"SIOS training course on metrology in Svalbard

Andrea Merlone

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
"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
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
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**
  ✓ fulfills regulatory requirements that arise from the need for protection of health, public safety, the environment, enabling taxation, protection of consumers and fair trade
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

- 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 Committees, 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

- 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
SIOS training course on metrology in Svalbard – 18-20 June 2022
Regional Metrology Organisations (RMO)
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 (1975 as Austria-Hungary)
- Belgium (1875)
- Brazil (1921)
- Bulgaria (1911)
- Cameroon (1970)
- Canada (1907)
- China (1904)
- China (1977)
- Croatia (2008)
- Czech Republic (1992 as part of Czechoslovakia)
- Denmark (1875)
- Dominican Republic (1954)
- Egypt (1952)
- Fiji (1903)
- France (1875)
- Germany (1875)
- Greece (2001)
- Hungary (1920)
- India (1967)
- Indonesia (1992)
- Iran (1971)
- Ireland (1925)
- Israel (1950)
- Italy (1875)
- Japan (1895)
- Kazakhstan (2008)
- Korea (2010)
- Malaysia (2001)
- Mexico (1990)
- Netherlands (1929)
- New Zealand (1960)
- North Korea (1962)
- Norway (1875 as part of Sweden and Norway)
- Pakistan (1973)
- Poland (1825)
- Portugal (1875)
- Romania (1854)
- Russia (1775 as the Russian Empire)
- Saudi Arabia (2011)
- Serbia (2001)
- Singapore (1994)
- Slovakia (1992 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 (1975)
- United Kingdom (1584)
- United States (1783)
- Uruguay (1990)
- Venezuela (1879)

Associates
At its 21st meeting (October 1999), the CGPM created the category of “associates” for those states not yet members of the BIPM and for economic unions.[6]
- Albania (2007)
- Bangladesh (2010)
- Belarús (2003)
- Bhutan (2006)
- Botswana and Herzegovina (2011)
- Bolivia (2012)
- Caribbean Community (2005)
- China (2006)
- Cuba (2005)
- Ecuador (2006)
- Estonia (2005)
- Georgia (2008)
- Ghana (2009)
- Hong Kong (2003)
- Jamaica (2006)
- Latvia (2001)
- Macedonia (2006)
- Malta (2001)
- Mauritius (2010)
- Montenegro (2011)
- Namibia (2012)
- Oman (2002)
- Panama (2003)
- Paraguay (2009)
- Fiji (2006)
- Philippines (2002)
- Moldova (2007)
- Seychelles (2010)
- Slovenia (2003)
- Sri Lanka (2007)
- Syria (2012)
- Ukraine (2012)
- Vanuatu (2003)
- Zambia (2010)
- Zimbabwe (2010)

International Organisations
The following international organisations have signed the CGPM MRA:
- International Atomic Energy Agency (IAEA), Vienna, Austria (1959)
- Institute for Reference Materials and Measurements (IRMM), Geel, Belgium (1990)
- World Meteorological Organization (WMO), Geneva, Switzerland (2010)
- European Space Agency (ESA), Paris, France (2012)

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Did you know?...

New SI based on fundamental constants.

Adoption of new definitions: 20 May 2019

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

• the ground state hyperfine splitting frequency of the caesium 133 atom \(^{133}\text{Cs}\)\(_{\text{hfs}}\) 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 6.626 070 \times 10^{-34} \text{ J s}

• the elementary charge \(e\) is exactly 1.602 176 634 \times 10^{-19} \text{ C},

• the Boltzmann constant \(k_B\) is exactly 1.380 649 \times 10^{-23} \text{ J/K}

• the Avogadro constant \(N_A\) is exactly 6.022 140 76 \times 10^{23} \text{ mol}^{-1},

• the luminous efficacy \(K_{cd}\) of monochromatic radiation of frequency 540 \times 10^{12} \text{ Hz}
  is exactly 683 \text{ lm/W},
The SI is the system of units in which the following constants have these **exact** values.

<table>
<thead>
<tr>
<th>Symbol</th>
<th>Base Unit</th>
<th>Constant</th>
<th>Numerical Value</th>
<th>Unit</th>
</tr>
</thead>
<tbody>
<tr>
<td>$\Delta v_{\text{CS}}$</td>
<td>second</td>
<td>the unperturbed ground state hyperfine transition frequency of the caesium 133 atom</td>
<td>9 192 631 770 Hz</td>
<td>Hz</td>
</tr>
<tr>
<td>$c$</td>
<td>metre</td>
<td>the speed of light in vacuum</td>
<td>299 792 458 m s$^{-1}$</td>
<td></td>
</tr>
<tr>
<td>$h$</td>
<td>kilogram</td>
<td>the Planck constant</td>
<td>$6.626 \times 10^{-34}$ J s</td>
<td></td>
</tr>
<tr>
<td>$e$</td>
<td>Ampere</td>
<td>the elementary charge</td>
<td>$1.602 \times 10^{-19}$ C</td>
<td></td>
</tr>
<tr>
<td>$k$</td>
<td>Kelvin</td>
<td>the Boltzmann constant</td>
<td>$1.380 \times 10^{-23}$ J/K</td>
<td></td>
</tr>
<tr>
<td>$N_A$</td>
<td>mole</td>
<td>the Avogadro constant</td>
<td>$6.022 \times 10^{23}$ mol$^{-1}$</td>
<td></td>
</tr>
<tr>
<td>$K_{\text{cd}}$</td>
<td>candela</td>
<td>the luminous efficacy of monochromatic radiation of frequency $540 \times 10^{12}$ hertz</td>
<td>683 lm/W.</td>
<td></td>
</tr>
</tbody>
</table>
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 NMI’s to their calibration customers will be broadly unaffected.
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.
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 \( k = 1.380 \, 649 \times 10^{-23} \, \text{J/K} \). 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 \( 1.380 \, 649 \times 10^{-23} \, \text{J} \).
• 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 unnoticed. 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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**Base Units**
- kg
- m
- s
- A
- K
- mol
- cd

**Derived Units**
- kg m⁻³
- m s⁻¹
- m s⁻²
- kg m s⁻²: newton, N
- N m: joule, J
- N / m²: Pascal, Pa
- kg m² s⁻²
- kg m⁻¹ s⁻²
Fundamental Metrology
Fundamental Metrology

Applied Metrology
Fundamental Metrology

Applied Metrology

Traceability
How to ensure traceability?

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

- Fixed points
- ITS 90
- Liquid thermostats
- Climatic Chamber

-39 °C ± 0.001 °C
-39 °C to 30 °C ± 0.005 °C
-39 °C to 30 °C ± 0.05 °C
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

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;
Purpose of Interlaboratory comparison

- **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)*.

http://www.iso.org/sites/JCGM/JCGM-introduction.htm

Charter
Joint Committee for Guides in Metrology (JCGM)
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»
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»