6th Marine instrumentation workshop

From the new SI to environmental observations. BIPM activities and interaction with the WMO.

WEATHER CLIMATE WATER
TEMPS CLIMAT EAU

Andrea Merlone
WMO ET MU Chair
BIPM WG Environment Chair
INRiM

WMO OMM

World Meteorological Organization
Organisation météorologique mondiale

14 December 2021

The Importance of Metrology

- Metrology is the “science of measurements”.
- It deals with
  - The **definition** of internationally accepted units of measurement
  - The **realization** of units of measurement by scientific methods
  - **Dissemination** and **traceability** through accreditation and certification
  - Prescriptions of **calibration** procedures
  - Guidelines for **terminology** (VIM) and evaluation of **uncertainty** (GUM)
  - Support in evaluation of **measurement uncertainties**

WMO OMM

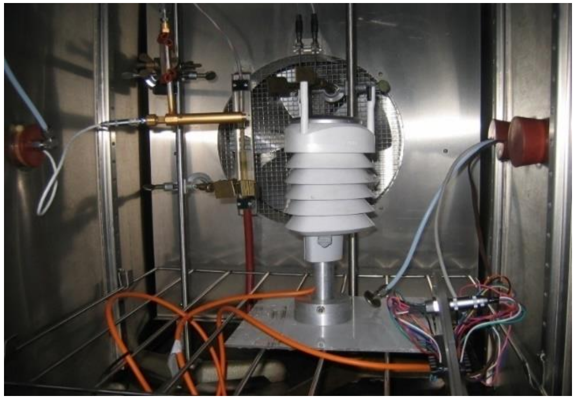
METROLOGY - GENERAL

The Science of Measurement:

- ✓ **Scientific Metrology –**
  - ✓ establishment of units of measurement,
  - ✓ the development of new measurement methods,
  - ✓ the realisation of measurement standards
- ✓ **Industrial and applied Metrology**
  - ✓ application of measurement to manufacturing and other processes
- ✓ **Legal Metrology**
  - ✓ fullfils regulatory requirements that arise from the need for protection of health, public safety, the environment, enabling taxation, protection of consumers and fair trade

METROLOGY - GENERAL

New fields of metrology



- ✓ **Metrology for Meteorology and Climate**
  - ✓ Cooperation with WMO
  - ✓ Support in evaluating field uncertainties
  - ✓ Contribution to guidelines and best practices
- ✓ **Health Metrology**
  - ✓ Evaluation of performances
  - ✓ Quality control
  - ✓ Instrumental uncertainties
- ✓ **Soft Metrology** The set of measurement techniques and models which enable the objective quantification of properties which are determined by human perception

The Importance of Metrology

Have you ever considered that…

with the single unit **"the meter"** and a decimal system of multiples and fractions, we can make measurements in nanotechnologies up to astronomy, for physics, geology, infrastructures, GPS or miniaturized techniques, in designing dresses or buildings, etc.

Or with the **kilogram** we can buy tomatoes at the marketplace, or evaluate the mass of nanoparticles or samples in biology, weight the amount of load of a containers cargo, up to the mass of asteroids and planets…

The Importance of Metrology

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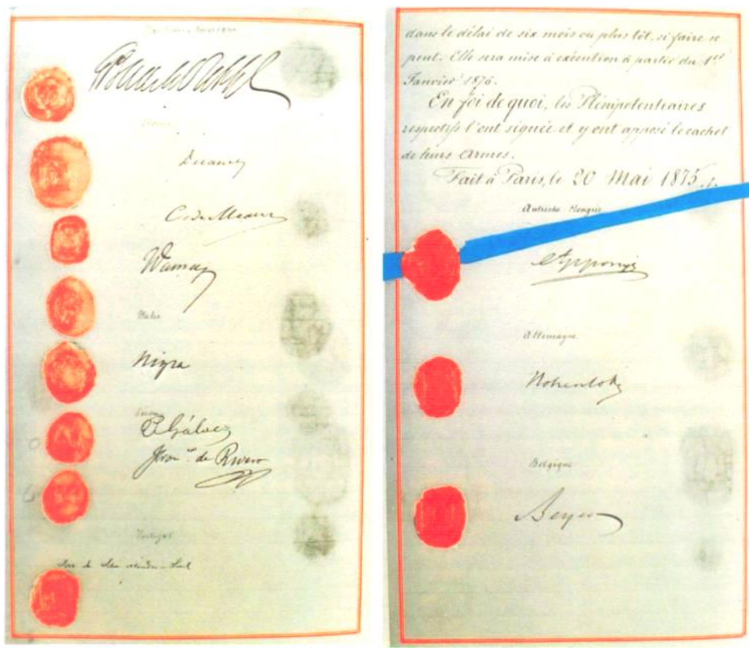
Or with the **kilogram** we can buy tomatoes at the marketplace, or evaluate the mass of nanoparticles or samples in biology, weight the amount of load of a containers cargo, up to the mass of asteroids and planets…

With just seven units and a decimal system we can measure everything!

The **Metre Convention** (French: *Convention du Mètre*), also known as the **Treaty of the Metre**, is the international treaty that was signed in Paris on 20 May 1875 by representatives of 17 nations

(Argentina, Austria-Hungary, Belgium, Brazil, Denmark, France, Germany, Italy, Peru, Portugal, Russia, Spain, Sweden and Norway, Switzerland, Ottoman Empire, United States of America, and Venezuela).



dans le délai de six mois ou plus tôt, si faire se peut. Elle sera mise à exécution à partir du 1er Janvier 1876.

En foi de quoi, les Plénipotentiaires respectifs l'ont signée et y ont apposé le cachet de leurs armes.

Fait à Paris, le 20 Mai 1875.

Meteorology

Geneve - Swiss

Founded (as IMO) in **1873**

Metrology

Sevres - France

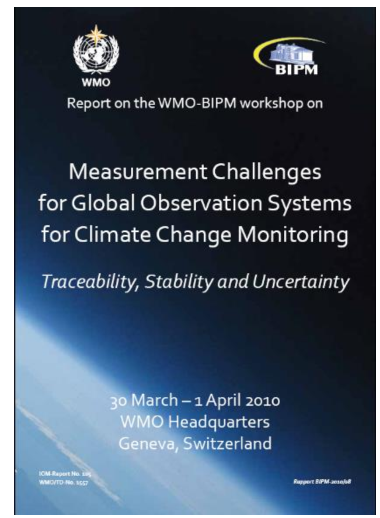
Convention of the metre in **1875**

World Meteorological Organization
Working together in weather, climate and water

MRA

BIPM

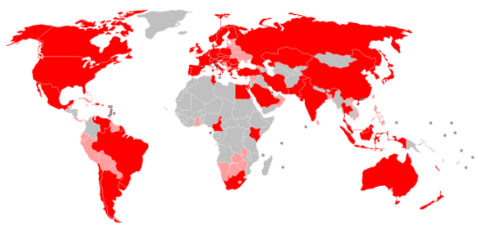
WMO entered the Convention du Metre by signing the Mutual recognition Arrangement.
The signing ceremony took place on *1 April 2010*



Left to right: Len Barrie (WMO), Andrew Wallard (Director BIPM), Michel Jarraud (Secretary General WMO), Ernst Göbel (President CIPM), Wenjie Zhang (WMO)

Metrology

Convention du Mètre today



Member States

- Argentina (1877)
- Australia (1947)
- Austria (1875 as Austria-Hungary)
- Belgium (1875)
- Brazil (1921)
- Bulgaria (1911)
- Cameroon (1970)
- Canada (1907)
- Chile (1908)
- China (1977)
- Croatia (2008)
- Czech Republic (1922 as part of Czechoslovakia)
- Denmark (1875)
- Dominican Republic (1954)
- Egypt (1962)
- Finland (1923)
- France (1875)
- Germany (1875)
- Greece (2001)
- Hungary (1925)
- India (1957)
- Indonesia (1960)
- Iran (1975)
- Ireland (1925)
- Israel (1985)
- Italy (1875)
- Japan (1885)
- Kazakhstan (2008)
- Kenya (2010)
- Malaysia (2001)
- Mexico (1890)
- Netherlands (1929)
- New Zealand (1991)
- North Korea (1982)
- Norway (1875 as part of Sweden and Norway)
- Pakistan (1973)
- Poland (1925)
- Portugal (1876)
- Romania (1884)
- Russia (1875 as the Russian Empire)
- Saudi Arabia (2011)
- Serbia (2001)
- Singapore (1994)
- Slovakia (1922 as part of Czechoslovakia)
- South Africa (1964)
- South Korea (1959)
- Spain (1875)
- Sweden (1875 as part of Sweden and Norway)
- Switzerland (1875)
- Thailand (1912)
- Tunisia (2012)
- Turkey (1875)
- United Kingdom (1884)
- United States (1878)
- Uruguay (1908)
- Venezuela (1879)

Associates

At its 21st meeting (October 1999), the CGPM created the category of "associate" for those states not yet members of the BIPM and for economic unions.[49]

- Albania (2007)
- Bangladesh (2010)
- Belarus (2003)
- Bolivia (2008)
- Bosnia and Herzegovina (2011)
- Botswana (2012)
- Caribbean Community (2005)
- Chinese Taipei (2002)
- Costa Rica (2004)
- Cuba (2000)
- Ecuador (2000)
- Estonia (2005)
- Georgia (2008)
- Ghana (2009)
- Hong Kong (2000)
- Jamaica (2003)
- Latvia (2001)
- Lithuania (2001)
- Macedonia (2006)
- Malta (2001)
- Mauritius (2010)
- Montenegro (2011)
- Namibia (2012)
- Oman (2012)
- Panama (2003)
- Paraguay (2009)
- Peru (2009)
- Philippines (2002)
- Moldova (2007)
- Seychelles (2010)
- Slovenia (2003)
- Sri Lanka (2007)
- Syria (2012)
- Ukraine (2002)
- Vietnam (2003)
- Zambia (2010)
- Zimbabwe (2010)

International Organisations

The following international organisations have signed the CIPM MRA:

- International Atomic Energy Agency (IAEA), Vienna, Austria (1999)
- Institute for Reference Materials and Measurements (IRMM), Geel, Belgium (1999)
- World Meteorological Organization (WMO), Geneva, Switzerland (2010)
- European Space Agency (ESA), Paris, France (2012)

WMO OMM

BIPM is located in Sevres

Meeting of the CCT (Consultative Committee for Thermometry) at BIPM

WMO OMM

Did you know?...

New SI in 2019. Based on fundamental constants.

Last values submission to CODATA: **01 July 2017**

Adoption of new values: CGPM **2018**

Adoption of new definitions: 20 May 2019

Further, the definitions of all seven base units of the SI will also be uniformly expressed using the explicit-constant formulation, and specific ***mises en pratique*** will be drawn up to explain the **realization** of the definitions of each of the base units in a **practical way**.

https://www.bipm.org/utils/en/pdf/CGPM/Draft-Resolution-A-EN.pdf

The (new) SI will be the system of units in which:

•the ground state hyperfine splitting frequency of the caesium 133 atom (^{133}Cs)$_{hfs}$ is exactly 9 192 631 770 Hz,

•the speed of light in vacuum *c* is exactly 299 792 458 m/s,

•the Planck constant *h* is exactly 6.626 0**70** x $10^{–34}$ J s

•the elementary charge *e* is exactly 1.602 17**6 634** x $10^{–19}$ C,

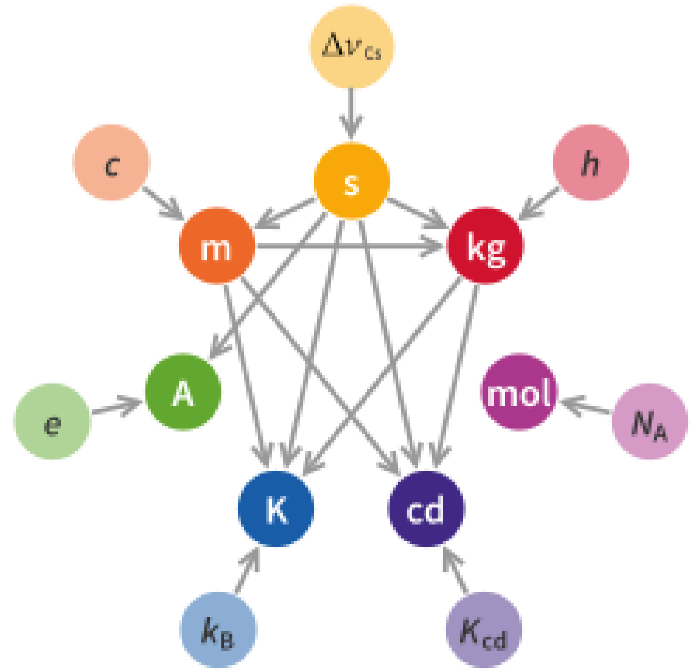
•the Boltzmann constant k_B is exactly 1.380 6**49** x $10^{–23}$ J/K

•the Avogadro constant N_A is exactly 6.022 14**0 76** x 10^{23} mol^{-1},

•the luminous efficacy K_{cd} of monochromatic radiation of frequency 540 x 10^{12} Hz is exactly 683 lm/W,

WMO OMM

The SI based on fundamental constants



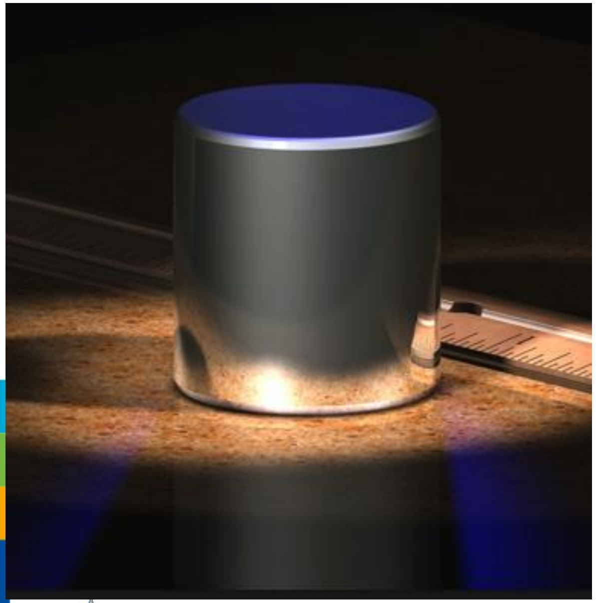
2019 May 20. The new System of Units

The SI is the system of units in which the following constants have these *exact* values.

Symbol	Base Unit	Constant	Numerical Value	Unit
$\Delta\nu_{Cs}$	second	the unperturbed ground state hyperfine transition frequency of the caesium 133 atom	9 192 631 770	Hz
c	metre	the speed of light in vacuum	299 792 458	$m\ s^{-1}$
h	kilogram	the Planck constant	$6.626\ 070\ 15 \times 10^{-34}$	J s
e	Ampere	the elementary charge	$1.602\ 176\ 634 \times 10^{-19}$	C
k	Kelvin	the Boltzmann constant	$1.380\ 649 \times 10^{-23}$	J/K
N_A	mole	the Avogadro constant	$6.022\ 140\ 76 \times 10^{23}$	mol^{-1}
K_{cd}	candela	the luminous efficacy of monochromatic radiation of frequency 540×10^{12} hertz	683	lm/W.

Kilogram

•The kilogram can then be realized by any suitable method, (for example the Kibble (watt) balance or the Avogadro (X-ray crystal density) method).. The value of the Planck constant will be chosen to ensure that there will be no change in the SI kilogram at the time of redefinition. The uncertainties offered by NMIs to their calibration customers will be broadly unaffected.



Kelvin

Old definition of the kelvin.

The kelvin, symbol K, *is the fraction 1/273.16 of the thermodynamic temperature of the triple point of water.*

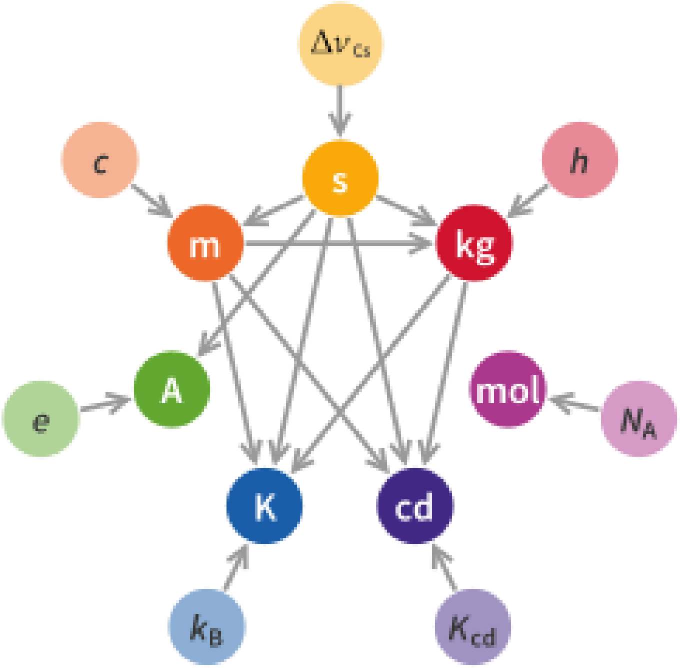
Kelvin

New definition of the kelvin.

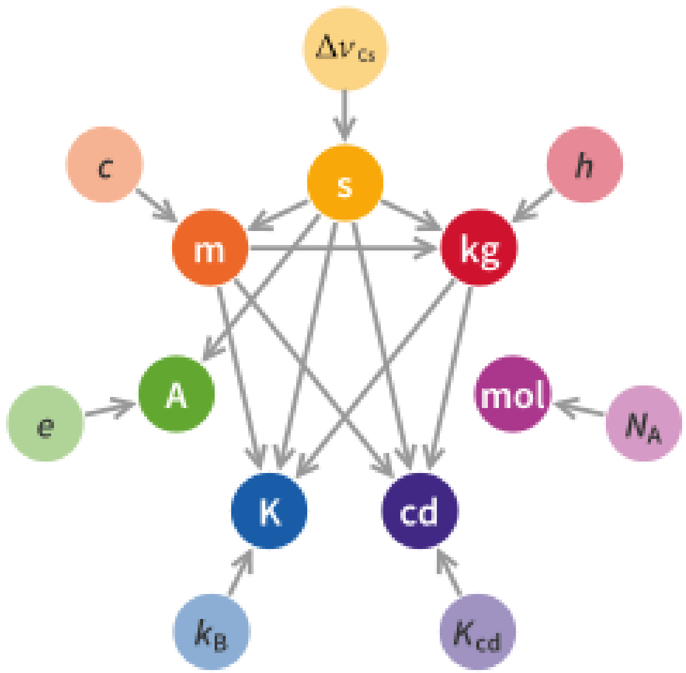
***The kelvin, symbol* K*, is the SI unit of thermodynamic temperature; its magnitude is set by fixing the numerical value of the Boltzmann constant to be equal to exactly* $1.380\ 649 \times 10^{-23}$ *when it is expressed in the SI base unit* $s^{-2}\ m^{2}\ kg\ K^{-1}$*, which is equal to* $J\ K^{-1}$** where the kilogram, metre and second are defined in terms of h, c and $\Delta\nu_{Cs}$

WMO OMM

The SI based on fundamental constants



The SI based on fundamental constants



But no worries… nothing will change for instrument and measurement results.

Fundamental Metrology

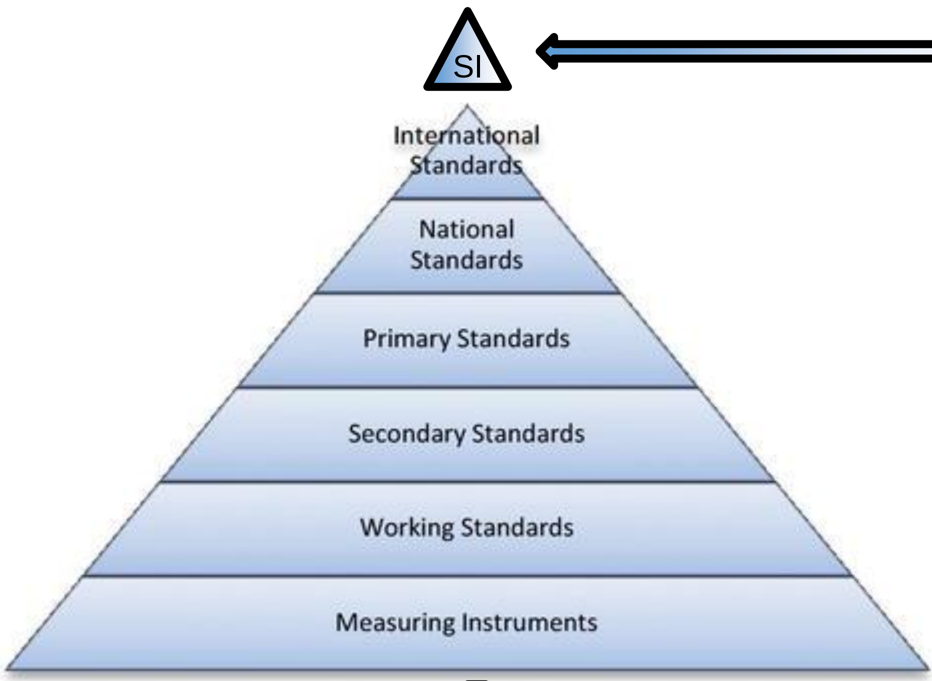
Fundamental Metrology

Applied Metrology

WMO OMM

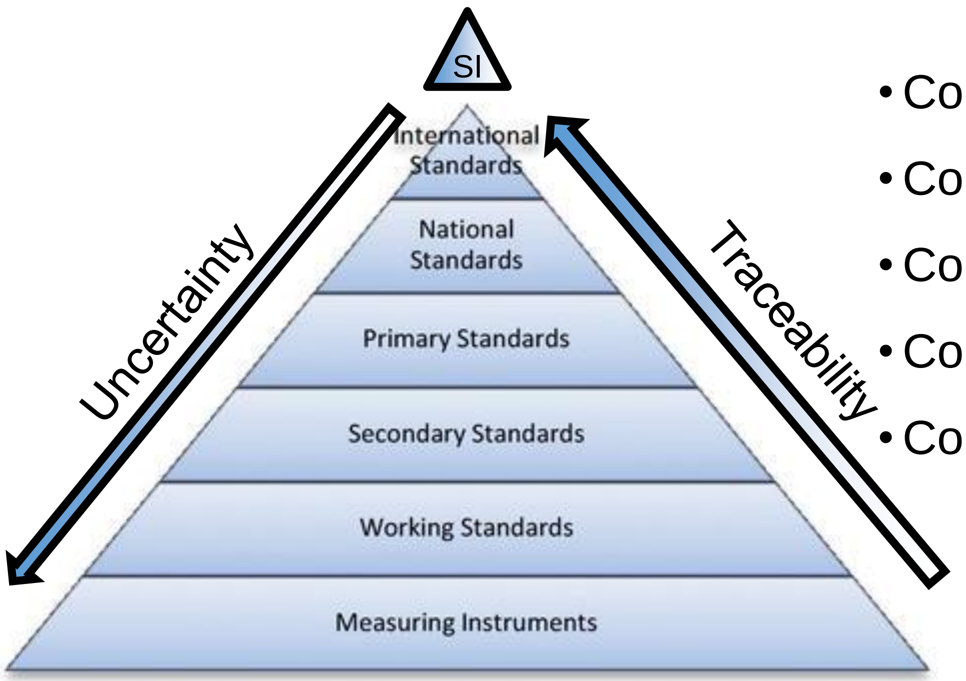
Traceability

Fundamental Metrology

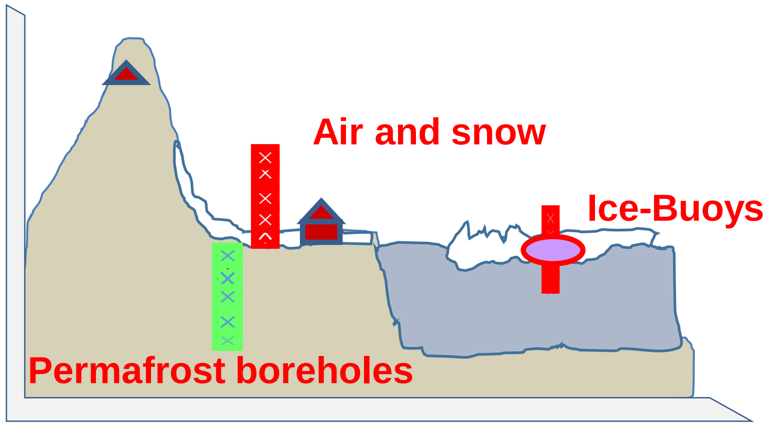


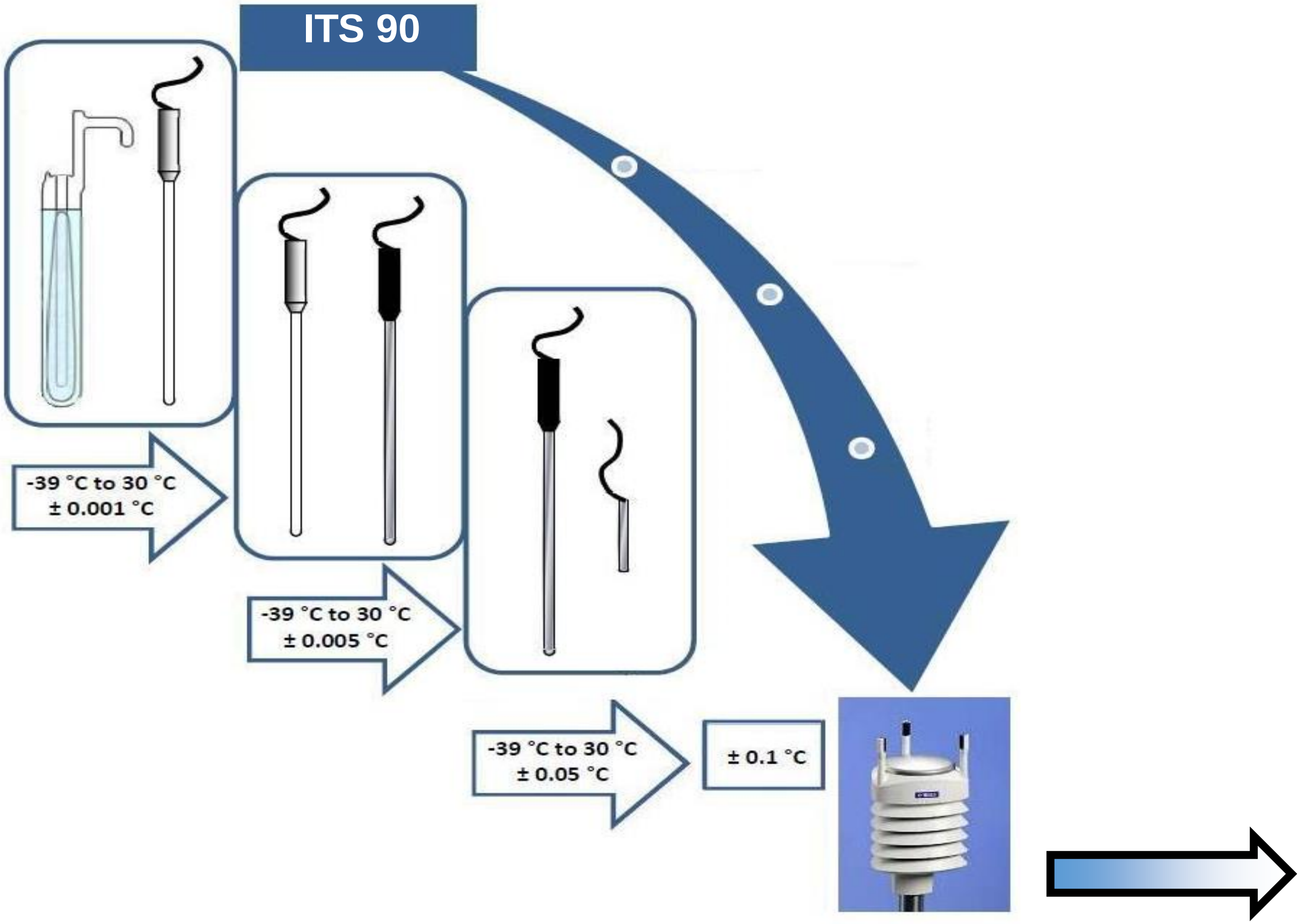
Applied Metrology

Traceability is required to reach full comparability



- Comparability on climate-change scales
- Comparability to fundamental physical models
- Comparability across generations
- Comparability across borders & organizations
- Comparability across metodologies



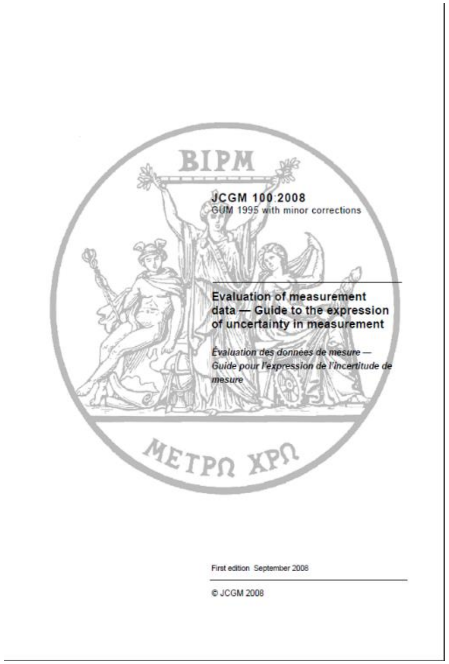

ITS 90
-39 °C to 30 °C
± 0.001 °C
-39 °C to 30 °C
± 0.005 °C
-39 °C to 30 °C
± 0.05 °C
± 0.1 °C

The Importance of Metrology

A common understanding, expression and evaluation of uncertainties

Guide to the expression of uncertainty in measurement – JCGM 100:2008

aka the “GUM”



→ **See training module on «Uncertainties»**

Uncertainty:

a logical doubt

about our limits to know the true

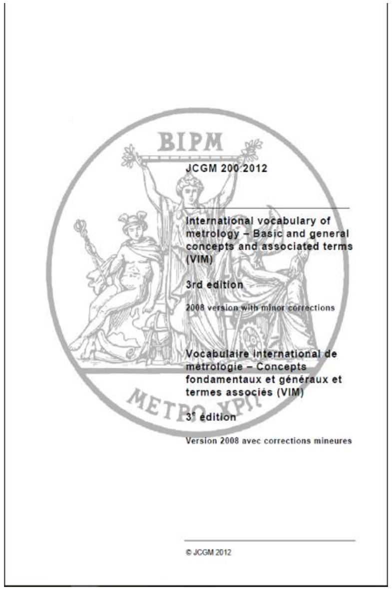
WMO OMM

The Importance of Metrology

A common terminology.

International vocabulary of basic and general terms in metrology
JCGM 200:2012

Aka the "VIM"



→ See training module on «International Vocabulary of Metrology»

WMO OMM

The JCGM

The Joint Committee has the responsibility for maintaining and updating the *International vocabulary of basic and general terms in metrology* (***VIM***) and the *Guide to the expression of uncertainty in measurement* (***GUM***)

Charter
Joint Committee for Guides in Metrology (JCGM)

http://www.bipm.org/en/committees/jc/jcgm/wg1.html
http://www.iso.org/sites/JCGM/JCGM-introduction.htm

Metrology for climate and environment

Metrology for climate and environment

Understanding
and
evaluating uncertainties

Influence quantities
in field

In-field calibrations

Climate Reference Data
and
Reference Stations

Metrology from
high mountains
to deep oceans

Validation
of extremes

Innovative
instrumentation
(non contact)

Improve
the siting classification

Normatives

Interlaboratory
comparisons

Instruments testing
and intercomparisons

WMO OMM

Understanding
and
evaluating uncertainties

Influence quantities in field

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Climate Reference Data
and
Reference Stations

METEOMET

Metrology for Meteorology

Metrology from high mountains to deep oceans

Validation of extremes

Innovative instrumentation (non contact)

Improve the siting classification

Normatives

Interlaboratory comparisons

Instruments testing and intercomparisons

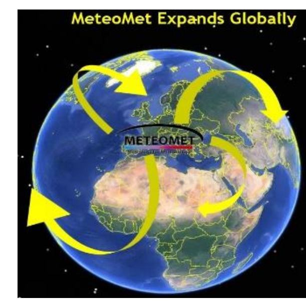
2011 -> 2023

METEOMET

Metrology for Meteorology

a worldwide consortium born as a EURAMET project

- 24 National Institutes of Metrology
- 12 Universities
- 13 Research centers
- 11 Instrument Companies
- 19 Meteorologycal services



WMO OMM

CoAT

2020-2023

ATM

Air Temperature Metrology

2017-2024

METEOMET

Metrology for Meteorology

2011 - 2017

CRS

Climate Reference Station

a MeteoMet initiative

2019-2022

INCIPIT

Metrology for non-catching rain instruments

2018-2022

WMO OMM

A thermometer measures the temperature of the air.

A thermometer measures the temperature of the air.

?

A thermometer measures the temperature ? of the air ?.

A (contact) thermometer gives an indication of its heat equilibrium at that time in that place under those conditions.

Different sensors, *different* solar shields, *different* technical solutions, *different* effects of environmental factors…

all of them introduce *different* errors and uncertainties, resulting in biases in records and data series

Issues on the definition of the measurand, similar to sea surface temperature

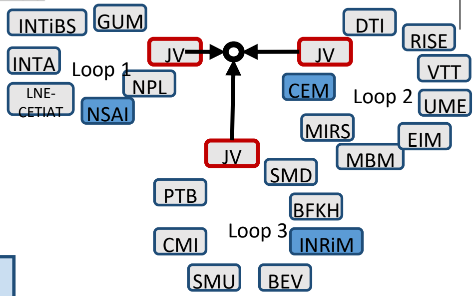
Air Temperature Metrology

1. A pilot study in the form of interlaboratory comparisons
2. World guide on calibration of thermometers in air
3. Propose a reference definition (practical) of air temperature
4. Provide a complete uncertainty budget for field measurements

EURAMET P1459

Document: G-OPS-TMP-024 Version: 2.0
Approved: Head of Secretariat 2013-02-01

1	Status: X proposed ☐agreed	Reference No: (if already existing)
2	Subject Field	T - Temperature T - Temperature
3	Type of collaboration	Cooperation in Research
3A	In the case of a comparison Registered as Key comparison (KC) or Supplementary Comparison (SC) in the KCDB: X no ☐yes If yes: No. of KC/SC: In case of a KC: Protocol approved by the responsible CC WG? ☐no ☐yes	
4	Coordinator Institute/Country: INRiM - Italy Name: Andrea Merlone Phone: +39011 3919 734 E-mail: a.merlone@inrim.itT	
5	Participating Partners	
5A	EURAMET members or associates (Institute's standard acronym with country code in brackets) as registered on EURAMET website. INRiM (IT) CEM (ES) CMI (CZ) DTI (DK) LNE (FR) INTiBs (PL) NPL (UK) NSAI NML (IE) MIRS/UL-FE/LMK (SI) SMD (BE) UME (TK)	



BIPM CCT Task Group Air Temperature kick off meeting 8 November 2021

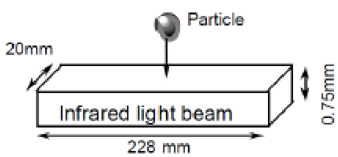
WMO OMM

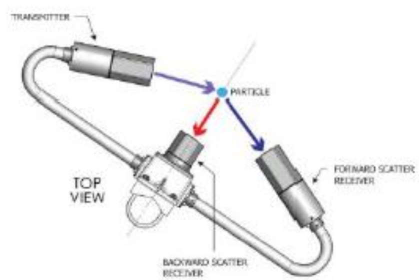
Innovative instrumentation (non contact)

INCIPIT

Metrology for non-catching rain instruments

Normatives

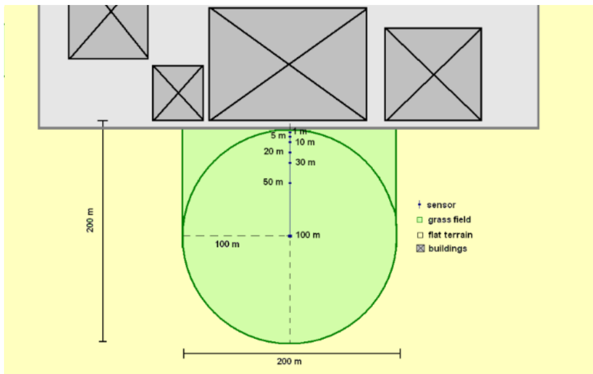




Traceable calibration methods for non-catching precipitation gauges to be incorporated into standards.

no.	Participant Type	Short Name	Organisation legal full name	Country
1	Internal Funded Partner	INRIM	Istituto Nazionale di Ricerca Metrologica	Italy
2	Internal Funded Partner	CEM	Centro Español de Metrología	Spain
3	Internal Funded Partner	DTI	Teknologisk Institut	Denmark
4	Internal Funded Partner	SMD	Federale Overheidsdienst Economie, KMO, Middenstand en Energie	Belgium
5	External Funded Partner	UNIGE	Università degli Studi di Genova	Italy
6	Unfunded Partner	EDI	Eidgenössische Departement des Innern	Switzerland

MeteoMet siting experiments



Three identical experiments

Thermometers at 2 m, 5 m, 10 m, 50 m, 100 m following the WMO classification

Experiments to support the siting classification

Road (Italy)

Trees (Czech Rep.)

Buildings (Spain)

Preliminary result (2020)

The WMO siting classification

over-estimates the uncertainties

METEOMET
Metrology for Meteorology

Interlaboratory comparisons

World Meteorological Organisation
Working Group on Technology Development and Implementation (WG TDI)
in RAVI
Task Team on Regional Instrument Centre

in cooperation with

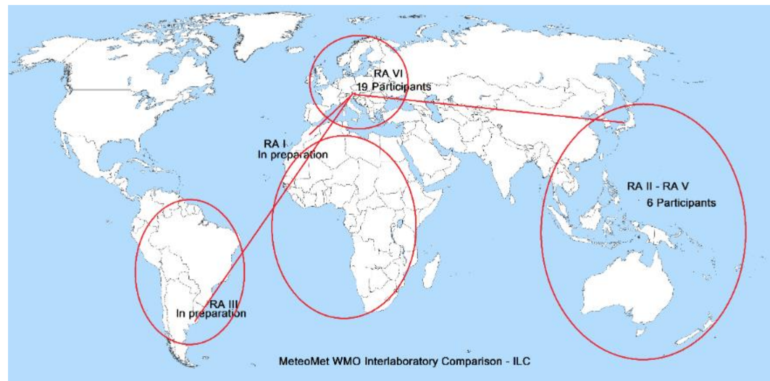
METEOMET

Final ILC protocol
INSTRUCTION FOR THE PARTICIPANTS IN THE INTERLABORATORY COMAPRISON

Title: Intercomparison in the field of temperature, humidity and pressure
MM-ILC-2015-THP

Date of approval of the protocol:
04.04.2016

Items:
- Two Pt-100 resistance thermometers ELPRO type 2210 4700/X in combination with Keysight/Agilent/Hewlett Packard 34420A
- Capacitive hygrometer Vaisala HMP155 A2GB11A0A1A1A0A
- Barometer Vaisala PTB220 ACA2A3A1AB



WMO-MM-ILC-2015-THP in WMO region VI published as IOM Report No. 128

University of Ljubljana
Faculty of electrical engineering

WMO-MM-ILC-2018-THP-2 in WMO region II and V is in a final draft stage

気象庁
Japan Meteorological Agency

To spread the same idea is planned WMO-MM-ILC-2020-THP in WMO region I, III and IV

Instituto Nacional de Tecnología Industrial
INTI

WMO OMM

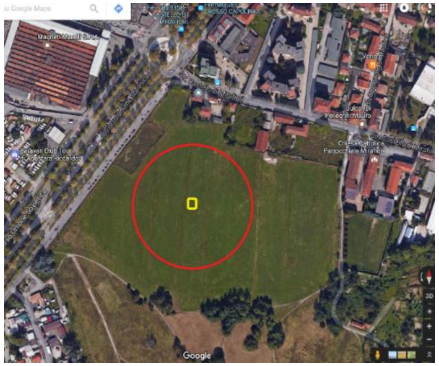
CRS
Climate Reference Station
a MeteoMet initiative

Instruments testing and intercomparisons

Study and characterisation in laboratory and field
for instruments to establish a research site associated to the GCOS GSRN

Hysteresis, robusteness, stability.

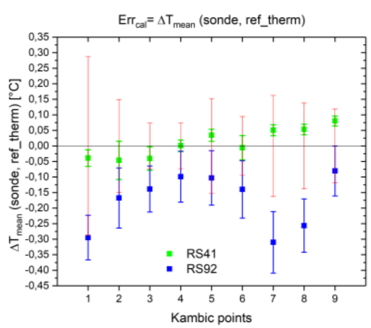
Site selection

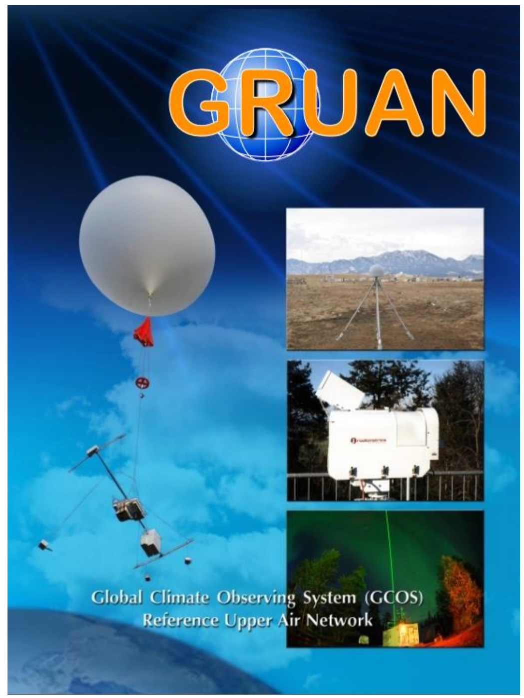


WMO OMM

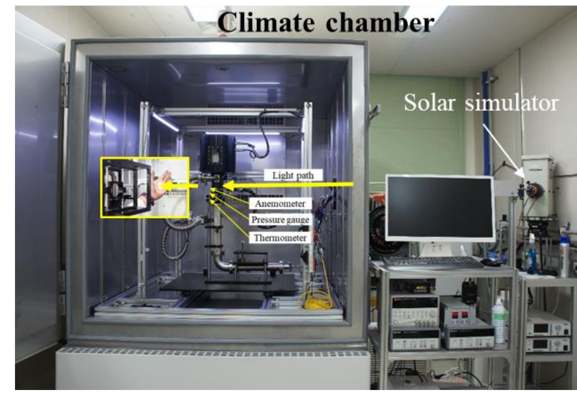
Climate Reference Data

Comparison between Vaisala RS41 and RS92 radiosondes at INRiM and CNR





Studies on the solar radiation correction of radiosonde at KRISS



Low-Temperature and Low-Pressure Humidity Chamber

- Temperature: (-70 – 30) °C
- Pressure: (50 – 1000) hPa
- Dew/frost point temperature: (-90 – 20) °Cdp/fp
- Relative humidity: (2 – 100) %rh
- U = 1.96 %rh (*k* = 2)

Metrology for
high mountains and
polar environment

July 2017, August 2018, August 2019.
A metrology lab at 3000 m

In-field calibrations

Ny-Ålesund 10 May 2017

New Metrology lab opened in Ny-Ålesund

CoAT

WMO OMM

Intercomparison of thermometers and shields in polar environment

-Internal Management actions in order Spain supports the *European Marine Sensor Calibration Network (EMSCN) of JPI Oceans*

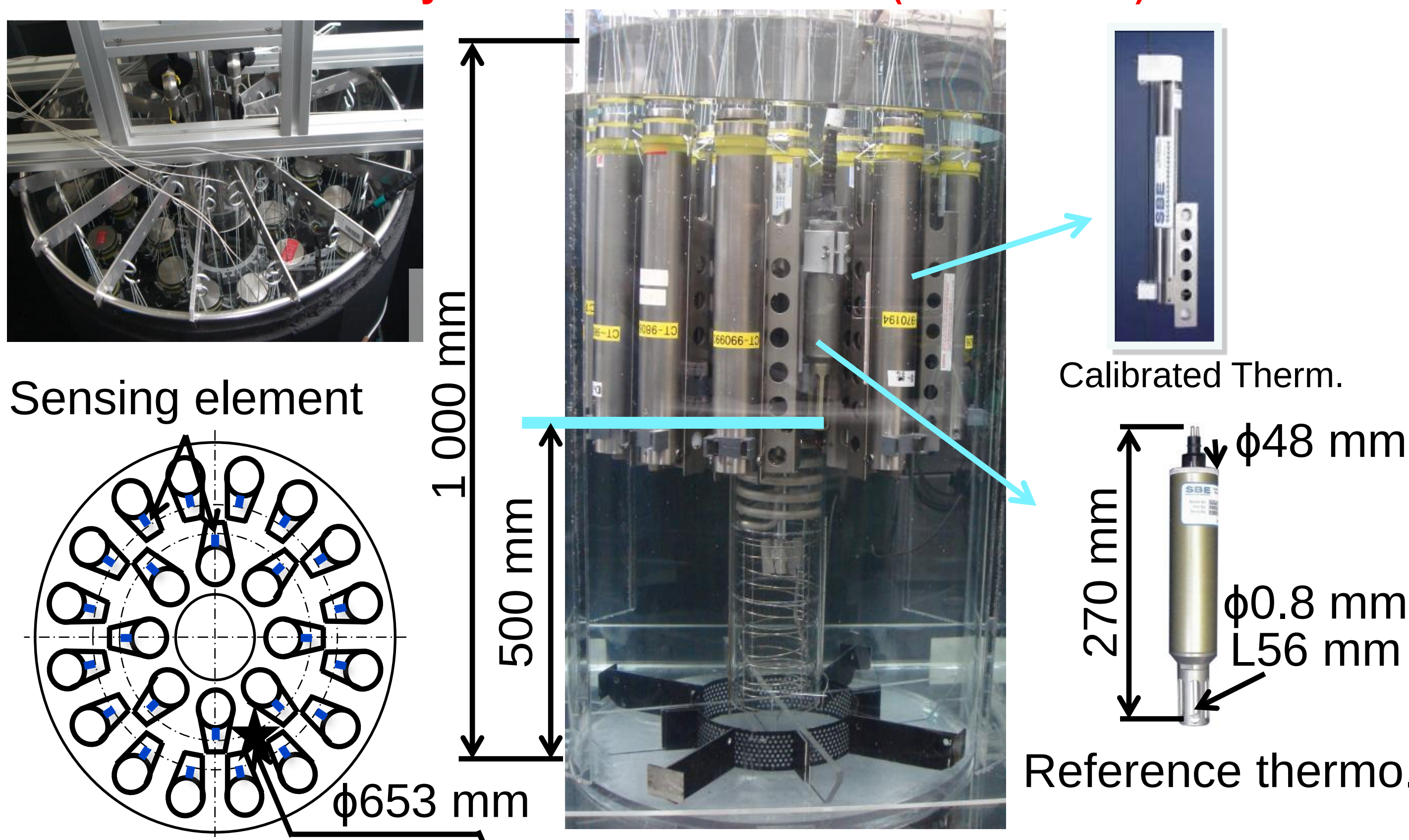
- Contribution to the paper*: White Paper on Marine Calibrations in Europe (JPI Oceans) C. Garcia Izquierdo*

CEM, CNAM, VSL activities in metrology for sea (deep sea, sea surface) temperature measurements.

Jamstec and NMIJ/AIST

Setup of ocean thermometers for calibration

Uncertainty of calibration: < 10 mK (0 ˚C to 30 ˚C)*



Loading; 24 DUTs, 1 reference thermometer

METEOMET

Metrology for Meteorology

Pressure sensitivity of deep ocean thermometers (JRP-v03 MeteoMet2)

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Pressure sensitivity of SBE35 and SBE3: experimental set-up

- Mounted in comparator block:
  - At atmospheric pressure:
    - I. SPRT Rosemount (sn 3223)
    - II. SBE35 (sn 0012)
  - At chamber pressure:
    - III. SBE 35 (sn 0081)
    - IV. SBE3 (sn 4812)

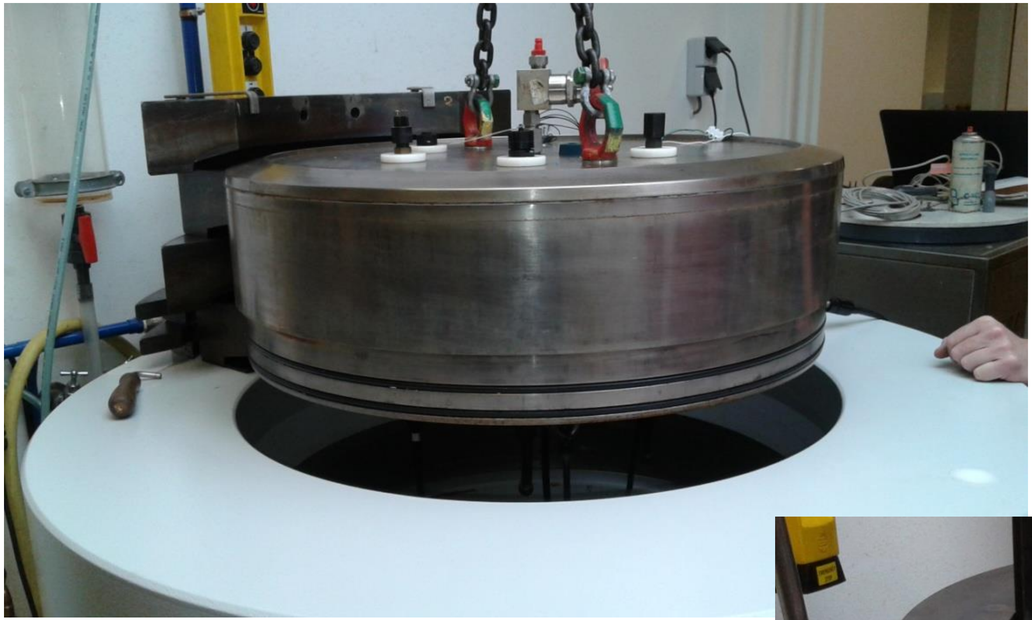
- Comparator block submersed in the water of the pressure cham

- Chamber pressurized at *P*
- Overnight temperature stabilization
- Simultaneous monitoring of the 4 devices for ~ 1 h
- Repeated for different pressure values: 0.1 MPa, 10 MPa, 20 M
30 MPa, 40 MPa, 50 MPa, 60 MPa

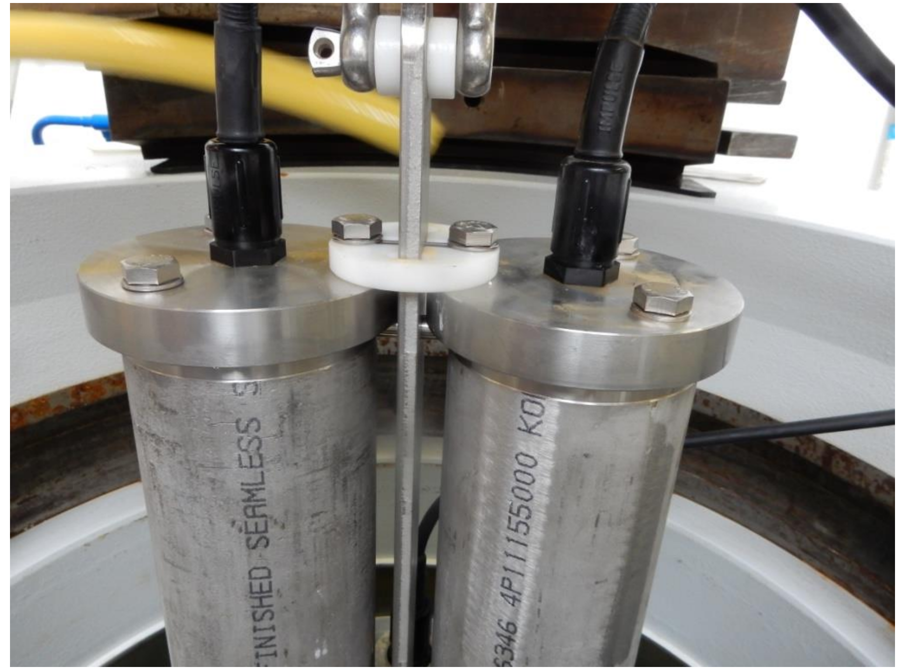
- 2 measurement runs in June 2016

- Temperature not controlled (maximum drift ≈ 10 $mK \cdot h^{-1}$)

Pressure chamber



Under-water connections



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Calibration of SBE35 and SBE3 in the VSL sub-millikelvin calibration facility

- Calibration by comparison in water bath 0 ^{o}C to 30 ^{o}C

- Resistance ratio bridge: Isotech MicroK 70

- Homemade temperature control of the water temperature

- Brass comparator block:
    - SBE35 (sn 0019)
    - SBE3 (sn 4812)
    - 2 reference SPRTs

- Investigation of potential heating of SBE35 from SBE3 sensor and head:
    - Both SBE35 and SBE3 on
    - SBE35 on and SBE3 off
    - Both SBE35 and SBE3 on but bath stirring motor disabled

    → No measurable effect observed

METEOMET

Metrology for Meteorology

New collaboration activities are welcome.

WEATHER CLIMATE WATER
TEMPS CLIMAT EAU

Thank you

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