. There are different technologies, technical and configuration specifications for the most varied meteorological data networks currently available. This article proposes a possible innovation in an environmental observation system through the use of sensors embedded in automobiles, specifically the On-Board Diagnostics (OBD) system, as a source of data collection for environmental and meteorological monitoring. OBD is an automotive diagnostic system that monitors the proper functioning of the vehicle's engine, transmission, and exhaust systems. It can be used as an innovative source of data collection, since environmental monitoring can benefit from the following data provided by OBD: geographic location, date/time, air temperature and atmospheric pressure. Collecting this information remotely can increase data availability in a short amount of time. Data and their metadata (sensor specifications, including measurement uncertainty), organized in a database, have the potential to assist in meeting the demand for environmental data in places where there is a lack of data from meteorological station networks and to improve the evaluation and validation of data through its metadata. Thus, this work describes a proposal for the structuring and availability of a meteorological database with metadados and the evaluation of the reliability of the information, based on measurements carried out by sensors embedded in vehicles. In this work, an atmospheric pressure sensor in the range of 500 hPa to 1100 hPa and an air temperature sensor in the range of -15 ^{o}C to +45 ^{o}Cwere calibrated, whose largest uncertainties of type A (k=1) were 0.04 hPa and 0.004 ^{o}C. The measurement uncertainties expanded to a coverage probability of 95.45% evaluated ranged from 0.21 hPa to 0.22 hPa and from0.14 ^{o}C to 0.58 ^{o}C. The greatest contributions of uncertainty were from the calibration systems (type B), that is, uncertainties can be lower using other calibration systems. Based on the collected and corrected data and the measurement uncertainties of the two sensors, it is proposed the development of protocols for comparisons with other environmental monitoring systems (weather stations and remote observational systems), use of Artificial Intelligence techniques for validation and qualifying data from vehicles, testing the use of data in meteorological models and using it in several other meteorological

applications and climate studies. The involvement of the important automotive sector in the important activity of environmental monitoring has already become one of the great positive results of this project.

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METROLOGY FOR METEOROLOGY AND CLIMATE

WMO PRE-CLOSING REMARKS

Friday 11:25 to 11:40

Papers

O-90: WMO ROLLING REVIEW OF OBSERVATIONAL REQUIREMENTS – WHAT ROLE METROLOGY COMMUNITY COULD PLAY?

Krunoslav Premec, World Meteorological Organization (WMO)

The WMO Rolling Review of Requirements (RRR) process aims at providing a systematic and transparent process to support the high-level design and evolution of the WMO Integrated Global Observing System (WIGOS) aligned with its Vision in 2040. The RRR process compiles information about requirements for observations, observing system capabilities, their cost-effectiveness, and draws on experts and impact studies to provide guidance on the most important priorities for addressing the gaps between requirements and capabilities, with consideration of WMO priorities. The observational user requirements are mainly borne by the Numerical Weather Prediction community and described with several attributes, for example, horizontal and vertical resolution, observing cycle and geophysical uncertainty. User requirements are collated in a comprehensive, systematic, technology free and quantitative way in the WMO Observing Systems Capability Analysis and Review (OSCAR) / Requirements database.

The recently approved, updated RRR process includes the requirements across all Earth System domains and calls for close collaboration of different stakeholders, particularly in the process of comparing the user requirements with observing system capabilities and development of the Statement of Guidance (SoG). SoG is essentially a gap analysis with the main aim to draw attention to the most important gaps between user requirements and observing system capabilities and to provide resource materials useful for the implementation, improvement or development of the new observing systems.

It seems that there is still a lack of uniform interpretation of the user requirements, particularly with regard to the expressed uncertainty, by the numerical modelling communities and measurement communities, as well as engagement of the measurement community in the development of critical review and SoGs that are main drivers for the future development of the observing systems.

This presentation provides a brief insight into the updated RRR process, highlights some key issues with interpretation and common understanding of the user requirements and proposes some possible ways for better engagement of the metrology community in this process.

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Book of Abstracts of the MMC 2023– International Conference on Metrology for Meteorology and Climate

26 – 29 September 2023, Stupinigi Palace, Italy

Editors: Graziano Coppa, Andrea Merlone, Francesca Sanna
Cover photograph: Graziano Coppa

Torino, 2024

METEOMET

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