"SIOS training course on metrology in Svalbard

ISP Istituto di Scienze Polari
Consiglio Nazionale delle Ricerche

Andrea Merlone

INRiM
ISTITUTO NAZIONALE DI RICERCA METROLOGICA

BIPM – CCT WG Environment chair
BIPM – TG Air Temperature Co-Chair
WMO - ET Uncertainties Chair
WMO - GCW Permafrost Co-Chair
GCOS – GSRN SG5 Chair
IMEKO TC 12 Scientific Secretary
MeteoMet coordinator
Co-chair ISTI

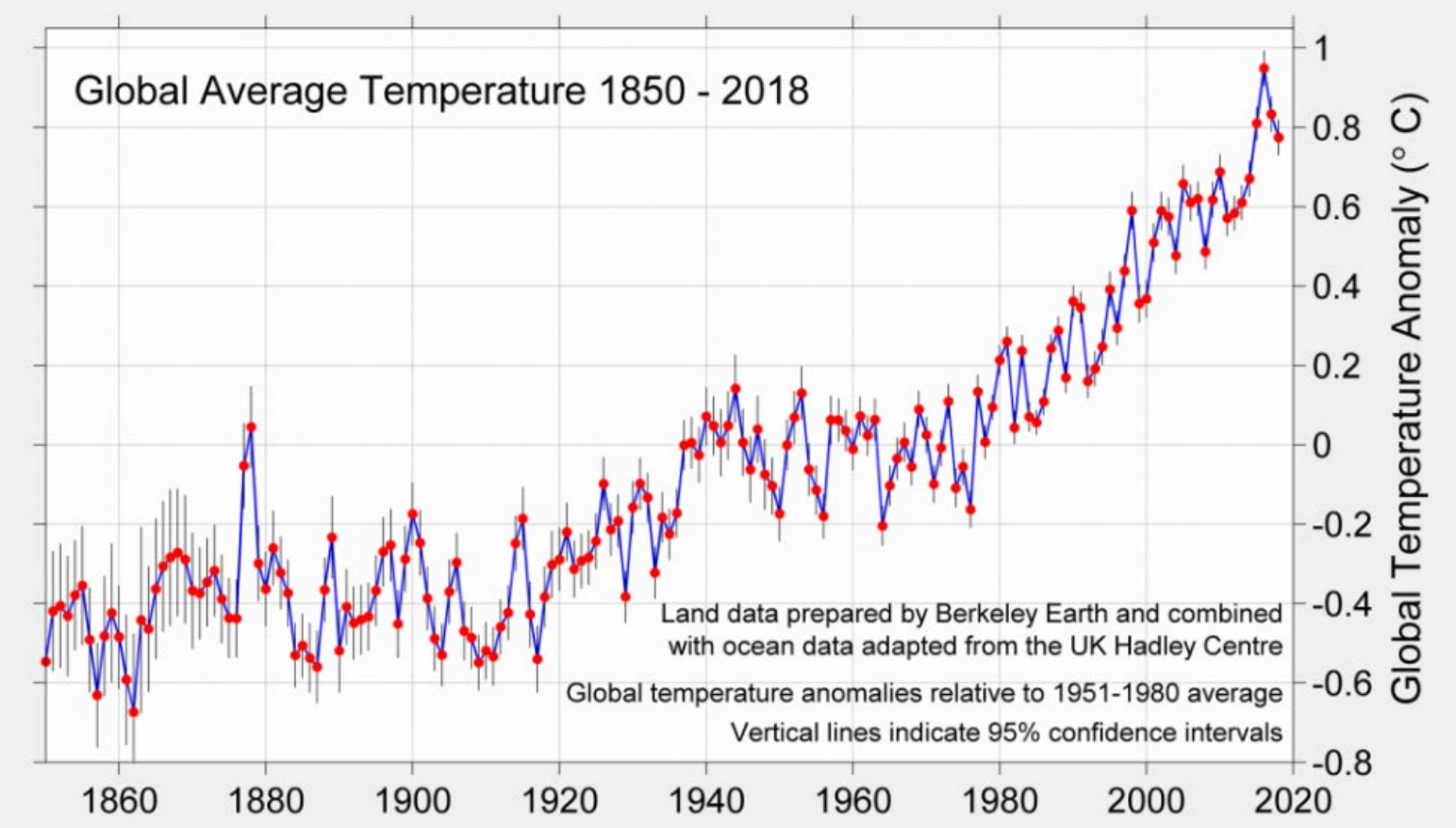
BIPM
ΜΕΤΡΩ ΧΡΩ

World Meteorological Organization

International Surface Temperature Initiative

GCOS

"**Global warming**, reality or fiction? Only measurements can prove it!“



"Global warming, reality or fiction?
Only **measurements** can prove it!“

Measurements

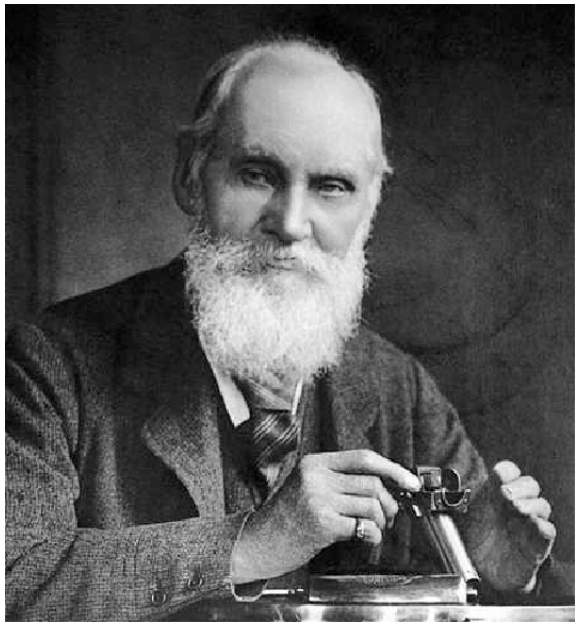
are so far the best way we found to understand nature

To understand a phenomenon, we observe its **properties** that can be **measured** quantitatively **using a sensor**

"Global warming, reality or fiction?
Only **measurements** can prove it!“

Measurements

are so far the best way we found to understand nature



“To measure is to know.”

“If you cannot measure it, you cannot improve it.”

“When you can measure what you are speaking about, and express it in numbers, you know something about it; but when you cannot measure it, when you cannot express it in numbers, your knowledge is of a meagre and unsatisfactory kind.”

William Thompson (Lord Kelvin) (1892 b. C.)

Measurements

results need validation, quality check and understanding of uncertainties and processes.

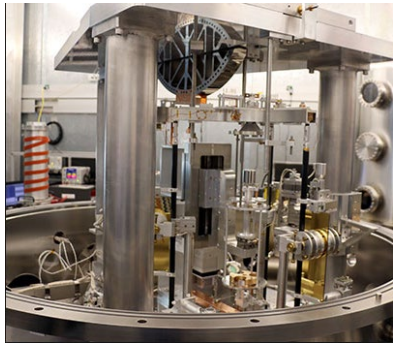
This is the role of Metrology: the science of measurements

METEOMET
Metrology for Meteorology

Andrea Merlone

The Importance of Metrology

- It deals with
  - Establishing a common understanding of units, through their definition and the dissemination of a unique System of Units – the “SI”
  - Providing realization of the units, through appropriate standards
  - The transfer of traceability from these standards to users in a society.
  - The development of new measurement methods, the realisation of measurement standards



METEOMET
Metrology for Meteorology

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METROLOGY - GENERAL

- 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**

METROLOGY - GENERAL

- ✓ **Scientific Metrology –**
  - ✓ establishment of units of measurement,
  - ✓ realisation of measurement standards
  - ✓ development of new measurement methods,

- ✓ **Industrial and applied Metrology – Testing**
  - ✓ application of measurement to manufacturing and other processes

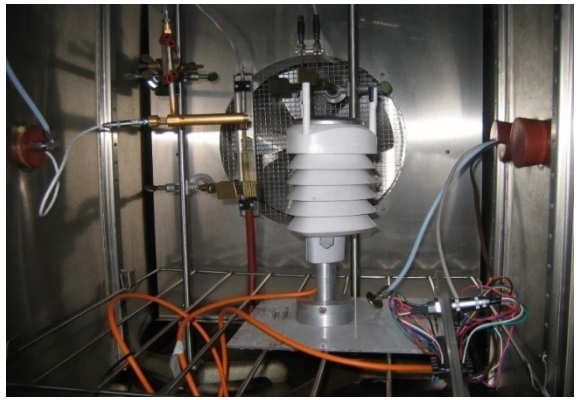
- ✓ **Legal Metrology - Certification**
  - ✓ fullfils regulatory requirements that arise from the need for protection of health, public safety, the environment, enabling taxation, protection of consumers and fair trade

OIML

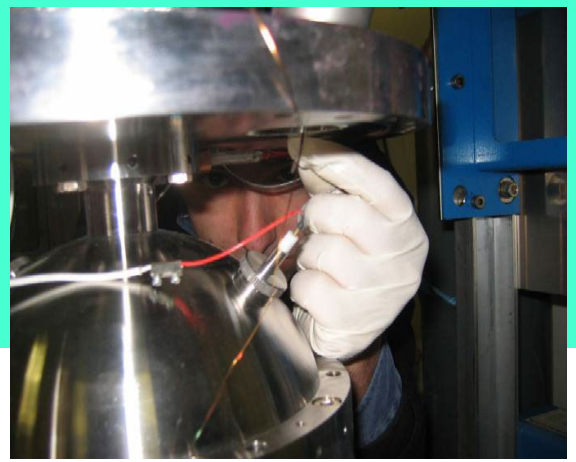
METROLOGY - GENERAL

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



Metrology



The Importance of Metrology

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- Metrology guarantees
  - Universal standards, commonly adopted with unique definitions
  - Mutual acceptance and recognition of procedures and certificates
  - Links among Regions, Organizations, Laboratories, through continuous comparisons at various level
  - Unique definition of base units and derived units for every application: all scientific disciplines, medicine, commerce, construction, trade…
  - 7 units and a decimal system to measure…. Everything!

For example, with the single unit 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 Metre Convention established a permanent organizational structure for member governments to act in common accord on all matters relating to units of measurement based on

• The **International Bureau of Weights and Measures** (*Bureau international des poids et mesures* - **BIPM**), located in Sevres, close to Paris

•The **General Conference on Weights and Measures** (*Conférence générale des poids et mesures* - **CGPM**) – the plenary organ of the BIPM which consists of the delegates of all the contracting Governments;

•The **International Committee for Weights and Measures** (*Comité international des poids et mesures* - **CIPM**) – the direction and supervision organ of the BIPM

The Comité International des Poids et Mesures is assisted by its Consultative Committeees, regularly meeting at BIPM:

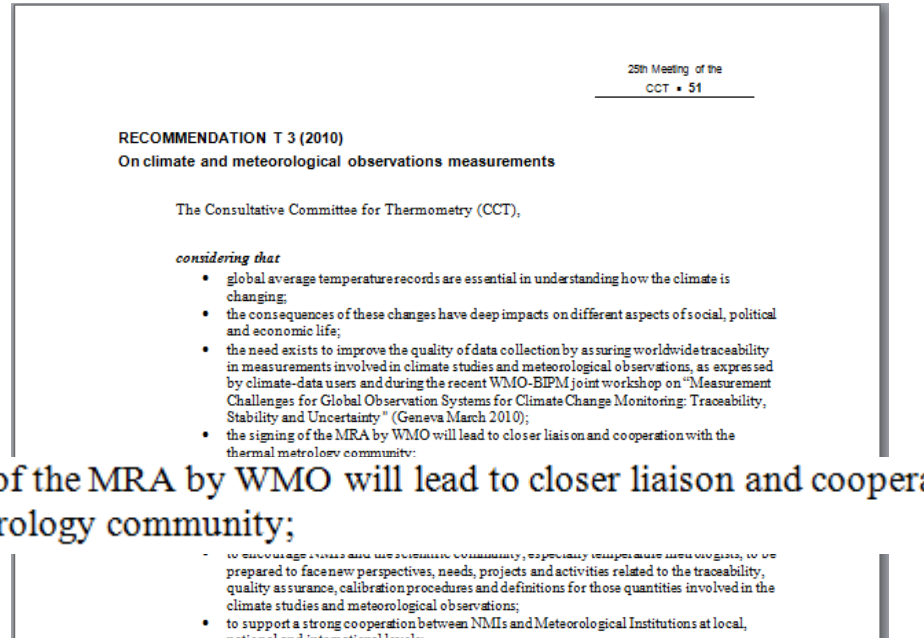
CCAUV: Consultative Committee for Acoustics, Ultrasound and Vibration
CCEM: Consultative Committee for Electricity and Magnetism
CCL: Consultative Committee for Length
CCM: Consultative Committee for Mass and Related Quantities
CCPR: Consultative Committee for Photometry and Radiometry
CCQM: Consultative Committee for Amount of Substance, Chemistry and Biology
CCRI: Consultative Committee for Ionizing Radiation
CCT: Consultative Committee for Thermometry
CCTF: Consultative Committee for Time and Frequency
CCU: Consultative Committee for Units

+JCGM - Joint Committee for Guides in Metrology (Publishes GUM and VIM)

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

May 2010

CCT Recommendation to CIPM



25th Meeting of the CCT • 51

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

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

2014 XXVII CCT launches the Task Group «Environment»
(A. Merlone Chair)

2017, the TG ENV becomes the permanent **Working Group Environment**

2021, a new **TG «Air T»** is created within the WG ENV

Metrology

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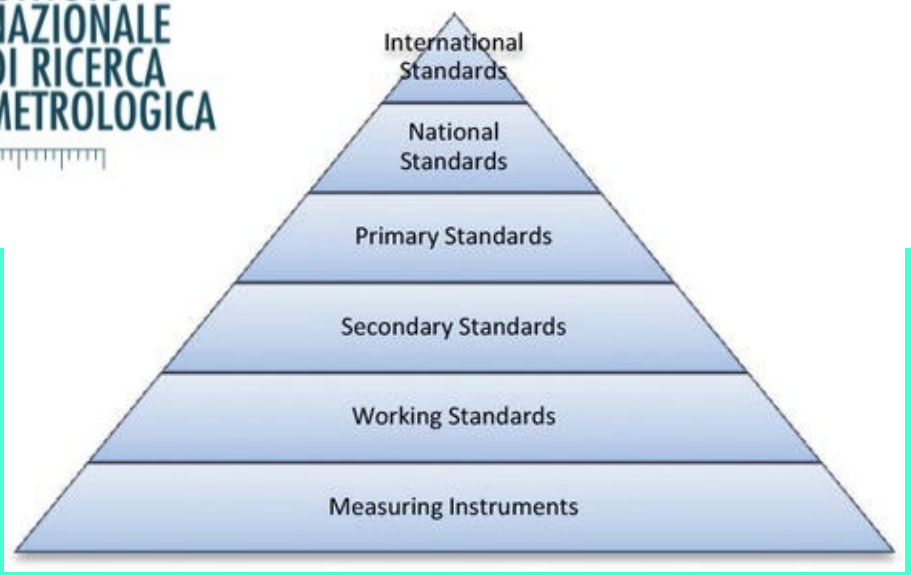

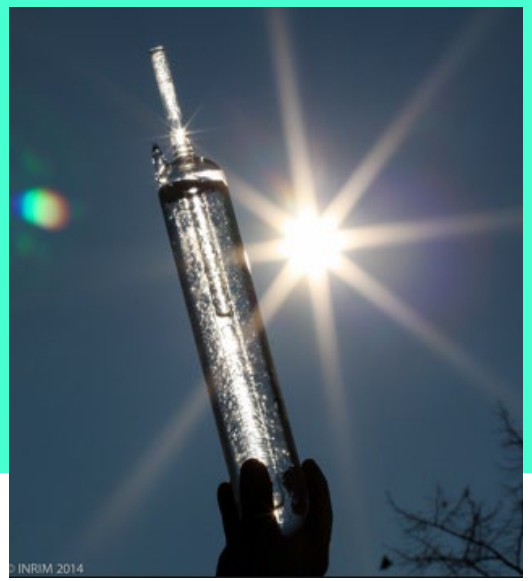

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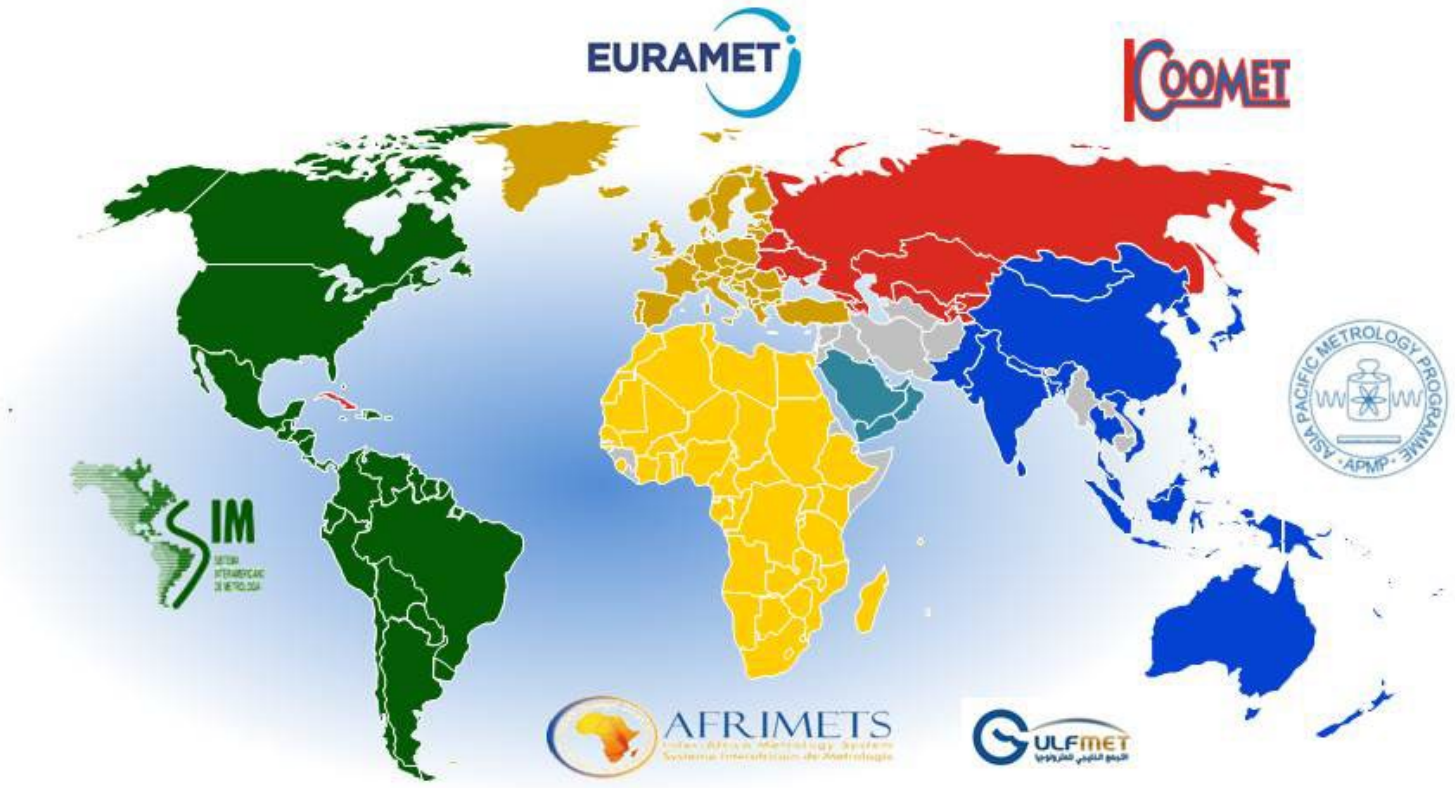
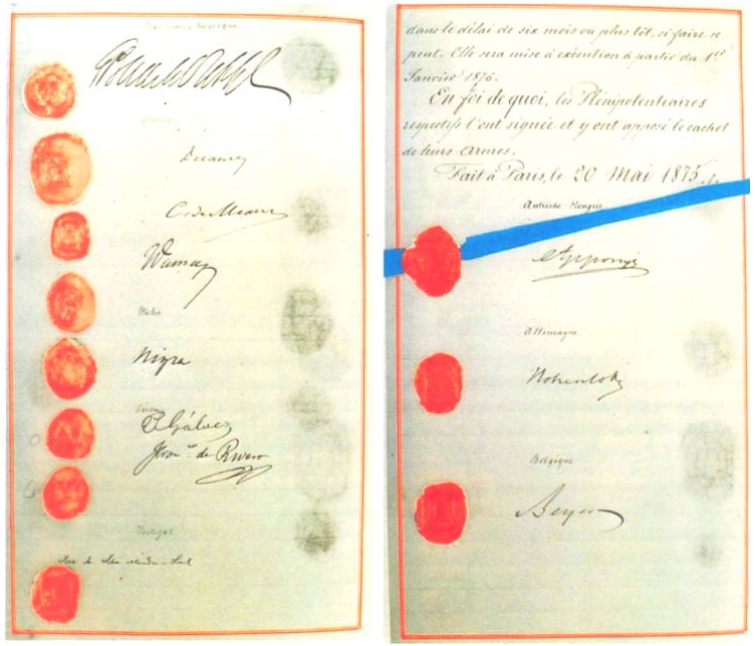
Regional Metrology Organisations (RMO)



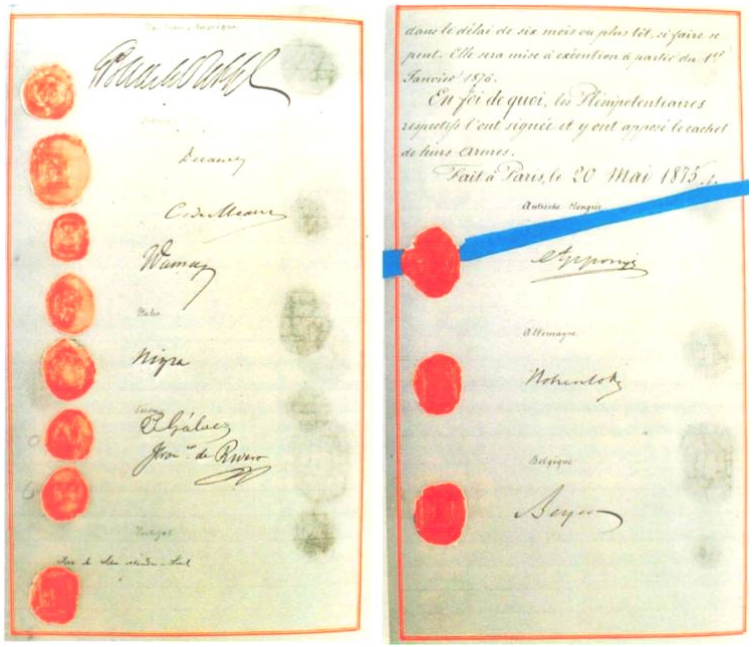
BIPM

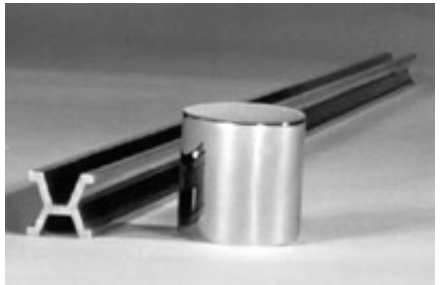
20 May 1875
Convention du mètre



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

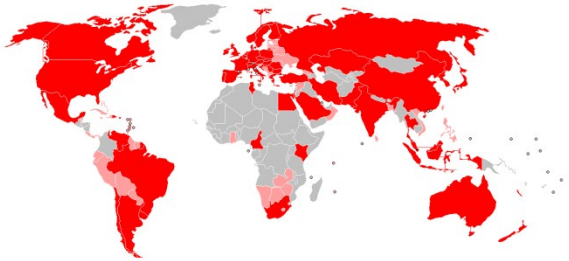
(Argentina, Austria-Hungary, Belgium, Brazil, Denmark, France, Germany, Italy, Peru, Portugal, Russia, Spain, Sweden and Norway, Switzerland, Ottoman Empire, United States of America, and Venezuela).





Metrology

Convention du Mètre



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.[40]

- 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)

Did you know?...

New SI based on fundamental constants.

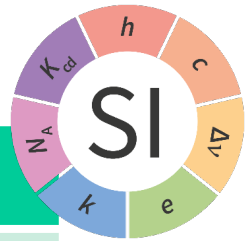
Adoption of new definitions: 20 May 2019

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,

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

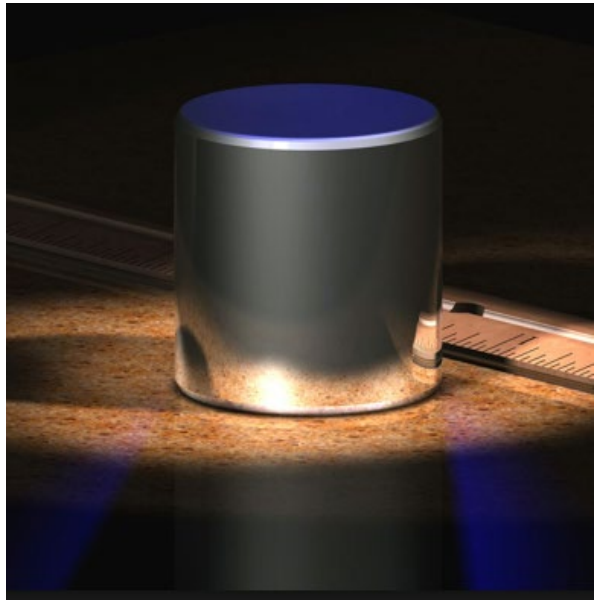


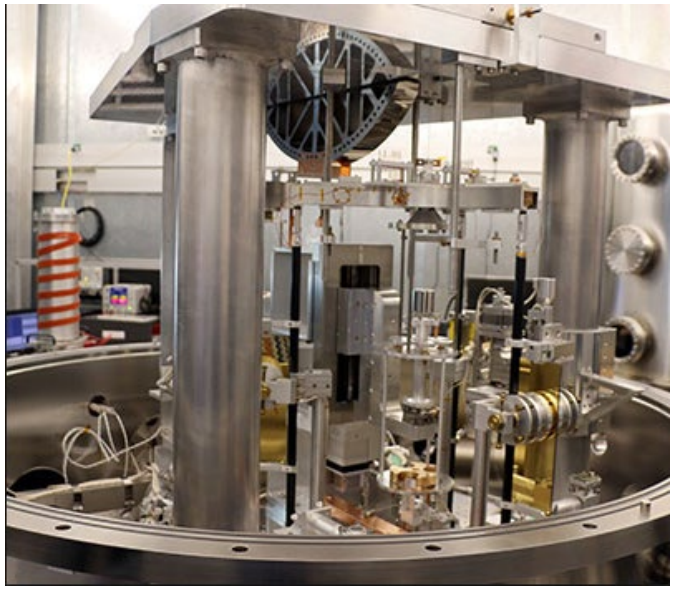
Symbol	Base Unit	Constant	Numerical Value	Unit
$\Delta\nu_{Cs}$	second	the unperturbed ground state hyperfine transition frequency of the caesium 133 atom	9 192 631 770	Hz
c	metre	the speed of light in vacuum	299 792 458	m s^{-1}
h	kilogram	the Planck constant	$6.626\ 070\ 15 \times 10^{-34}$	J s
e	Ampere	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

Andrea Merlone

•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

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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

Andrea Merlone

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 × 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 $\Delta\nu_{Cs}$

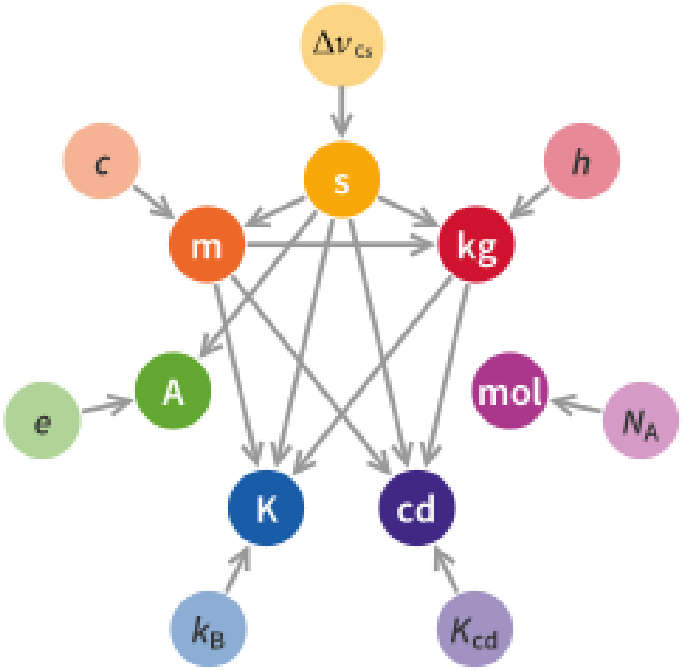
Thus one has the exact relation k = 1.380 649 × 10^{-23} J/K. The effect of this definition is that the kelvin is equal to the change of thermodynamic temperature T that results in a change of thermal energy kT by 1.380 649 × 10^{-23} J.

Kelvin

Andrea Merlone

- The kelvin is redefined with no immediate effect on temperature measurement practice or on the traceability of temperature measurements, and **for most users, it will pass unnotice**d. A definition free of material and technological constraints enables the development of new and more accurate techniques for making temperature measurements traceable to the SI, especially at extremes of temperature. After the redefinition, the guidance on the practical realization of the kelvin will support its world-wide dissemination

The SI based on fundamental constants



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

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Derived Units

$kg\ m^{-3}$	$m\ s^{-1}$	$m\ s^{-2}$
$kg\ m\ s^{-2}$	newton, N	
N m	$kg\ m^{2}\ s^{-2}$	joule, J
$N\ /\ m^{-2}$	$kg\ m^{-1}\ s^{-2}$	Pascal, Pa

Base Units

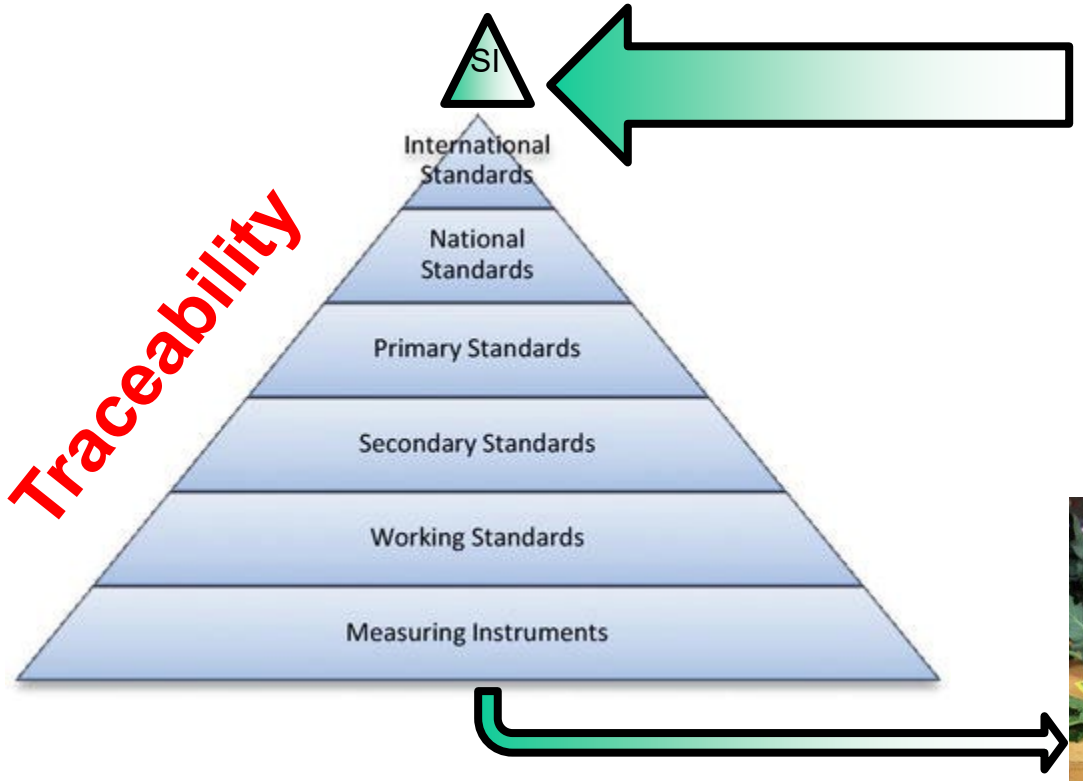
kg | m | s | A | K | mol | cd

Fundamental Metrology

Fundamental Metrology

Applied Metrology

Fundamental Metrology



Applied Metrology

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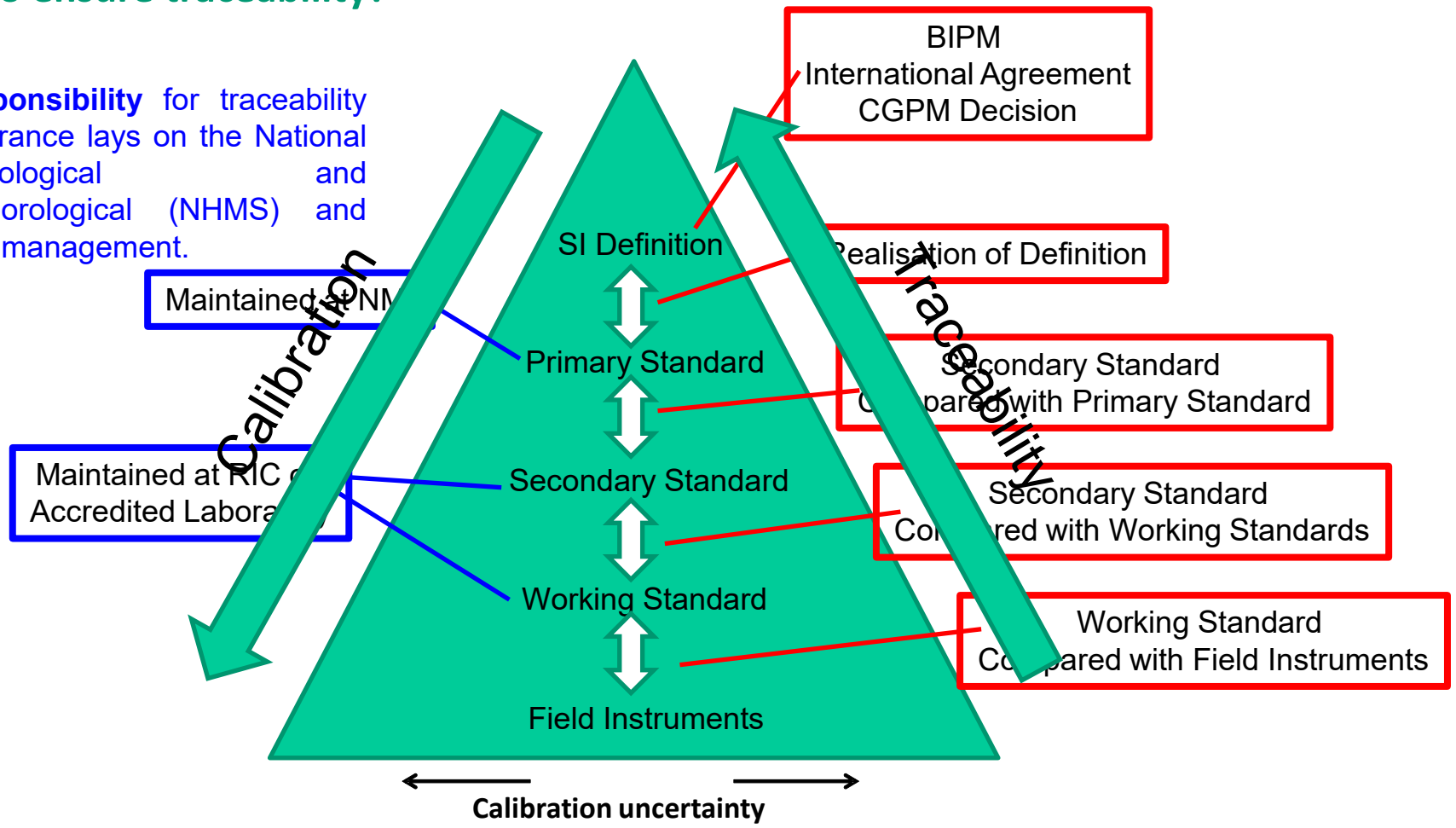
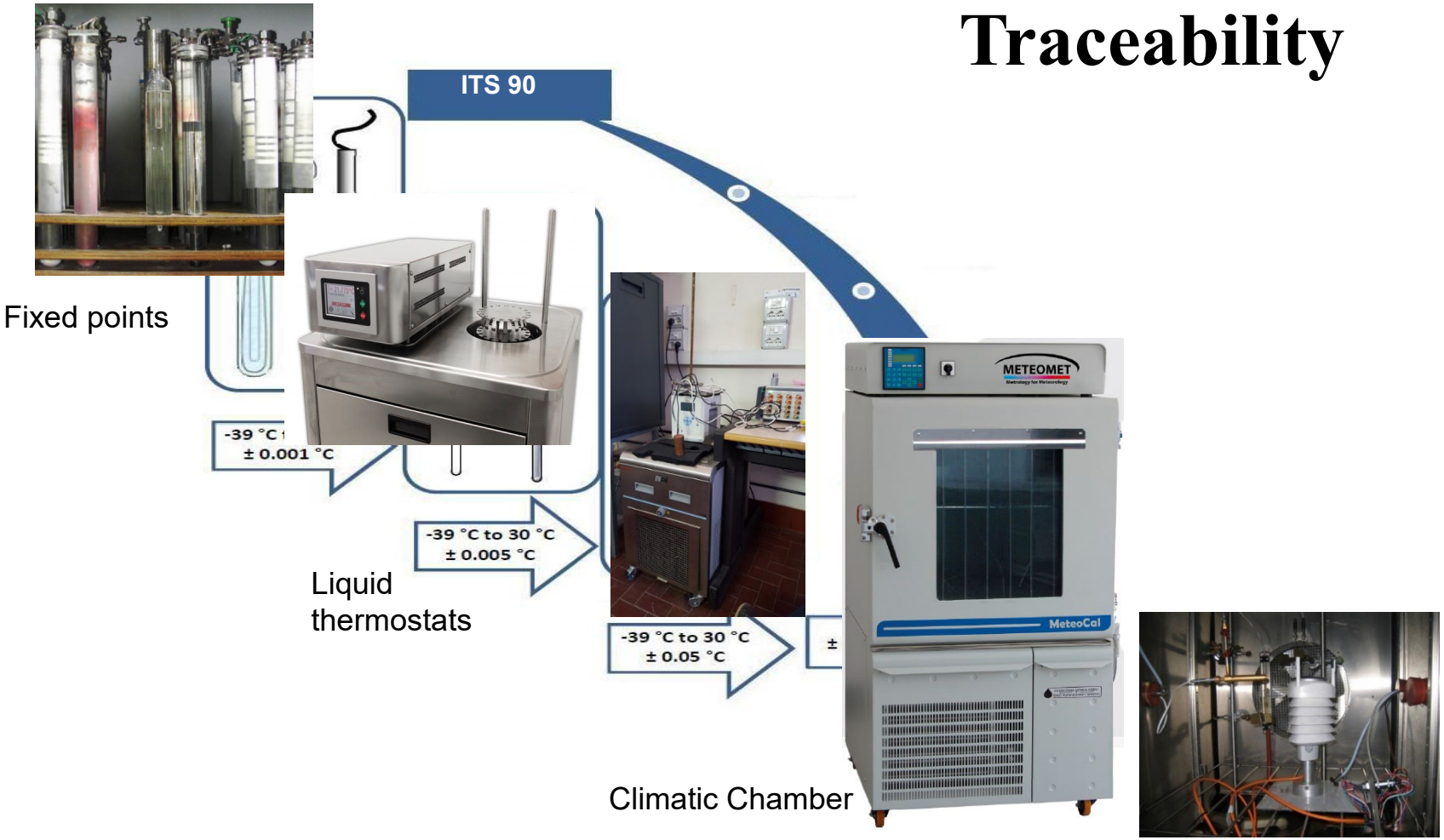
How to ensure traceability?

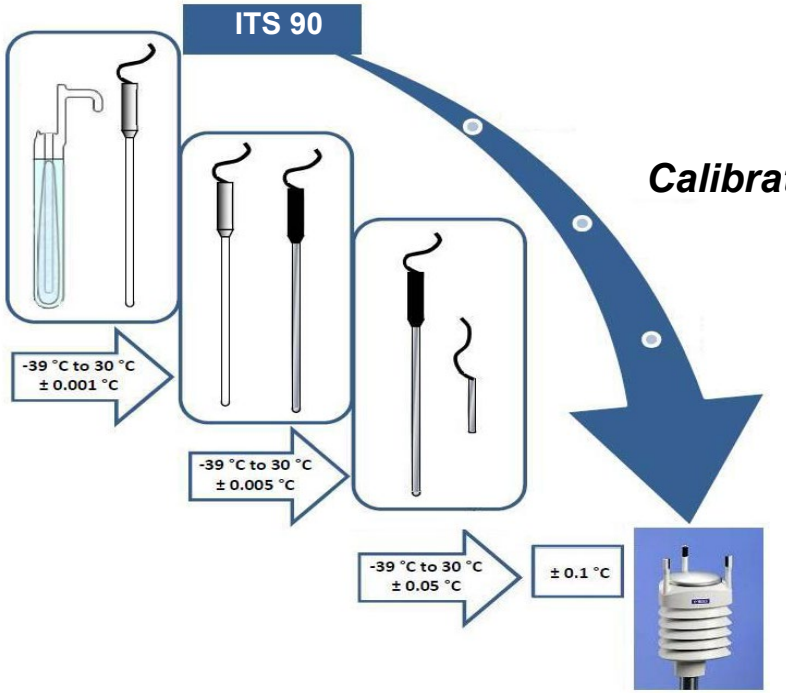
Responsibility for traceability assurance lays on the National Hydrological and Meteorological (NHMS) and their management.



Traceability



Primary standards



Calibrations

Field measurements

Traceability

- VIM definition of metrological traceability:

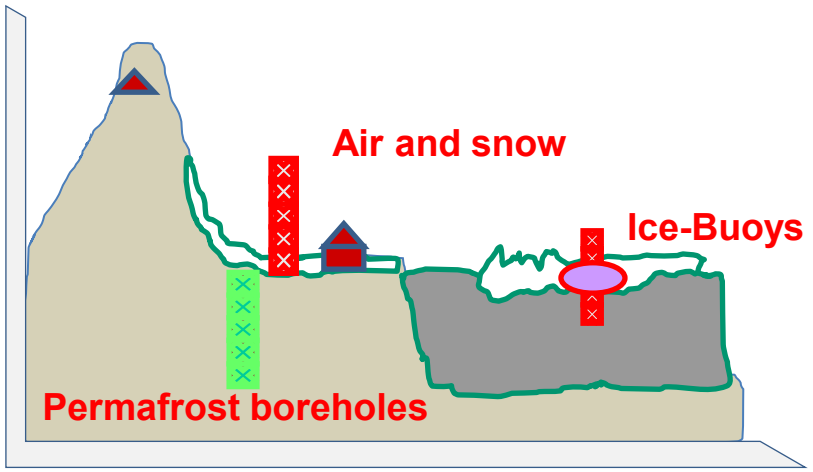
"property of a measurement result whereby the result can be related to a stated reference through a documented unbroken chain of calibrations, each contributing to the measurement uncertainty."

- Traceability is a crucial element in establishing comparability between different measurement methods and instrument responses.

Calibrations and Uncertainties evaluations
to establish complete traceability

Traceability is the key conditions for comparability

- Comparability on climate-change scales
- Comparability to fundamental physical models
- Comparability across generations
- Comparability across borders & organizations
- Comparability across instrument/measurement types



Interlaboratory comparison – ILC

Andrea Merlone

Organization, performance and evaluation of measurements or tests on the same or similar items by two or more laboratories in accordance with predetermined conditions.

- NOTE – In some circumstances, one of the laboratories involved in the intercomparison may be the laboratory which provided the assigned value for the test item

Purpose of Interlaboratory comparison

- **evaluation of the performance** of laboratories for specific tests or measurements and monitoring laboratories' continuing performance;
- **identification of problems** in laboratories and initiation of actions for improvement which, for example, may be related to inadequate test or measurement procedures, effectiveness of staff training and supervision, or calibration of equipment;
- establishment of the effectiveness and **comparability** of test or measurement methods;
- **provision of additional confidence** to laboratory customers;

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Purpose of Interlaboratory comparison

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- **identification** of interlaboratory differences;
- **education** of participating laboratories based on the outcomes of such comparisons;
- **validation** of uncertainty claims;
- evaluation of the **performance** characteristics **of a method**

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

The Importance of Metrology

Andrea Merlone

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»**

METEOMET
Metrology for Meteorology

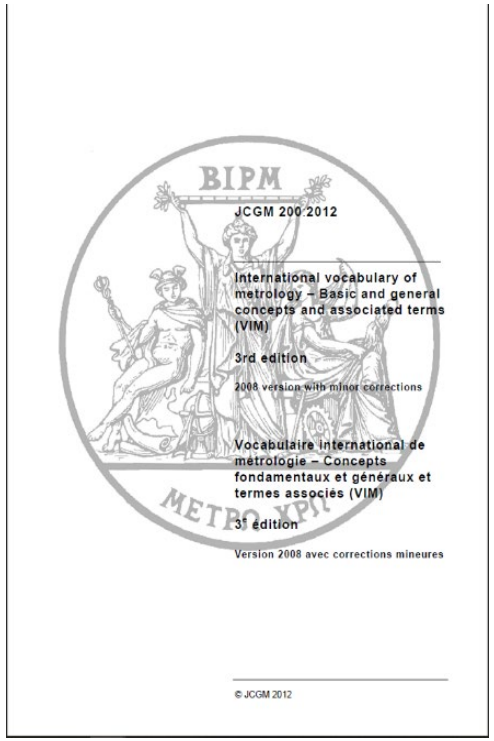
The Importance of Metrology

Andrea Merlone

A common terminology.

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

Aka the "VIM"


BIPM
JCGM 200:2012

International vocabulary of metrology – Basic and general concepts and associated terms (VIM)

3rd edition

2008 version with minor corrections

Vocabulaire international de métrologie – Concepts fondamentaux et généraux et termes associés (VIM)

3e édition

Version 2008 avec corrections mineures

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→ See training module on «International Vocabulary of Metrology»