WMO Online Training Workshop on Quality, Traceability and Compliance – General Metrology and Temperature, for RICs and RMICs

WEATHER CLIMATE WATER
TEMPS CLIMAT EAU

Terminology

Andrea Merlone

WMO OMM

World Meteorological Organization
Organisation météorologique mondiale

18-20 June 2022

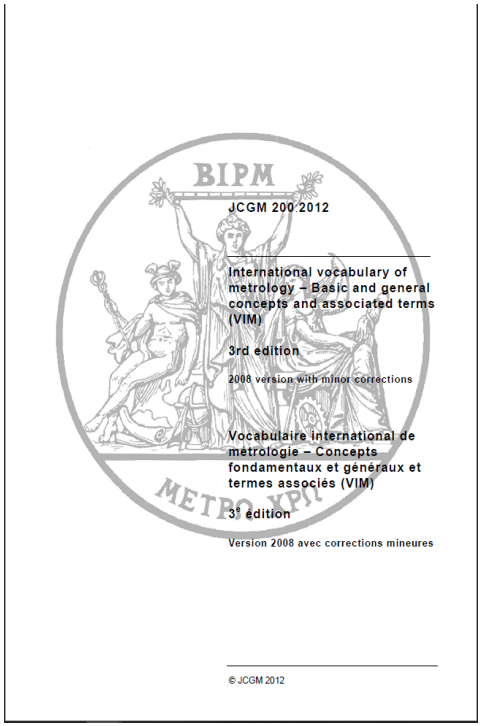
Content

- Why we need common terminology
- The VIM
- Some terms
- Calibration and traceability

WMO OMM

A common terminology

- To better communicate within members of the same community
- To compare information among different communities
- To keep correct interpretation of measurement in time and across nations/languages
- For unique interpretation and use of terms
- For a correct link between terms and concepts
- For clear interpretation of recommendations, prescriptions and guides
- To avoid misunderstanding in evaluating measurements results
- To avoid cheating or fraud in tenders and specifications


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

© JCGM 2012

…also to avoid common mistakes

Uncertainty. Parameter, associated with the result of a measurement, that characterizes the dispersion of the values that could reasonably be attributed to the measurand

Accuracy. It is not a quantitative value. Do not write “Accuracy of 0.1 °C”.

Error. Must be corrected. Not to be used in place of uncertainty. Don’t say “error bars”!

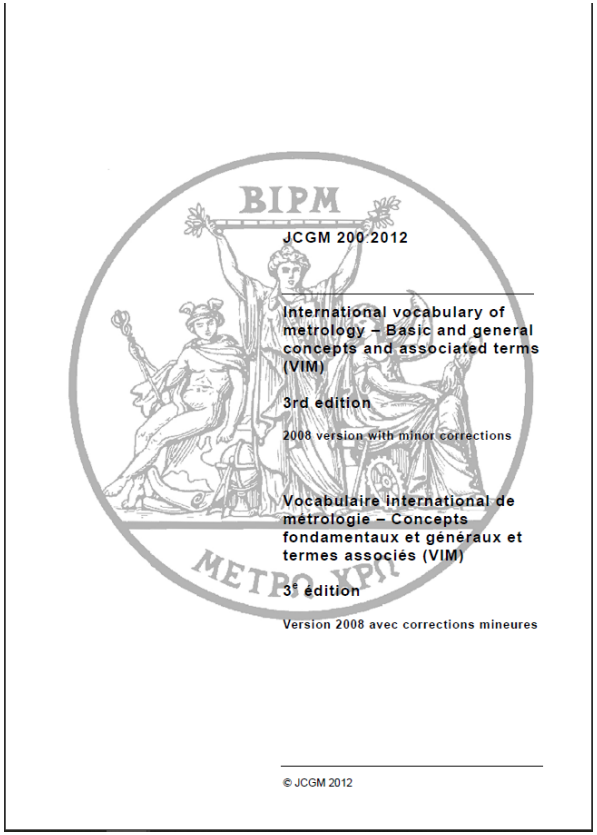
Precision. Sometimes misleading. (Resolution, sensibility, suggested instead)

WMO OMM

Two key documents on terminology published by JCGM: GUM and VIM

International vocabulary of basic and general terms in metrology

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

© JCGM 2012

The VIM

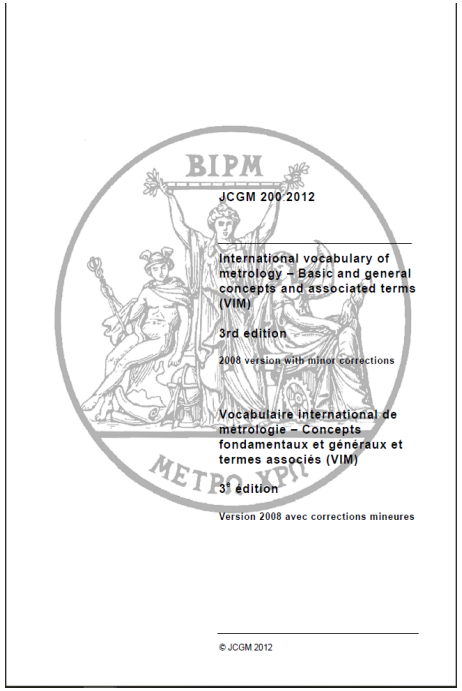
International Vocabulary of Metrology – Basic and General Concepts and Associated Terms

JCGM 200:2012:

…« In general, a vocabulary is a "*terminological dictionary which contains designations and definitions from one or more specific subject fields*" (ISO 1087-1:2000, 3.7.2).

The VIM pertains to metrology, the "science of measurement and its application". It also covers the basic principles governing quantities and units.»…

…« *this Vocabulary is intended to promote global harmonization of terminology used in metrology*. »…


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

© JCGM 2012

(VIM 3rd edition) Free download at

https://www.bipm.org/en/publications/guides/vim.html

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

OIML Organisation Internationale de Métrologie Légale
International Organization of Legal Metrology

The International Organization of Legal Metrology is an intergovernmental treaty organization which

- develops model regulations, standards and related documents for use by legal metrology authorities and industry,
- provides mutual recognition systems which reduce trade barriers and costs in a global market,
- represents the interests of the legal metrology community within international organizations and forums concerned with metrology, standardization, testing, certification and accreditation,
- promotes and facilitates the exchange of knowledge and competencies within the legal metrology community worldwide,
- cooperates with other metrology bodies to raise awareness of the contribution that a sound legal metrology infrastructure can make to a modern economy.

Some terms…

MEASUREMENT

The process of experimentally obtaining one or more **quantity values** that can reasonably be attributed to a **quantity.**

MEASUREMENT RESULT (result of measurement)

Set of **quantity values** being attributed to a **measurand** together with any other available relevant information.

MEASURAND

Quantity intended to be measured.

The **measurement**, including the **measuring system** and the conditions under which the measurement is carried out, might change the phenomenon, body, or substance such that the quantity being measured may differ from the measurand as defined. In this case, adequate **correction** is necessary (with associated uncertainties).

MEASUREMENT

3.1 Measurement

3.1.1 The objective of a measurement (B.2.5) is to determine the value (B.2.2) of the measurand (B.2.9), that is, the value of the **particular quantity (B.2.1, Note 1) to be measured. A measurement therefore begins** with an appropriate specification of the measurand, the **method of measurement (B.2.7), and the measurement procedure (B.2.8).**

3.1.2 In general, the result of a measurement (B.2.11) is only an approximation or estimate (C.2.26) of the value of the measurand and thus **is complete only** when accompanied by a statement of the **uncertainty** (B.2.18) of that estimate.

3.1.3 In practice, the required specification or definition of the measurand is dictated by the required accuracy of measurement (B.2.14). The measurand should be defined with sufficient completeness with respect to the required accuracy so that for all practical purposes associated with the measurement its value is unique. It is in this sense that the expression "value of the measurand" is used in this *Guide.*

In the end the result of a measurement is an estimated ratio among the measured quantity and a reference standard

WMO OMM

International System of Units, SI

system of units, based on the **International System of Units**, their names and symbols, including a series of prefixes with (their names and symbols), together with rules for their use, adopted by the General Conference on Weights and Measures (CGPM)

Base quantity	Base unit	Base unit
Name	Name	Symbol
length	metre	m
mass	kilogram	kg
time	second	s
Electric current	ampere	A
Thermodynamic temperature*	kelvin	K
Amount of substance	mole	mol
Luminous intensity	candela	cd

* Temperature can also be expressed in degrees Celsius, symbol °C, where $t/°C = T/K + 273.15$

WMO OMM

BASE UNIT

measurement unit that is adopted by convention for a **base quantity**

NOTE 1 In each **coherent system of units**, there is only one base unit for each base quantity.
EXAMPLE In the **SI**, the metre is the base unit of length.

DERIVED UNIT

measurement unit for a **derived quantity**

EXAMPLES The metre per second, symbol m/s, and the centimetre per second, symbol cm/s, are derived units of speed in the **SI**. The kilometre per hour, symbol km/h, is a measurement unit of speed outside the SI but accepted for use with the SI.

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

MEASUREMENT ACCURACY

closeness of agreement between a **measured quantity value** and a **true quantity value** of a **measurand**

NOTE 1 In general the ‘true value’ is unknown. That is why we speak about

- measurement uncertainty (which we can evaluate using procedures) rather than
- accuracy (which can never be known!)

ACCURACY is a quality, not expressed by a number

WMO OMM

MEASURING INSTRUMENT

device used for making **measurements**, alone or in conjunction with one or more supplementary devices

NOTE 1 A measuring instrument that can be used alone is a measuring system.
NOTE 2 A measuring instrument may be an indicating measuring instrument or a material measure.

For example a resistance bridge to measure resistance of thermometers

MEASURING SYSTEM

set of one or more measuring instruments and often other devices, including any reagent and supply, assembled and adapted to give information used to generate measured quantity values within specified intervals for quantities of specified kinds

NOTE A measuring system may consist of only one measuring instrument.
For example a resistance bridge, associated standard resistors and resistance thermometer to measure temperature

SENSOR

element of a **measuring system** that is directly affected by a phenomenon, body, or substance carrying a **quantity** to be measured

EXAMPLES Sensing coil of a platinum resistance thermometer, rotor of a turbine flow meter, Bourdon tube of a pressure gauge, float of a level-measuring instrument, photocell of a spectrometer, thermotropic liquid crystal which changes colour as a function of temperature.

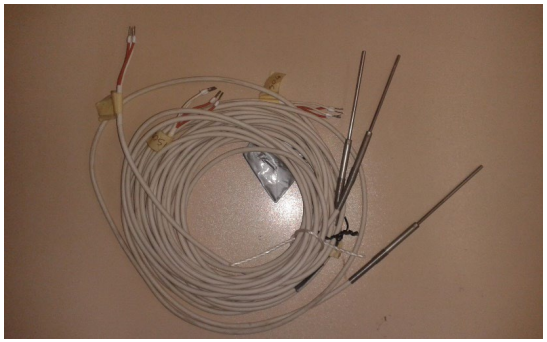
DETECTOR

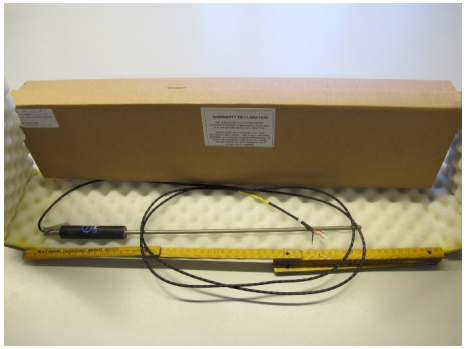
device or substance that indicates the presence of a phenomenon, body, or substance when a threshold value of an associated quantity is exceeded

MEASURING TRANSDUCER

device, used in measurement, that provides an output quantity having a specified relation to the input quantity

EXAMPLES Thermocouple, electric current transformer, strain gauge, pH electrode, Bourdon tube, bimetallic strip.





INDICATION

quantity value provided by a **measuring instrument** or a **measuring system**

NOTE 1 An indication may be:

- presented in visual or acoustic form
- transferred to another device.
- given by the position of a pointer on the display for analog outputs,
- a displayed or printed number for digital outputs,
- a code pattern for code outputs,
- an assigned quantity value for material measures.

4.12 SENSITIVITY (of a measuring system)

quotient of the change in an **indication** of a **measuring system** and the corresponding change in a **value** of a **quantity** being measured

NOTE 1 Sensitivity of a measuring system can depend on the value of the quantity being measured.
NOTE 2 The change considered in a value of a quantity being measured must be large compared with the **resolution**.

4.14 RESOLUTION

smallest change in a **quantity** being measured that causes a perceptible change in the corresponding **indication**

SENSITIVITY (of a measuring system)

Also expressed as the smallest change in the measured quantity that causes a change in the indication

Not the same!

RESOLUTION

For digital instruments, it is normally expressed as last digit visualized. For analog devices is the amplitude of each mark or graduation in a scale.

For example, a datalogger records pressure values with 1 Pa as last digit, but the readed instrument has a sensitivity around 5 Pa

WMO OMM

PROPERTIES OF MEASURING DEVICES

STABILITY (of a measuring instrument)

property of a **measuring instrument**, whereby its metrological properties remain constant in time

NOTE Stability may be quantified in several ways.
EXAMPLE 1 In terms of the duration of a time interval over which a metrological property changes by a stated amount.
EXAMPLE 2 In terms of the change of a property over a stated time interval.

INSTRUMENTAL DRIFT

continuous or incremental change over time in **indication**, due to changes in metrological properties of a measuring instrument

NOTE Instrumental drift is related neither to a change in a **quantity** being measured nor to a change of any recognized **influence quantity**.

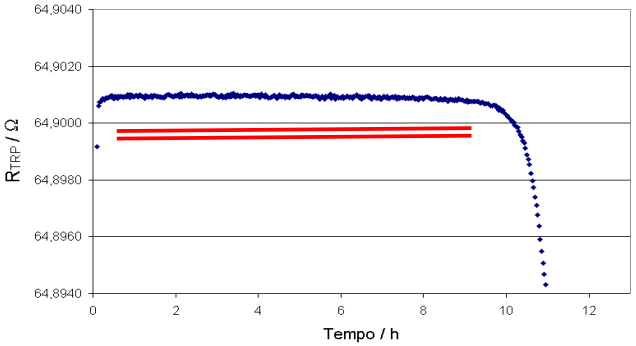
WMO OMM

PROPERTIES OF MEASURING DEVICES

STABILITY (of a measuring instrument)

Normally included as a component of uncertainty (suggested: rectangular distribution).

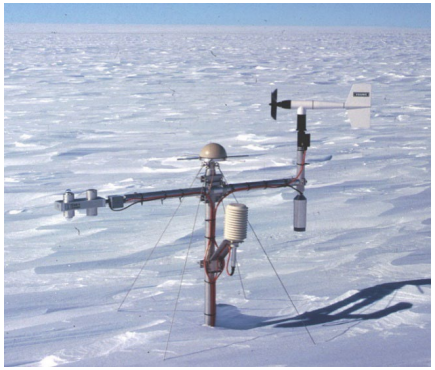
In calibration certificates, it indicates the stability of the sensor under calibration during a defined interval, where the reference value is considered stable (within a certain uncertainty).



INSTRUMENTAL DRIFT

For **instruments used in field**, drift can increase due to environmental conditions and influencing quantities (i.e. harsh environment). It is cheched at defined intervals (monts, years), according to the quality and typology of instruments.

If the drift is within correct operational features, it can be evaluated and corrected after recalibration. It's a component of instrument ageing.



WMO OMM

PROPERTIES OF MEASURING DEVICES

STEP RESPONSE TIME

duration between the instant when an input **quantity value** of a **measuring instrument** or **measuring system** is subjected to an abrupt change between two specified constant quantity values and the instant when a corresponding **indication** settles within specified limits around its final steady value.

- Example: for meteorological thermometers see the ISO 17714:2007

system response time: time needed for the temperature recorded by the thermometer within the screen to reach 63 % of a step change in the external temperature, with a given external wind speed of 1 $m \cdot s^{-1}$

- Note 1 to entry: The system response time is a combination of the response times of the screen and the thermometer, and depends on the thermometer time constant.
- Note 2 to entry: The response time of the system is also dependent on wind speed and design of shields. For this reason, a given air speed of 1 $m \cdot s^{-1}$ is used.

WMO OMM

PROPERTIES OF MEASURING DEVICES

REPEATABILITY

- Repeatability (of results of measurements) (GUM B.2.15 [VIM:1993, definition 3.6])

  closeness of the agreement between the results of successive measurements of the same measurand carried out under the same conditions of measurement.

Repeatability conditions include the **same** measurement procedure, the **same** observer, the **same** measuring instrument, used under the **same** conditions, the **same** location, repetition over a **short period** of time.

WMO OMM

PROPERTIES OF MEASURING DEVICES

REPRODUCIBILITY

- Reproducibility (of results of measurements) GUM B.2.16 [VIM:1993, definition 3.7]

closeness of the agreement between the results of measurements of the same measurand carried out under changed conditions of measurement

The changed conditions may include principle of measurement, method of measurement, observer, measuring instrument, reference standard, location, conditions of use, time.

Instrument drift/change between repeated calibrations

WMO OMM

MEASUREMENT PRECISION

Although the VIM includes the term precision as a «mix» of repeatability, reproducibility expressed by means of variance and standard deviation, this term should be used carefully. The GUM limits the use of «precision» to chemical test methods and basically does not include any other use of this term.

In most of the measurements, including all meteorological observations, those terms indicated by the VIM can be used each one with its meaning: repeatability, reproducibility, standard deviation etc.

Moreover, the term precision is still ambiguous and leaves large misunderstanding. It is still frequently used to indicate instrumental resolution or sometimes sensibility and even uncertainty. If used in commercial processes (datasheets,tenders) it can also lead to fraude.

It is recommended to avoid the use of the term «precision».

WMO OMM

Standards

MEASUREMENT STANDARD - Etalon:

realization of the definition of a given **quantity**, with stated **quantity value** and associated **measurement uncertainty**, used as a reference

NOTE 1: A “realization of the definition of a given quantity” can be provided by a **measuring system**, a material measure, or a reference material.

NOTE 2: A measurement standard is frequently used as a reference in establishing measured quantity values and associated measurement uncertainties for other quantities of the same kind, thereby establishing **metrological traceability** through calibration of other measurement standards, measuring instruments, or measuring systems.

EXAMPLE 1: 1 kg mass measurement standard with an associated standard measurement uncertainty of 3 µg.

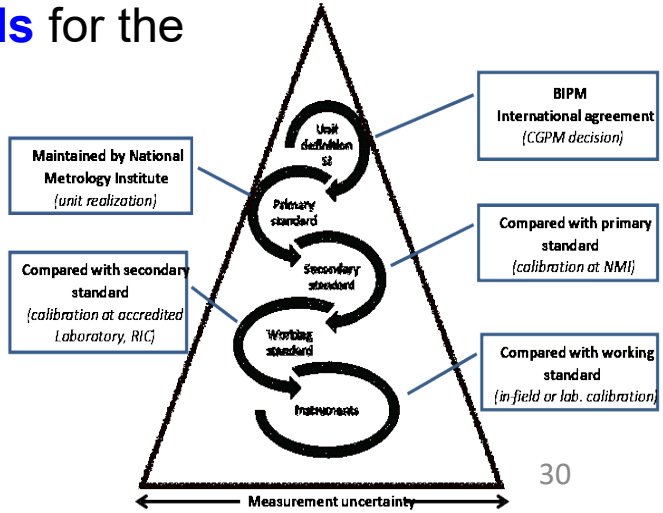
INTERNATIONAL MEASUREMENT STANDARD

measurement standard recognized by signatories to an **international agreement** and intended to serve worldwide

EXAMPLE 1 The international prototype of the kilogram.

NATIONAL MEASUREMENT STANDARD

measurement standard recognized by **national authority** to serve in a state or economy as the basis for assigning **quantity values** to other **measurement standards** for the **kind of quantity** concerned



PRIMARY STANDARD

measurement standard established using a **primary reference measurement procedure**, or created as an artifact, chosen by convention

EXAMPLE 4 Triple-point-of-water cell as a primary measurement standard of temperature.

SECONDARY STANDARD

measurement standard established through **calibration** with respect to a **primary measurement standard** for a **quantity** of the same **kind**

NOTE 1 Calibration may be obtained directly between a primary measurement standard and a secondary measurement standard, or involve an intermediate **measuring system** calibrated by the primary measurement

standard and assigning a **measurement result** to the secondary measurement standard.

REFERENCE MEASUREMENT STANDARD
Reference standard

measurement standard designated for the **calibration** of other measurement standards for **quantities** of a given **kind** in a given organization or at a given location

WORKING MEASUREMENT STANDARD
Working standard

measurement standard that is used **routinely to calibrate** or verify measuring instruments or measuring systems.

NOTE 1 A working measurement standard is usually calibrated with respect to a **reference measurement standard**.

WMO OMM

TRAVELLING MEASUREMENT STANDARD
Travelling standard

measurement standard, sometimes of special construction, intended for transport between different locations

TRANSFER MEASUREMENT DEVICE
Transfer device

device used as an intermediary to compare **measurement standards**

NOTE Sometimes, measurement standards are used as transfer devices.

Errors & Uncertainty

Great care must be taken to distinguish between the terms "error" and "uncertainty". They are not synonyms, instead they represent completely different concepts; they should not be confused with one another or misused.

Great care must be taken to distinguish between the terms "error" and "uncertainty". They are not synonyms, instead they represent completely different concepts; they should not be confused with one another or misused.

Errors can be corrected
Uncertainties can be reduced

Uncertainties are not mistakes (errors can be)

WMO OMM

ERRORS, EFFECTS, AND CORRECTIONS

3.2.1 In general, a measurement procedure and a measuring instrument have imperfections that give rise to an error (B.2.19) in the measurement result. Traditionally, an error is viewed as having two components, namely, a **random (B.2.21) component** and a **systematic (B.2.22) component.**

NOTE Error is an idealized concept and errors cannot be known exactly.

Uncertainty

RANDOM MEASUREMENT ERROR

(RANDOM ERROR OF MEASUREMENT, RANDOM ERROR)

component of **measurement error** that in replicate **measurements** varies in an unpredictable manner

CORRECTION

compensation for an estimated **systematic effect**

3.2.2 Random error presumably arises from unpredictable or stochastic temporal and spatial variations of influence quantities. The effects of such variations, hereafter termed *random effects, give rise to variations in* repeated observations of the measurand. Although it is not possible to compensate for the random error of a measurement result, it can usually be reduced by increasing the number of observations; its **expectation or expected value (C.2.9, C.3.1) is zero.**

WMO OMM

SYSTEMATIC MEASUREMENT ERROR

component of **measurement error** that in replicate **measurements** remains constant or varies in a predictable manner

MEASUREMENT BIAS (BIAS)

estimate of a **systematic measurement error**

WMO OMM

3.2.3 Systematic error, like random error, cannot be eliminated but it too can often be reduced. If a systematic error arises from a recognized effect of an influence quantity on a measurement result, hereafter termed a *systematic effect, the effect can be quantified and, if it is significant in size relative to the required* accuracy of the measurement, a **correction (B.2.23) or correction factor (B.2.24) can be applied to** compensate for the effect. It is assumed that, after correction, the expectation or expected value of the error arising from a systematic effect is zero.

NOTE The **uncertainty of a correction** applied to a measurement result to compensate for a systematic effect is *not* the systematic error, often termed bias, in the measurement result due to the effect as it is sometimes called. It is instead a measure of the *uncertainty of the result due to incomplete knowledge of the required value of the correction. The error* arising from imperfect compensation of a systematic effect cannot be exactly known. The terms “error” and “uncertainty” should be used properly and care taken to distinguish between them.

3.2.4 It is assumed that the result of a measurement has been corrected for all recognized significant systematic effects and that every effort has been made to identify such effects. (Calibration)

Calibration

CALIBRATION

operation that, **under specified conditions**, in a first step, establishes a relation between the **quantity values** with **measurement uncertainties** provided by **measurement standards** and corresponding **indications** with associated **measurement uncertainties** and, in a second step, uses this information to establish a relation for obtaining a **measurement result** from an **indication**.

NOTE 1 A calibration may be expressed by a statement, calibration function, **calibration diagram**, **calibration curve**, or calibration table. In some cases, it may consist of an additive or multiplicative **correction** of the indication with associated measurement uncertainty.

NOTE 2 Calibration should not be confused with **adjustment of a measuring system**, often mistakenly called “self-calibration”, nor with **verification** of calibration.

The calibration uncertainty

is NOT

the measurement uncertainty

…it is only one component of the overall measurement uncertainty

…in meteorological observations it is frequently not the major component

…the calibration procedure should be such that the instrument is calibrated in conditions similar to those met in field use

…the effect of the uncontrolled (out of laboratory) environmental factors in field should be evaluated as further measurement uncertainty contributions

WMO OMM

INFLUENCE QUANTITY

quantity that, in a **measurement**, does not affect the quantity that is actually measured, but affects the relation between the **indication** and the **measurement result**

Example of influence quantities in meteorological observations.

Measurand: near surface air temperature

Quantites of influence:

Solar radiation

Wind speed

Condensation – evaporation - icing

Albedo (in case of snow)

Precipitation

…

WMO OMM

Field Calibration

Field calibration allows the **field instrument** to be tested or **calibrated** under real use conditions, following a dedicated and validate procedure, involving traceable travelling standards

Calibration done under **field** conditions is usually very different from those done under laboratory conditions.

Cons.

Resulting calibration Uncertainties are larger than in laboratory

Pros.

Calibration is more close to instrument use in field, thus for some quantities total measurement uncertainty could be closer to the calibration uncertainty

WMO OMM

Field Validation is not a calibration

The following factors may contribute to the motivate field validation.

i. A desire to maximise the interval between exchanges of instruments or sensors at the site.

ii. A desire to reduce the workload of maintenance teams, by removing the need to change out instruments or sensors, which subsequently proves unnecessary.

iii. A desire to minimise the levels of uncertainty in the data provided by the observing network.

The validation does not produce a calibration correction. It gives important information about the optimal operational conditions of the instrument. It is based on a tolerance between the reading of the instrument under test and a travelling reference.

The calibration is the only way to establish and document traceability.

TRACEABILITY (metrological traceability)

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

METROLOGICAL TRACEABILITY CHAIN

sequence of **measurement standards** and **calibrations** that is used to relate a **measurement result** to a reference

NOTE 1 A metrological traceability chain is

- defined through a **calibration hierarchy**.
- used to establish **metrological traceability** of a measurement result.

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.
- However, this definition focusses on measurements made under controlled (laboratory) conditions. It doesn't reflect the impact that field conditions could have on the measurements.

WMO OMM

Traceability

- The prerequisite for the response (reading) of an instrument to be traceable is that the instrument is calibrated.
- The calibration uncertainty is only one component of the overall measurement uncertainty
- It is therefore suggested to talk about **“traceable instruments**”, instead of traceable measurement, when in field conditions the influencing quantities play a major role in the overall uncertainty budget.

Writing rules

A value must always be expressed as the number, a blank space and the correct unit/s symbol

Correct	Wrong
15 m	15m – 15M – 15mt – 15MT-15Mt
23 °C	23° C – 23C – 23°C – 23C°
9,23 s	9.23 sec
12 kg	12 KG – 12 Kg

Symbols must be those from the SI, not their interpretations…

WMO OMM

Use «.» or «,» to separate decimals according to your language rules

correct	wrong
15 mm	15mil
23 °C	23° C – 23C – 23°C – 23C°
9,23 μs	9.23 microsec
12 kg	12 KG – 12 Kg

Don’t be afraid of greek letters for multiples or decimals

WMO OMM

Symbol	Name	Quantity
s	second	time
m	metre	length
kg	kilogram	mass
A	ampere	electric current
°C or K	degree Celsius or Kelvin	thermodynamic temperature
mol	mole	amount of substance
cd	candela	luminous intensity

WMO OMM

SI derived units with special names and symbols[40]:15

Name	Symbol	Quantity	In SI base units	In other SI units
radian[N 1]	rad	plane angle	m/m	1
steradian[N 1]	sr	solid angle	m^2/m^2	1
hertz	Hz	frequency	s^{-1}	
newton	N	force, weight	$kg \cdot m \cdot s^{-2}$	
pascal	Pa	pressure, stress	$kg \cdot m^{-1} \cdot s^{-2}$	N/m^2
joule	J	energy, work, heat	$kg \cdot m^2 \cdot s^{-2}$	$N \cdot m = Pa \cdot m^3$
watt	W	power, radiant flux	$kg \cdot m^2 \cdot s^{-3}$	J/s
coulomb	C	electric charge	s·A	
volt	V	electrical potential difference (voltage), emf	$kg \cdot m^2 \cdot s^{-3} \cdot A^{-1}$	W/A = J/C
farad	F	capacitance	$kg^{-1} \cdot m^{-2} \cdot s^4 \cdot A^2$	C/V
ohm	Ω	resistance, impedance, reactance	$kg \cdot m^2 \cdot s^{-3} \cdot A^{-2}$	V/A
siemens	S	electrical conductance	$kg^{-1} \cdot m^{-2} \cdot s^3 \cdot A^2$	Ω^{-1}
weber	Wb	magnetic flux	$kg \cdot m^2 \cdot s^{-2} \cdot A^{-1}$	V·s
tesla	T	magnetic flux density	$kg \cdot s^{-2} \cdot A^{-1}$	Wb/m^2
henry	H	inductance	$kg \cdot m^2 \cdot s^{-2} \cdot A^{-2}$	Wb/A
degree Celsius	°C	temperature relative to 273.15 K	K	
lumen	lm	luminous flux	cd·sr	cd·sr
lux	lx	illuminance	$cd \cdot sr \cdot m^{-2}$	lm/m^2
becquerel	Bq	radioactivity (decays per unit time)	s^{-1}	
gray	Gy	absorbed dose (of ionising radiation)	$m^2 \cdot s^{-2}$	J/kg
sievert	Sv	equivalent dose (of ionising radiation)	$m^2 \cdot s^{-2}$	J/kg
katal	kat	catalytic activity	$mol \cdot s^{-1}$	

Notes

1. ^ a b The radian and steradian are defined as dimensionless derived units.

SI prefixes

V · T · E

Prefix		Base 10	Decimal	English word		Adoption[nb 1]	Etymology	
Name	Symbol			Short scale	Long scale		Language	Derived word
yotta	Y	10^{24}	1 000 000 000 000 000 000 000 000	septillion	quadrillion	1991	Greek	eight[nb 2]
zetta	Z	10^{21}	1 000 000 000 000 000 000 000	sextillion	trilliard	1991	Latin	seven[nb 2]
exa	E	10^{18}	1 000 000 000 000 000 000	quintillion	trillion	1975	Greek	six
peta	P	10^{15}	1 000 000 000 000 000	quadrillion	billiard	1975	Greek	five[nb 2]
tera	T	10^{12}	1 000 000 000 000	trillion	billion	1960	Greek	four[nb 2], monster
giga	G	10^{9}	1 000 000 000	billion	milliard	1960	Greek	giant
mega	M	10^{6}	1 000 000	million		1873	Greek	great
kilo	k	10^{3}	1 000	thousand		1795	Greek	thousand
hecto	h	10^{2}	100	hundred		1795	Greek	hundred
deca	da	10^{1}	10	ten		1795	Greek	ten
		10^{0}	1	one		–		
deci	d	10^{-1}	0.1	tenth		1795	Latin	ten
centi	c	10^{-2}	0.01	hundredth		1795	Latin	hundred
milli	m	10^{-3}	0.001	thousandth		1795	Latin	thousand
micro	µ	10^{-6}	0.000 001	millionth		1873	Greek	small
nano	n	10^{-9}	0.000 000 001	billionth	milliardth	1960	Greek	dwarf
pico	p	10^{-12}	0.000 000 000 001	trillionth	billionth	1960	Spanish	peak, beak, little bit
femto	f	10^{-15}	0.000 000 000 000 001	quadrillionth	billiardth	1964	Danish	fifteen
atto	a	10^{-18}	0.000 000 000 000 000 001	quintillionth	trillionth	1964	Danish	eighteen
zepto	z	10^{-21}	0.000 000 000 000 000 000 001	sextillionth	trilliardth	1991	Latin	seven[nb 2]
yocto	y	10^{-24}	0.000 000 000 000 000 000 000 001	septillionth	quadrillionth	1991	Greek	eight[nb 2]

1. ^ Prefixes adopted before 1960 already existed before SI. The introduction of the CGS system was in 1873.
2. ^ a b c d e f Part of the beginning of the prefix was modified from the word it was derived from, ex: "peta" (prefix) vs "penta" (derived word).

When a value is expressed in number use the unit symbol

When in words, use the unit name.

0.4 m	some tens of meters
6 cm	few centimeters
8 g	some grams

Summarizing

All instruments (and measurement results) are affected by errors (3.2.1)

Instruments have properties introducing uncertainty components (resolution, sensitivity, reproducibility…)

The calibration is the process that calculates systematic errors evaluable as differences between the readings of the instrument and a reference values (absolute reference standard or reading of a reference instrument) (3.2.4)

The calibration results (differences) are then used to correct the instrument reading, with associated correction uncertainty. This is the calibration uncertainty, which represents the residual *unknowable error* for the calibration process

After correction, the expected value of the systematic error is zero (3.2.3).

Using the correct terminology is fundamental not only for correct communication, but also to better understand our own measuring system and procedure.

WEATHER CLIMATE WATER
TEMPS CLIMAT EAU

Thank you

WMO OMM

World Meteorological Organization
Organisation météorologique mondiale