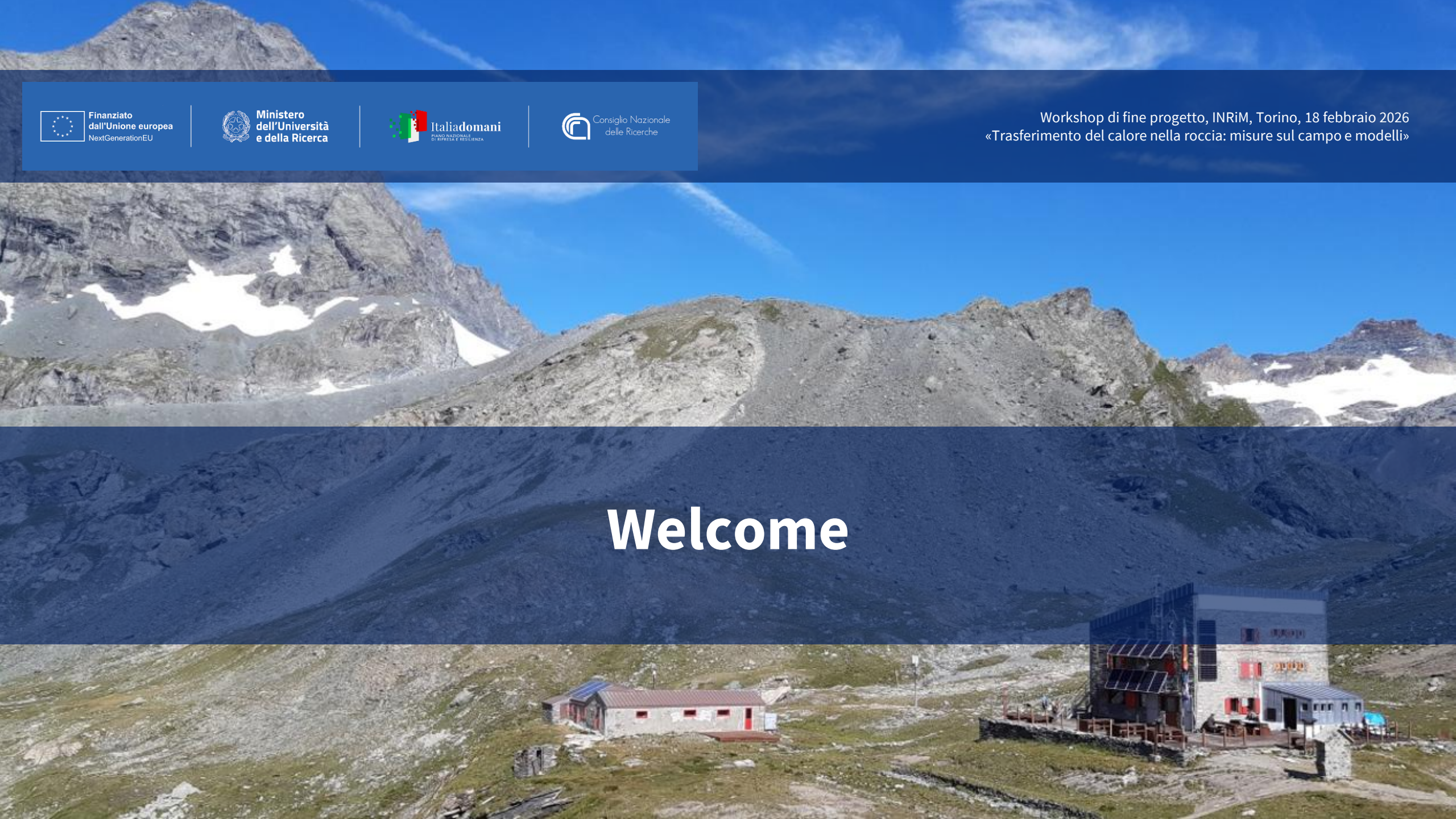

Finanziato dall'Unione europea NextGenerationEU

Ministero dell'Università e della Ricerca

Italiadomani
PIANO NAZIONALE DI RIPRESA E RESILIENZA

Consiglio Nazionale delle Ricerche

Workshop di fine progetto, INRiM, Torino, 18 febbraio 2026
«Trasferimento del calore nella roccia: misure sul campo e modelli»

Welcome

Finanziato dall'Unione europea NextGenerationEU

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Italiadomani — Piano Nazionale di Ripresa e Resilienza

Consiglio Nazionale delle Ricerche

Workshop di fine progetto, INRiM, Torino, 18 febbraio 2026
«Trasferimento del calore nella roccia: misure sul campo e modelli»

Trasferimento del calore nella roccia: misure sul campo e modelli

18 Febbraio 2026

Andrea Merlone

Meteorology

World Meteorological Organization

Geneve

Founded (as IMO) in **1873**

Metrology

BIPM
Bureau International des Poids et Mesures

Sevres

Convention of the metre in **1875**

GCW Global Cryosphere Watch

CCT

RECOMMENDATION T 3 (2010)
On climate and meteorological observations measurements

The Consultative Committee for Thermometry (CCT),

considering that

- global average temperature records are essential in understanding how the climate is changing;
- the consequences of these changes have deep impacts on different aspects of social, political and economic life;
- the need exists to improve the quality of data collection by assuring worldwide traceability in measurements involved in climate studies and meteorological observations, as expressed by climate-data users and during the recent WMO-BIPM joint workshop on "Measurement Challenges for Global Observation Systems for Climate Change Monitoring: Traceability, Stability and Uncertainty" (Geneva March 2010);

- the signing of the MRA by WMO will lead to closer liaison and cooperation with the thermal metrology community;

recommends

- to encourage NMIs and the scientific community, especially temperature metrologists, to be prepared to face new perspectives, needs, projects and activities related to the traceability, quality assurance, calibration procedures and definitions for those quantities involved in the

- to encourage NMIs and the scientific community, especially temperature metrologists, to be prepared to face new perspectives, needs, projects and activities related to the traceability, quality assurance, calibration procedures and definitions for those quantities involved in the climate studies and meteorological observations;

quality assurance needs of the climate change and monitoring communities.

- to support a strong cooperation between NMIs and Meteorological Institutions at local, national and international levels;

- to encourage NMIs to work with the relevant meteorological networks to support a monitoring framework for traceable climate data over long temporal terms and wide spatial scales based on best practice metrology;

World Meteorological Organization
COMMISSION FOR OBSERVATION, INFRASTRUCTURE AND INFORMATION SYSTEMS
Second Session
24 to 28 October 2022, Geneva

INFCOM-2/Doc. 7.4(2)
Submitted by: Chair
24.X.2022
APPROVED

AGENDA ITEM 7: **PROCEDURAL AND COORDINATION ASPECTS**

AGENDA ITEM 7.4: **Process for approval of publication of technical document series, uncertainty assessment and harmonization of uncertainty terminology**

UNCERTAINTY ASSESSMENTS AND HARMONIZATION OF UNCERTAINTY TERMINOLOGY

DRAFT DECISION

Draft Decision 7.4(2)/1 (INFCOM-2)

Towards improved uncertainty evaluations and harmonization of the uncertainty terminology across the key INFCOM-related WMO publications

The Commission for Observation, Infrastructure and Information Systems decides:

(1) To intensify activities on the assessment of uncertainty evaluations;

(2) To harmonize the definitions and terminology related to the term "uncertainty" across technical publications overseen by the Commission to ensure their use is correct, consistent and understood when used among WMO communities;

Requests SC-MINT to further promote, organize and coordinate field experiments and studies, necessary to refine and improve the uncertainty evaluation and traceability of measurements, including in collaboration with partners from the metrology community;

Decision justification:

Evaluation of uncertainties in measurements, their interpretation, and representativeness are critical for measurement data quality, comparability, and compatibility, in different observing networks, for example, Global Basic Observing Network (GBON) and Global Climate Observing System (GCOS) Surface Reference Network (GSRN). The uncertainties that are already presented throughout different WMO publications and tools, such as in the Measurement Quality Classifications for Surface Observing Stations on Land and in OSCAR/Requirements, require more in-depth technical justifications. This can be achieved, among others, through continued research supported by field experiments.

The term "uncertainty" is widely used throughout WMO publications, but often it is used with different definitions and without the necessary accompanying details for its proper interpretation and use. For example, uncertainty is sometimes used to designate the root mean square error of a single standard deviation, expressed at 67% (or k=1) confidence level, and in other cases, it relates to a quantity defining an interval about the result of a measurement, designated as expanded measurement uncertainty, and is expressed at 95% (k=2) confidence level. This leads to confusion in the use of WMO publications. Furthermore, in many instances, the term uncertainty is used interchangeably with terms such as error, accuracy, and precision, although all these terms represent different concepts and have different meanings.

Ruolo attuale INRiM in metrologia per il clima:

BIPM – CCT – Chair Working Group "Environment"
Co-Chair Task Group "Air Temperature"

EURAMET - Chair "Air Temperature Metrology"
TC-T Chair Strategy

WMO - Chair Expert Team "Measurement Uncertainty"

GCOS - Chair Sub Group "Science and Research" GSRN

GCW - Co-Chair Permafrost best practice (Concluded!)

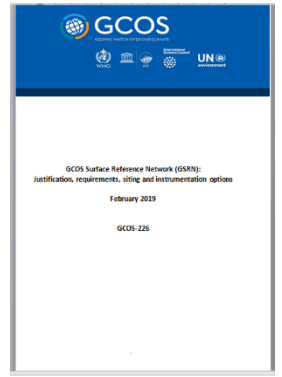
Membro Tavolo Artico – MAECI

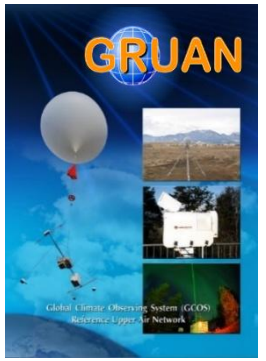
Componente Delegazione Nazionale WMO Congress e INFCOM

Ruolo attuale INRiM in metrologia per il clima:

Contributo a line guida:

Cap 4 Guide No8 – Permafrost	– Published
Requirements for Climate Reference Stations	– Published
Field validation of instruments	– Published
INFCOM Decision on Uncertainty evaluation	– Approved
GRUAN Guide an Manual reference radiosondes	– Published
Revision of Annex 1A	– Ongoing
Calibration of thermometers in air	– Ongoing
Siting classification	- Ongoing





Contribution to the WMO Guidelines for the evaluation of weather and climate extremes

The following are thanked for their outstanding contributions to this publication:

- Thomas C. Peterson, President of the former WMO Commission for Climatology, retired from the National Oceanic and Atmospheric Administration (NOAA), United States of America
- Derek Arndt, NOAA/National Centers for Environmental Information (NCEI), USA
- Randall S. Cerveny, Arizona State University, USA
- Fatima Driouech, Direction de la météorologie nationale du Maroc, Morocco
- Philip Jones, University of East Anglia (UEA)/Climatic Research Unit (CRU), United Kingdom of Great Britain and Northern Ireland
- Bianca Le, Monash University, Australia
- Andrea Merlone, Istituto Nazionale di Ricerca Metrologica (INRiM), Italy
- Blair Trewin, Bureau of Meteorology, Australia
- Xuebin Zhang, Environment and Climate Change Canada, Canada

WMO Secretariat:

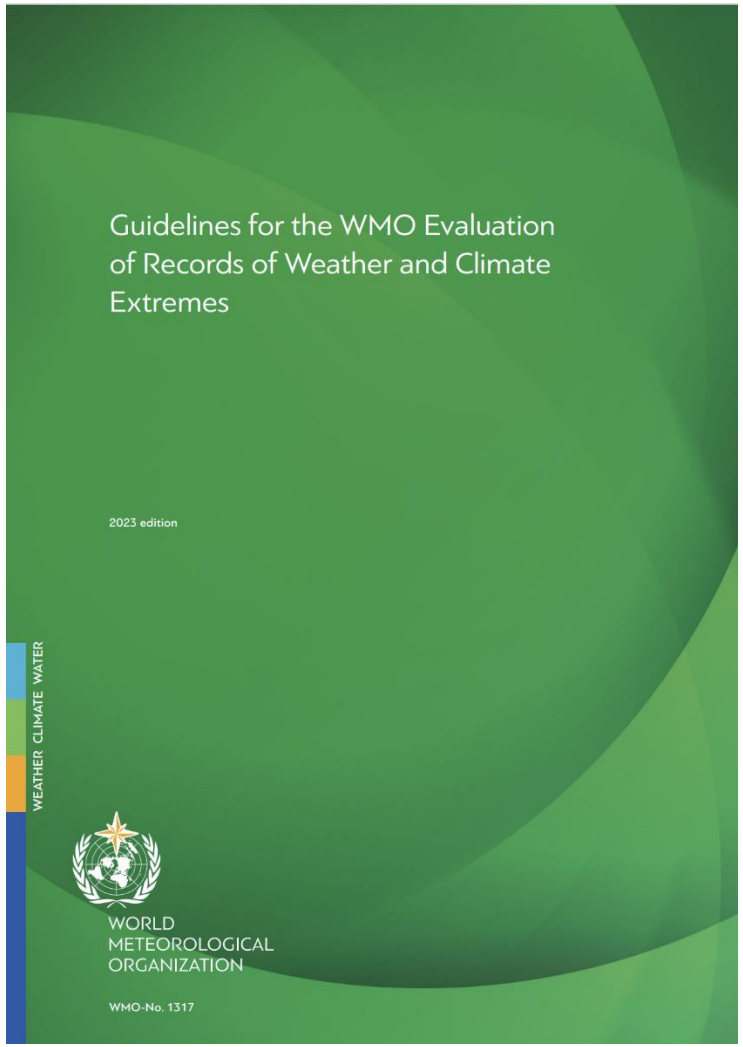
- José Álvaro Pimpão Silva
- Clare Nullis
- Krunoslav Premec

The review of these guidelines by experts from the following expert teams is highly appreciated:

- Expert Team on Climate Monitoring and Assessment (ET-CMA)
- Expert Team on Quality, Traceability and Calibration (ET-QTC)
- Expert Team on Measurement Uncertainty (ET-MU)

The following WMO Secretariat staff also contributed to the development of these guidelines or helped to review this publication:

- Omar Baddour
- Maxx Dilley
- Peer Hechler
- Nirina Ravalitera
- Isabelle Ruedi
- Igor Zahumensky



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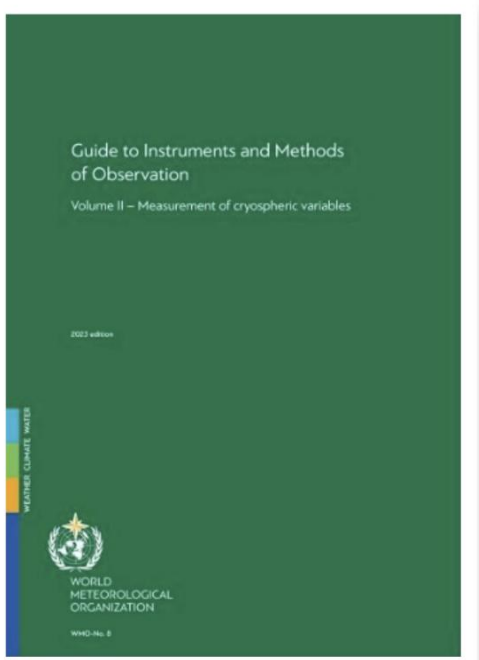

Guide to Instruments and Methods of Observation

Volume II – Measurement of Cryospheric Variables

WMO-No. 8

Collection(s)	Technical > Guides and other guidance
Authors	World Meteorological Organization (WMO)
Published by	WMO
Published in	Geneva

GCW Permafrost - Guide on Best Practices

(Work in Progress by the Permafrost Task Team of the GCW Advisory Group)

Under the guidance of the GCW Advisory Group and in coordination with the GCW Best Practices Coordinator, the Permafrost Task Team developed the Permafrost Best Practices Guide. It will be included in the WMO Guide for Instruments and Methods of Observation (WMO No.-8), Volume II, Measurement of Cryosphere Variables, as Chapter 4.

The guidelines cover measured variables, their common observation methods, the used instrumentation, the required configuration, and the relevant data reporting aspects.

WRITING TEAM 4
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Andrea
Merlone

Ruolo attuale INRiM in metrologia per il clima:

WMO Measurement Lead Center “Traceability and Field Metrology” (da giugno 2024)

World Meteorological Organization

Andrea
Merlone

Ruolo attuale INRiM in metrologia per il clima:

World Meteorological Organization

WMO Measurement Lead Center “Traceability and Field Metrology” (da giugno 2024)

Nuovi laboratori di metrologia per la meteorologia e il clima

Camere climatiche e bagni termostatici per caratterizzazione di strumenti meteorologici

Ruolo attuale INRiM in metrologia per il clima:

World Meteorological Organization

WMO Measurement Lead Center “Traceability and Field Metrology” (da giugno 2024)

EDDIE Chamber – wind tunnel

- **Temperature** control within 0.05 °C between -40 °C and 50 °C,
- **Pressure** control within 100 Pa between 75 kPa and 110 kPa.
- **Humidity** sensor calibration by comparison in the range 5 %rh to 98 %rh, (0.3%rh to 0.7 %rh uncertainty).
- **Wind speeds** up to 30 m/s in the test volume

Andrea
Merlone

Ruolo attuale INRiM in metrologia per il clima:

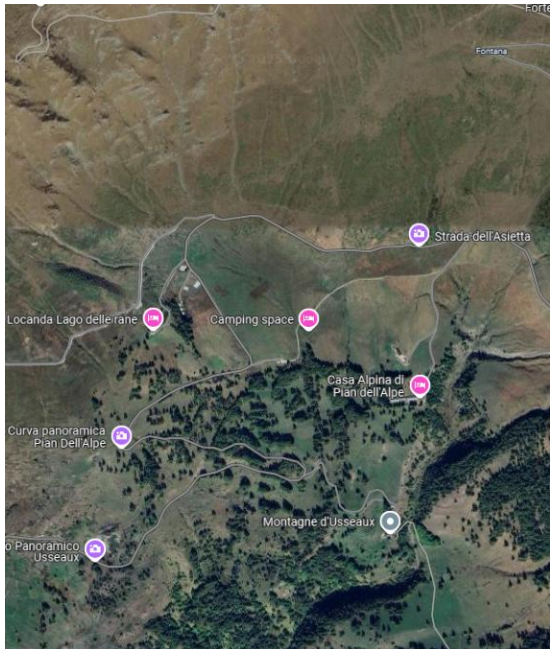
World Meteorological Organization

WMO Measurement Lead Center "Traceability and Field Metrology" (da giugno 2024)

Siti alpini e polari

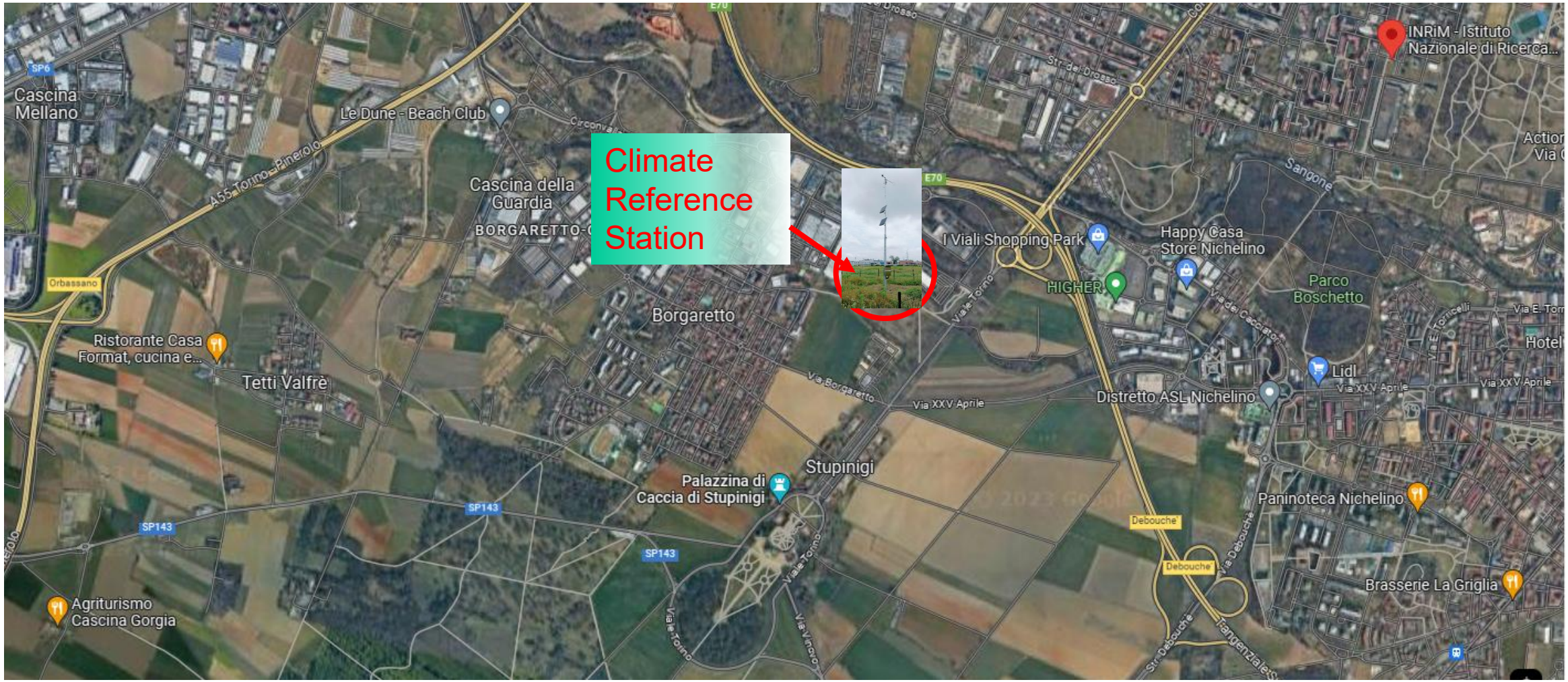
Alpine station (Balme verso Usseaux)

Permafrost Station – ARPA-P



Pian dell'Alpe – 2026?

Andrea
Merlone



Andrea
Merlone

Ruolo attuale INRiM in metrologia per il clima:

World Meteorological Organization

WMO Measurement Lead Center "Traceability and Field Metrology" (da giugno 2024)

Siti esterni per studi in campo

Area di ricerca - Torino

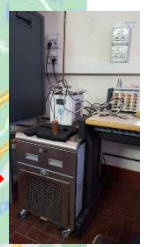
Climate Reference Station - Stupinigi

Ny-Ålesund arctic
Italian station

Andrea
Merlone

Mountain
experimental site
(twin stations)

BIPM



INRiM
laboratories
and primary
standards

WMO Measurement Lead Center "Traceability and Field Metrology

Usseaux
Nuova stazione
alpina

Reference
Station

Experimental
field

Ruolo attuale INRiM in metrologia per il clima:

World Meteorological Organization

WMO Measurement Lead Center “Traceability and Field Metrology” (da giugno 2024)

Sistemi di taratura e validazione trasportabili (temperature, pressione, aria, suolo, ghiaccio)

Impiego costante negli osservatori storici

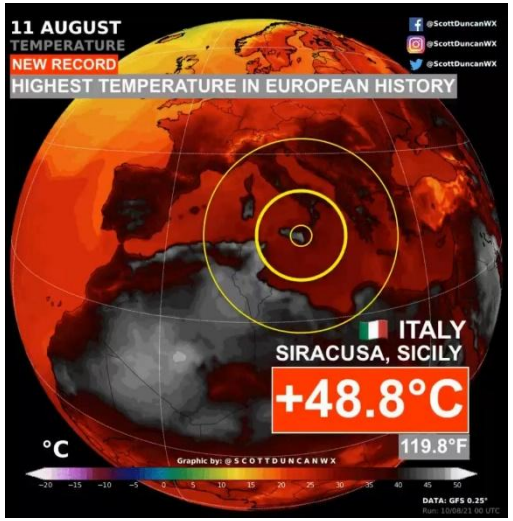
Andrea
Merlone

Ruolo attuale INRiM in metrologia per il clima:

World Meteorological Organization

WMO Measurement Lead Center “Traceability and Field Metrology” (da giugno 2024)

L’INRiM supporta formalmente la WMO nei processi di validazione di estremi di temperatura




METEOMET
Metrology for Meteorology
MeteoCal

Progetti

Andrea
Merlone

CoAt

2020-2023

METEOMET

Metrology for Meteorology

Since 2011

ATM

Air Temperature Metrology

2017-2024
A2TM 2025-2028

SoMMet

2022 - 2025

SimpleMet EU
2019-2022

CRIM

CLIMATE REFERENCE INSTRUMENTS AND MEASUREMENTS

2025-2028

cost
EUROPEAN COOPERATION IN SCIENCE & TECHNOLOGY

CRS

Climate Reference Station
a MeteoMet initiative

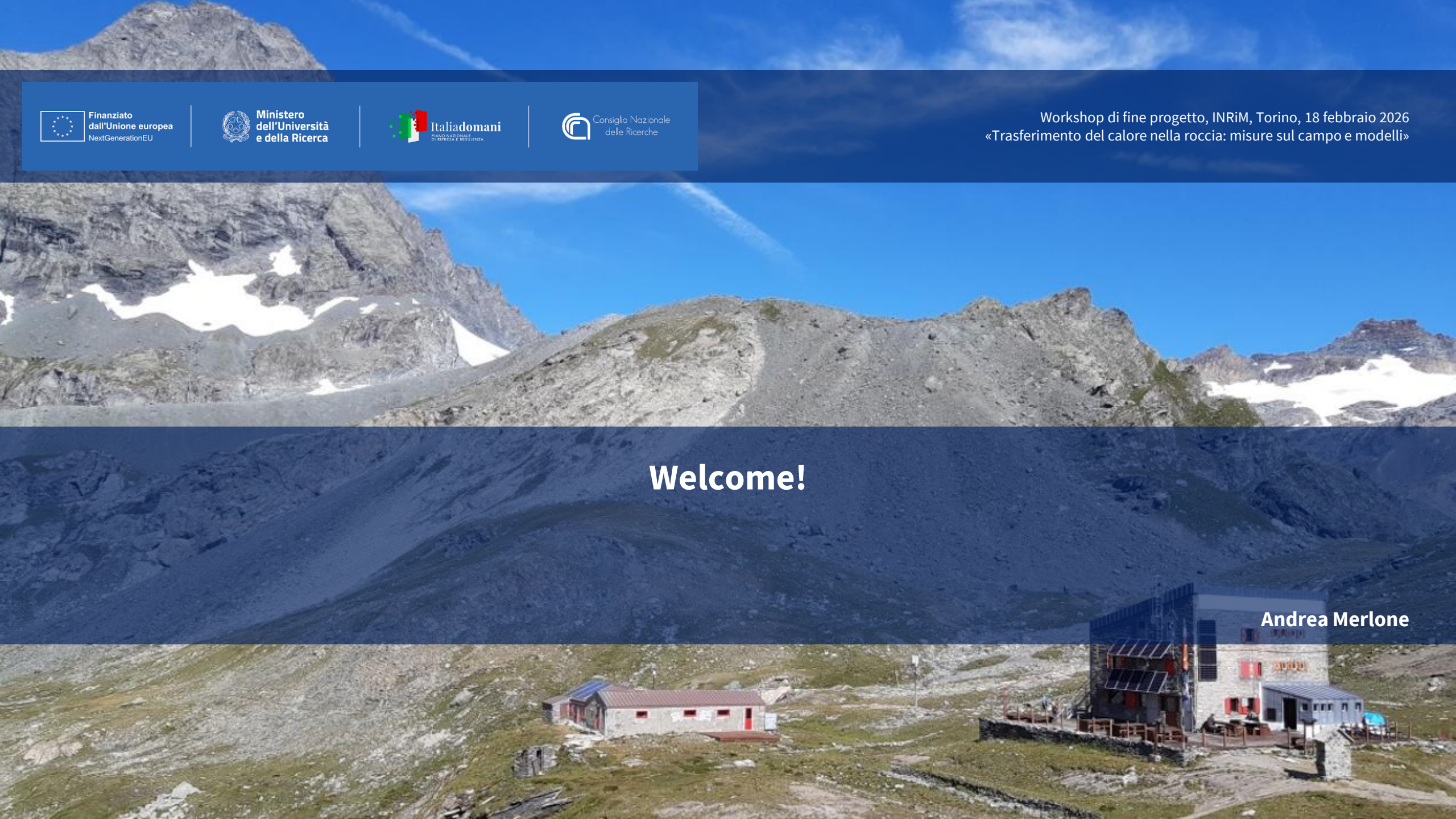
2019-2022

PRIN RockFall
2022 - 2025

INCIPIT

Metrology for non-catching rain instruments

2018-2022



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Italiadomani
PIANO NAZIONALE DI RIPRESA E RESILIENZA

Consiglio Nazionale delle Ricerche

Workshop di fine progetto, INRiM, Torino, 18 febbraio 2026
«Trasferimento del calore nella roccia: misure sul campo e modelli»

Welcome!

Andrea Merlone

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«Trasferimento del calore nella roccia: misure sul campo e modelli»

Termodinamica per il clima all'INRiM

Tra BIPM, WMO, GCOS e GCW

Il progetto «Rockfall»

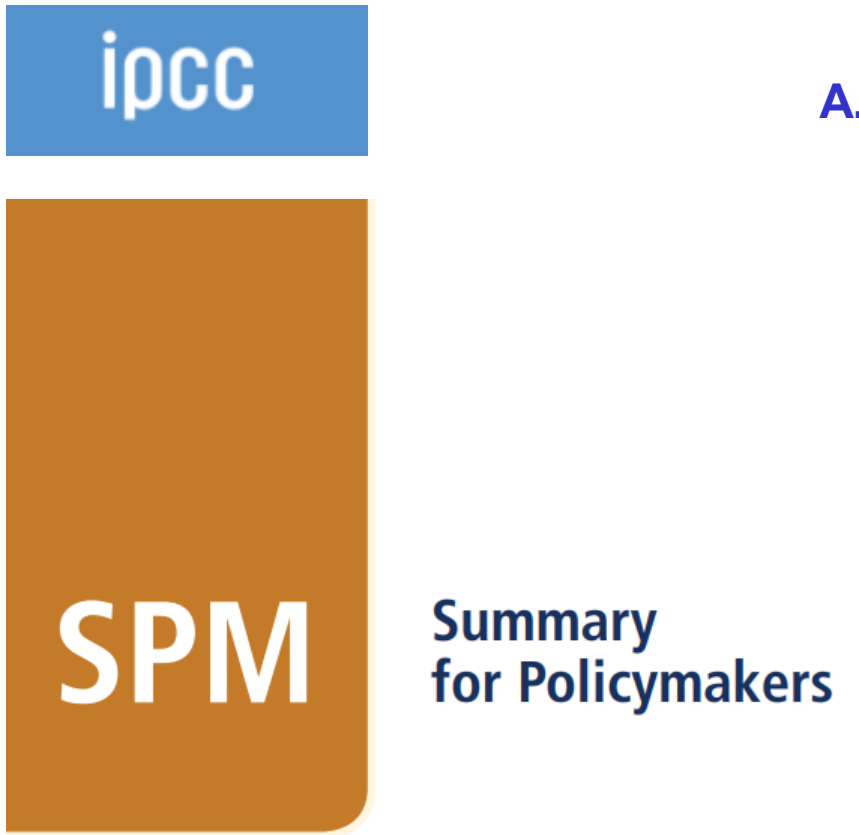
Andrea Merlone

Andrea
Merlone

ipcc

SPM

Summary
for Policymakers



A. Understanding Global Warming of 1.5 °C

A3. Climate-related risks for natural and human systems are higher for global warming of 1.5 °C than at present, but lower than at 2 °C (high confidence). These risks depend on the magnitude and rate of warming, […]

ipcc

SPM

Summary
for Policymakers

A. Understanding Global Warming of 1.5 °C

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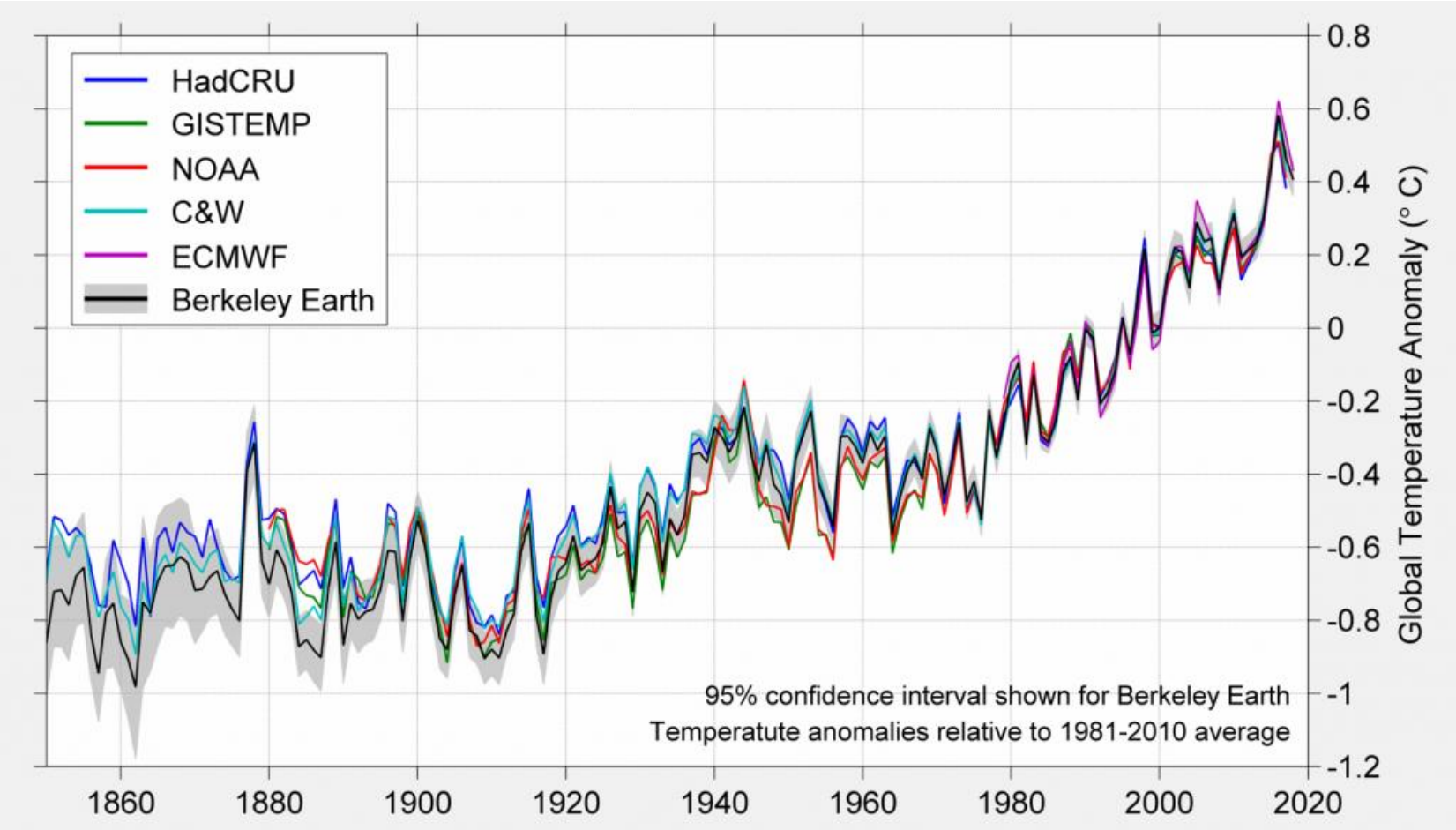


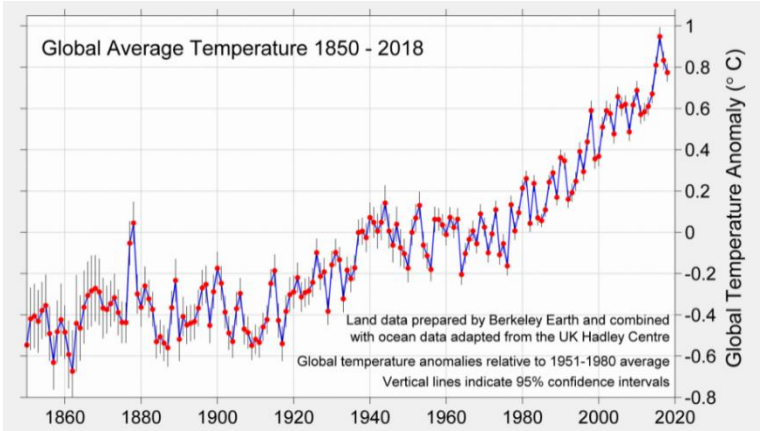
JONES, P. THE RELIABILITY OF GLOBAL AND HEMISPHERIC SURFACE TEMPERATURE RECORDS, ADVANCES IN ATMOSPHERIC SCIENCES

We need to measure air temperature

a) to make modern records comparable with historical series

b) to generate traceable, comparable and high quality climate data available for the future generations of climatologists

c) to improve comparability among different networks and different systems



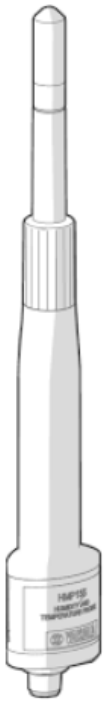
Ma…

Non esiste una definizione di «temperatura dell' aria»

Non esistono procedure di taratura per i termometri in aria

Non è (ancora) possibile calcolare le incertezze per una misura di temperatura dell'aria in meteorologia

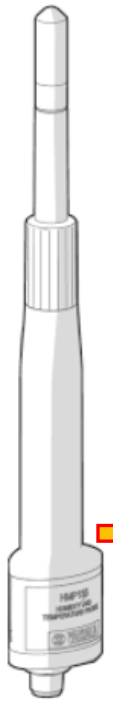
Calibration
Resolution
Drift
Logger
Sensitivity
Hysteresis
Repeatability

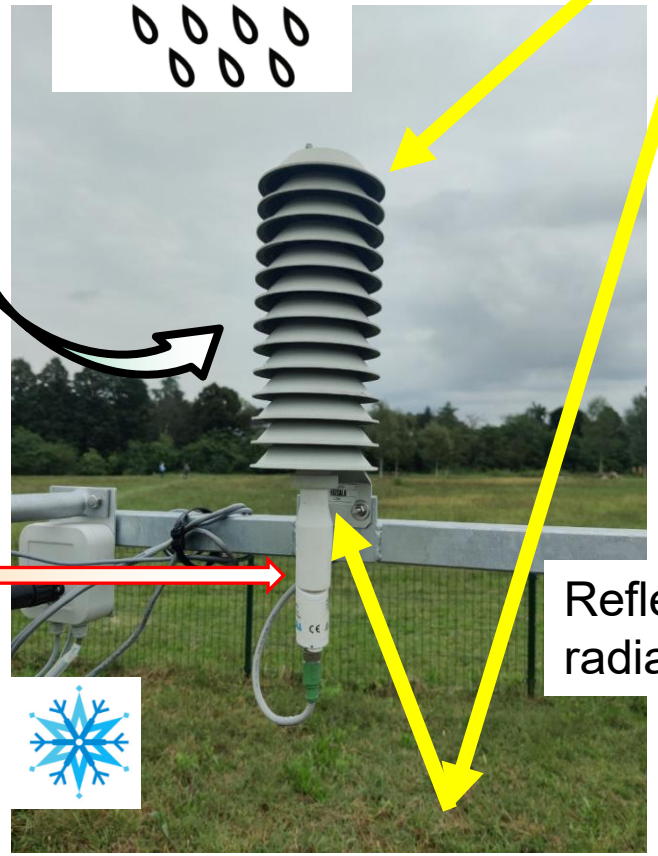


Associated quantities of influence

Andrea
Merlone

Calibration
Resolution
Drift
Logger
Sensitivity
Hysteresis
Repeatability





Main Factors

Heating
- Direct Radiation
- Reflected Radiation
- Screen Ageing

Cooling
- Screen Infrared Radiation
- Precipitation
- Evaporation
- Icing

www.nature.com/nphys / March 2024 Vol. 20 No. 3
nature physics
Universal dynamics out of equilibrium

Measure for measure

https://doi.org/10.1038/s41567-024-02428-w

The air temperature conundrum

Check for updates

Measuring air temperature is far from a trivial task, as Andrea Merlone, Graziano Coppa and Chiara Musacchio explain.

If you happen to have a thermometer within reach, try measuring the air temperature. As you will discover, this is much more difficult than it seems.

The results will be affected by radiative heat, so the thermometer needs to be protected from sunlight. If you are indoors, you will have to consider how to define room temperature and where to measure it. Or if you are outdoors, you will need to ask how representative the measurement will be. Pictured is a setup used to study the effect of meteorological thermometers' distances from the ground.

Indoors, you will experience temperature gradients – from the floor to the ceiling – or establish comparability among different

Temperature is a key quantity in climatology and the main observable we have for assessing whether climate change mitigation efforts will be efficient. The Intergovernmental Panel on Climate Change requires a careful consideration of the impacts associated with a global temperature increase of over 1.5 °C above pre-industrial levels. Thus air temperature needs to be measured and compared with historical records in locations where the effects of climate change are amplified, such as in the Arctic.

With both those needs and challenges in mind, the metrology and meteorology communities have started to work in close and intense cooperation, for example in a Task Group focusing on air temperature with three main goals: providing a definition of air temperature, assessing the corresponding measurement uncertainty, and publishing an international guideline for the calibration of thermometers in air.

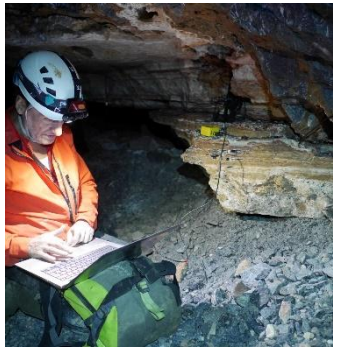
- Nella comprensione dei molteplici aspetti caratterizzanti l'evoluzione del clima, la variabile primaria è la temperatura…

dell'aria: misurata nelle tradizionali stazioni a terra o in alta atmosfera nei radiosondaggi

dell'acqua: in oceanografia, nelle acque interne e sotterranee

del ghiaccio e permafrost

del suolo: nelle relazioni di «eddie covariance»



- La complessità termodinamica di queste misurazioni richiede sforzi congiunti tra metrologia, ricerca applicata e teorica, modellizzazione, evoluzione degli strumenti di misura.

- In questo contesto si inserisce il PRIN «Rockfall» e il suo consorzio multidisciplinare

Istituto Nazionale di Ricerca Metrologica (INRiM).

Consiglio Nazionale delle Ricerche, Istituto di Ricerca per la Protezione Idrogeologica (CNR-IRPI).

Department of Energy of Politecnico di Torino (POLITO-DENERG).

Lab 3841

Trigger: Crescente rischio di instabilità dei versanti rocciosi dovuto all'aumento del trasferimento di calore.

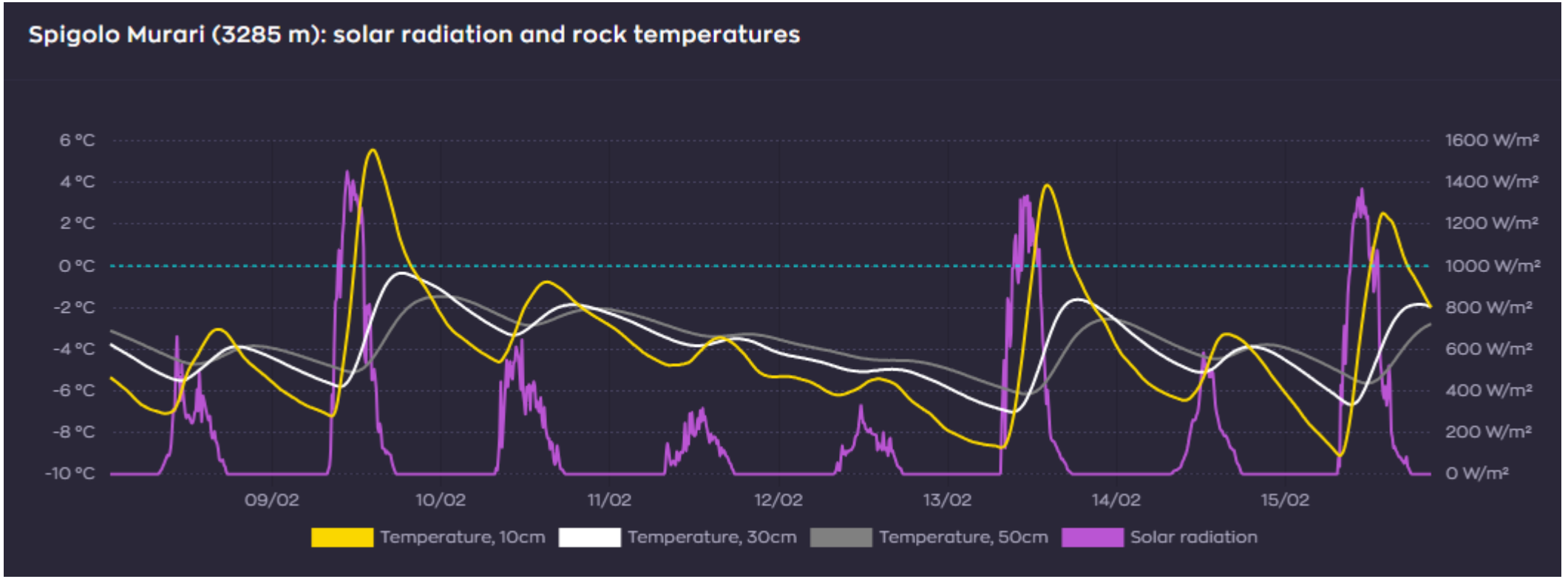
Objective: maggiore comprensione delle condizioni meteorologice e geologiche all base dei fenomeni di distacco nelle Alpi

Deliverable: un approccio metrologicao alle misure termiche e modellizzazione del trasferimento di calore in roccia in siti alpine.

- **A homogeneous rock temperature dataset**: essential to understand the effects of climate warming on slope instability. CNR-IRPI and INRiM were involved in the development of a new type of IoT device to measure rock temperature and solar radiation, with the capability to monitor additional environmental parameters at high-elevation sites.

CNR-IRPI installed the devices at different exposures and positions in the Bessanese glacial basin (10, 30 and 50 cm depths), allowing the creation of a dataset of rock temperature and solar radiation. The temperature measurements are traceable to national standards and allow the data comparability in space and time. CNR-IRPI also created a project website:

https://bessanese.lab3841.it.


Spigolo Murari (3285 m): solar radiation and rock temperatures
6 °C
4 °C
2 °C
0 °C
-2 °C
-4 °C
-6 °C
-8 °C
-10 °C
1600 W/m²
1400 W/m²
1200 W/m²
1000 W/m²
800 W/m²
600 W/m²
400 W/m²
200 W/m²
0 W/m²
09/02
10/02
11/02
12/02
13/02
14/02
15/02
Temperature, 10cm
Temperature, 30cm
Temperature, 50cm
Solar radiation

- **Application of numerical heat transfer simulation on the experimental zones:** POLITO-DENERG developed a heat transfer model for the Bessanese glacial area and the simulation results were compared with real rock temperature measurements at depths of 10 cm, 30 cm, and 50 cm.
- **Validation of numerical heat transfer model**: The verification of the model with the real measurement data showed a time shift and amplitude difference between the real and the simulated ones. For this, the model was calibrated, establishing model reliability and accuracy.
- **Assessment of thermal behaviour of rocks**: After application and calibration of the model, results highlight its capability to simulate heat transfer processes in complex geological settings, making it a useful tool to forecast thermal dynamics in alpine environments in future climate.
- https://bessanese.lab3841.it/project

Calibration of the temperature sensors: INRiM performed dedicated laboratory calibration of the rock temperature sensors, in the range of -20 °C to 40 °C, according to rock temperature in high mountains.

Characterization and uncertainty budget evaluation:
the laboratory calibration was designed in a way to best represent the measurement conditions in the field, in order to reduce uncertainties.

La metrologia termodinamica applicata fornisce:

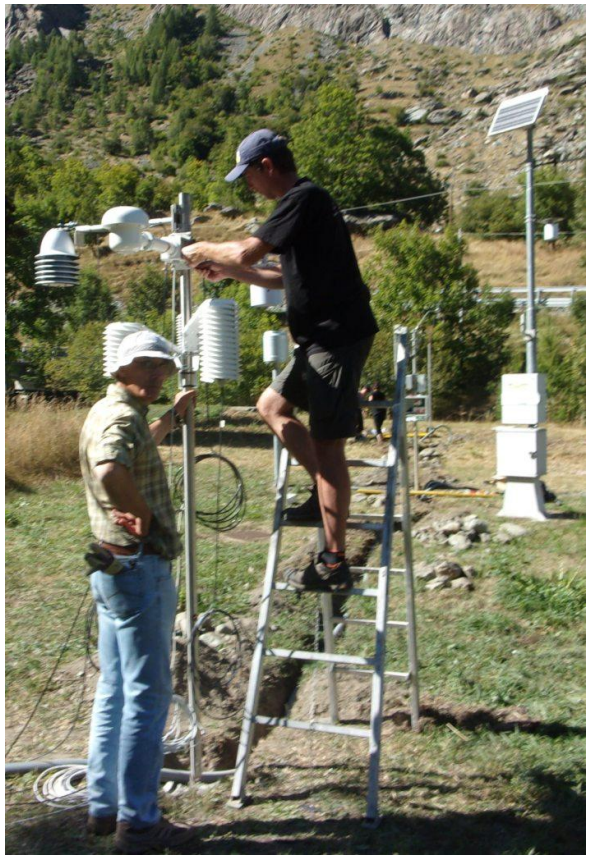
- Tarature specifiche e riferibilità metrologica delle misure
- Valutazione delle incertezze di misura (strumentali e complessive)
- Confrontabilità dei dati all'interno di network e tra network diversi
- Standardizzazione delle procedure di misura e linee guida

- Più in generale: metrologia per la criosfera e misure in roccia

Stazioni meteorologiche alpine

Balme Research station

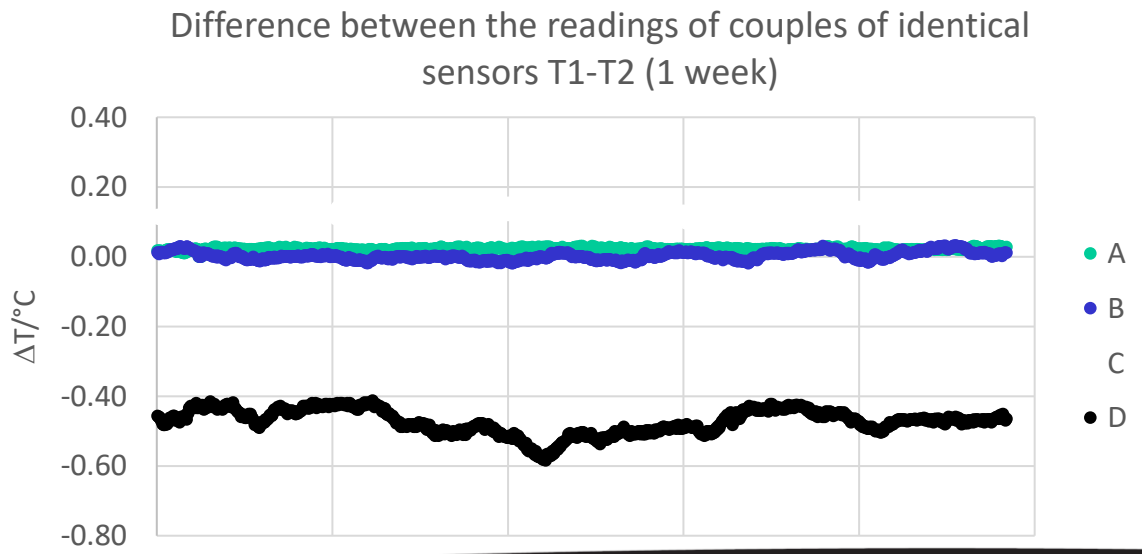
Installation and start-up



Laboratory for characterisation of sensors and complete systems
(in cooperation with IRPI – CNR)

Study of the different dataloggers,
evaluation of best mounting solutions.

Evaluations of difference between couples
of sensors, including shields, in a controlled
environment with slow temperature change.



Climate Data Quality Lab at IRPI

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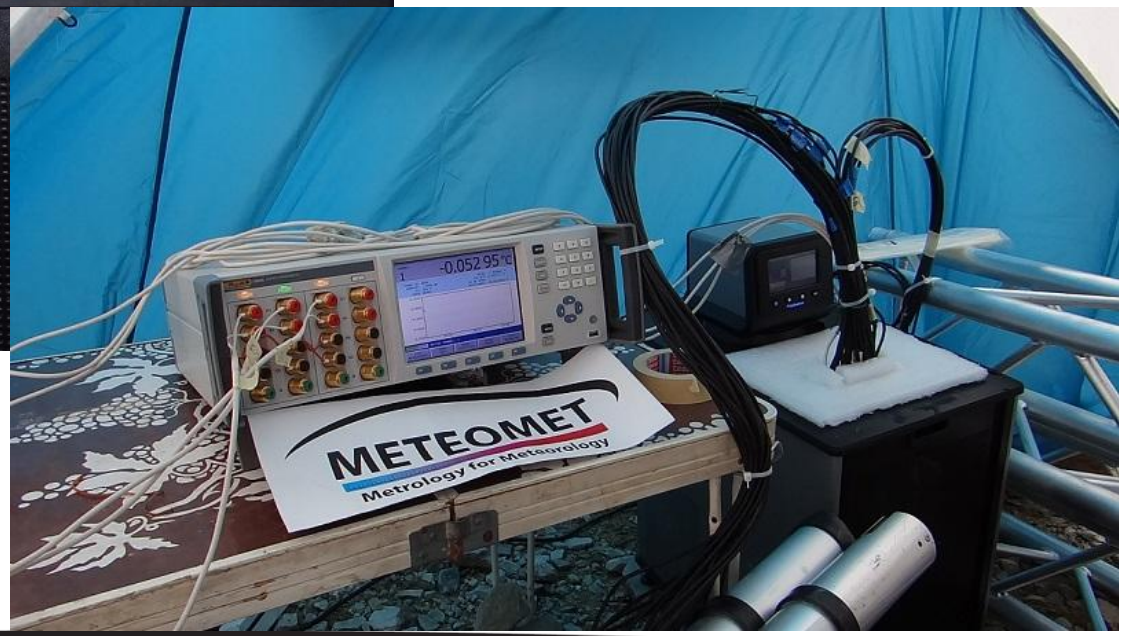
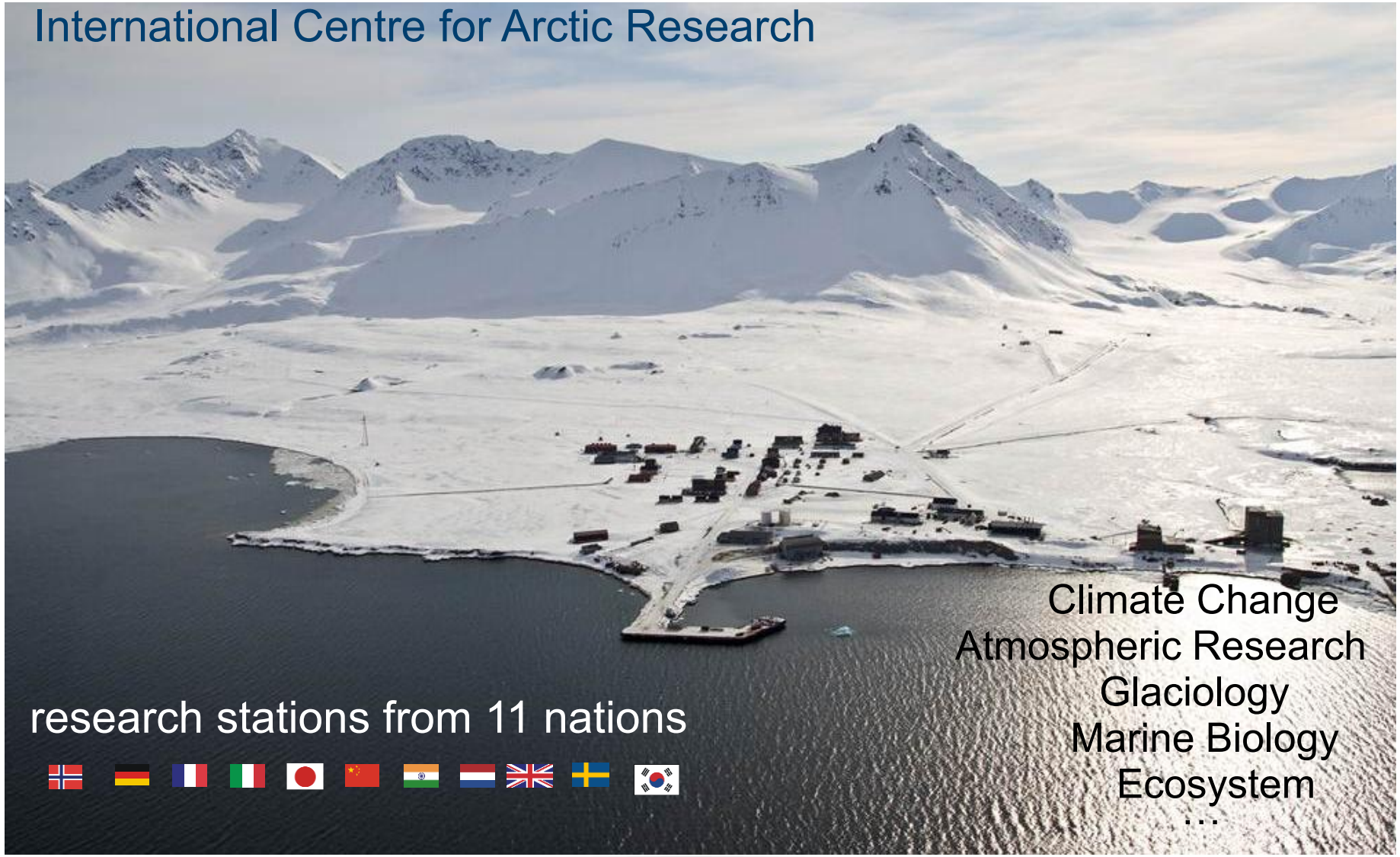
Merlone

Transportable calibration facilities for ice, soil, water and air thermometers and barometers.

A metrology lab at 3000 m


-0.052 95 °C
METEOMET
Metrology for Meteorology

Abbiamo (purtroppo) confermato alla sparizione definitiva di un area di permafrost (Colletta 2020)


International Centre for Arctic Research
research stations from 11 nations
Climate Change
Atmospheric Research
Glaciology
Marine Biology
Ecosystem
…

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Merlone

metrology in the Arctic

Ny-Ålesund 10 May 2017

New Metrology lab opened and presented at the station leaders in Ny-Ålesund

- In tutto ciò…

…se eliminiamo tutti gli errori,

il risultato di una misurazione
risulterà univoco (quindi perfetto)?

Finanziato dall'Unione europea NextGenerationEU

Ministero dell'Università e della Ricerca

Italiadomani
PIANO NAZIONALE DI RIPRESA E RESILIENZA

Consiglio Nazionale delle Ricerche

Workshop di fine progetto, INRiM, Torino, 18 febbraio 2026
«Trasferimento del calore nella roccia: misure sul campo e modelli»

Grazie

Andrea Merlone