Infrastructure Commission (INFCOM)

Standing Committee on Measurements, Instrumentation and Traceability (SC-MINT)

Expert Team on Quality, Traceability and Calibration (ET-QTC)

Calibration and Measurement Uncertainty

Part-2: Different Types of Uncertainty

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Random uncertainties – Type A

Type A evaluation

Make a series of observations of a quantity x_i

$$average\ \bar{x} = \frac{1}{n}\sum_{i=1}^{n} x_i$$

$$Standard\ Deviation, \sigma = \sqrt{\frac{1}{n-1}\sum_{i=1}^{n}(x_i - \bar{x})^2}$$

$$standard\ uncertainty, u(\bar{x}) = \frac{\sigma}{\sqrt{n}}$$

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Random uncertainties – average out

- If we have random terms then averaging multiple measurements will improve the uncertainty.

- So, for a normally distributed system, if we have:
  - N measurements
  - with a random uncertainty, Um – which can be estimated as the standard deviation of a series of measurements of an unchanging quantity – then
  - the uncertainty of the mean =

$$\frac{Um}{\sqrt{N}}$$

This must be the same measurand for all measurement. A quantity that changes (for example air temperature) cannot be considered the same measurand for all records.

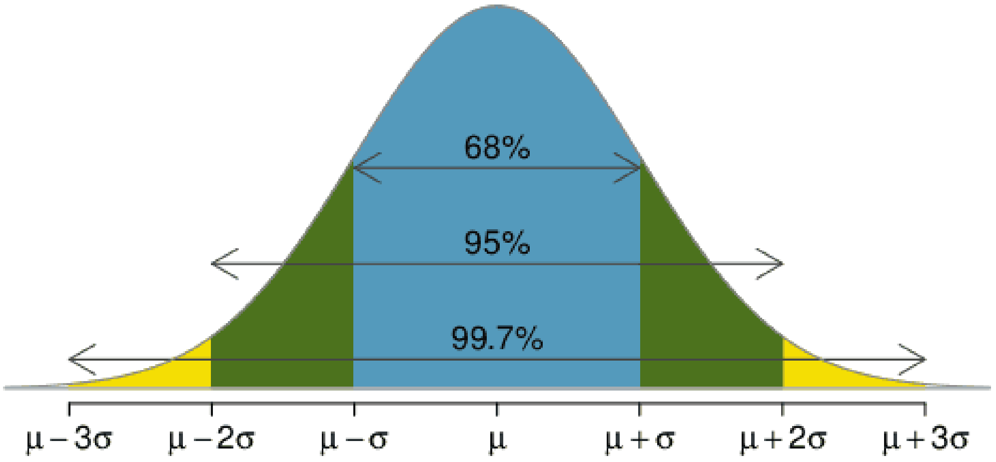
Types of Distributions

- Not everything has a normal distribution.
- Sometimes the distribution of a parameter is unknown and can only be guessed.
- Common distribution types are;
  - Rectangular – for example water in a rain gauge
  - Triangular – used if you are sure of the end points and believe the mode occurs at zero.

Normal Distribution

- The normal distribution leads to the least conservative estimate of uncertainty; i.e., it gives the smallest standard deviation.

- The calculation of the standard deviation is based on the assumption that the end-points, $(\mu \pm 3\sigma)$, encompass 99.7 percent of the distribution.



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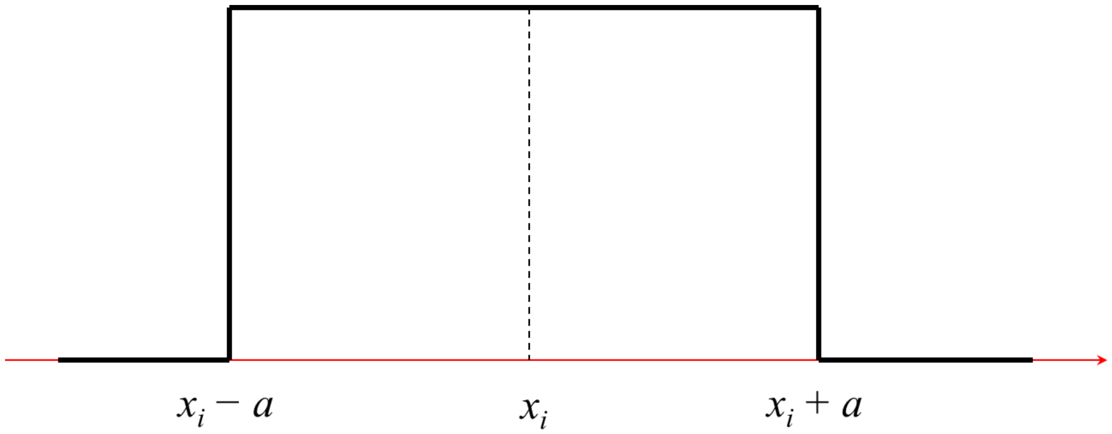
Rectangular Distribution

- This is the most conservative estimate of uncertainty.

Examples:

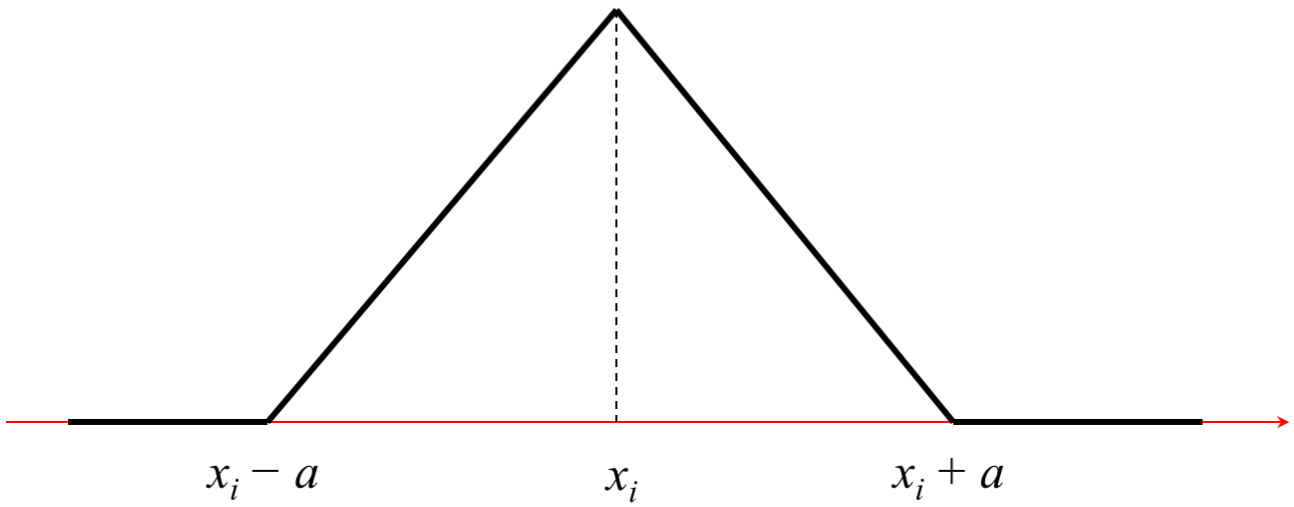
- Resolution is always considered as rectangular distribution.
- The water in the siphon of a tipping bucket rain gauge at a particular time.



$$u(x_i) = \frac{a}{\sqrt{3}}$$

Triangular Distribution

- Sometimes you can estimate a bound, *a*, for the error, but you believe that values near x_i are more likely than those farther away.
- In this case, you might assume a triangular distribution.



Systematic (instrumental) uncertainties – Type B

Main groups of type B uncertainties

- Calibration uncertainty (including uncertainty in standards)
- Instrumental components (stability, drift, repeatability, time constant, ...)
- Environmental conditions

There is no sense in evaluating an uncertainty budget for measurements made with an *uncalibrated* instrument!

Calibration

- Calibration ties down the uncertainties *at the conditions present during calibration*.

- Of course, the calibration itself introduces the uncertainty, associated to **the standards** used and their traceability

- Calibration therefore needs to be considered as one (important) part of the overall measurement process.

Manufacturer's specifications

Some component of uncertainty can be derived from instrument datasheets:

- Resolution
- Response time
- Hysteresis
- Sensitivity
- Stability
- Full scale uncertainty

Note: Some datasheet report a value of "accuracy" instead of "uncertainty". Clarification must be required from the manufacturer on the meaning.

Table 3. Instruction Specifications

NBS CONFORMITY

The thermometer conforms to the temperature/voltage tables of the National Bureau of Standards and to the IEC 584 standards for K-type and J-type thermocouples.

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Measurement Range:

K-type thermocouple:	-200°C to +1370°C (-328°F to +2498°F)
J-type thermocouple:	-200°C to +760°C (-328°F to +1400°F)

NOTE

This specification applies only to the thermometer and may differ from the thermocouple range. To prevent damage to the thermocouple, check the specification before using (see Appendix A).

Resolution: High: 0.1°C or 0.2°F
Low: 1°C or 1°F

Accuracy:

Accuracy is specified for operating temperatures over the range of 18°C to 28°C (64°F to 82°F), for 1 year, not including thermocouple error (see "Thermocouple Limitations").

For single-thermocouple measurements, accuracy is:

K-type thermocouple:	±(0.1% of reading + 0.7°C) (±[0.1% of reading + 1.3°F])
J-type thermocouple:	±(0.1% of reading +0.8°C) (±[0.1% of reading +1.4°F])

For T1-T2 measurements, accuracy is typically better than:

K-type thermocouples:	±(0.1% of T1-T2 reading + 1.0°C) (±[0.1% of T1-T2 reading + 1.8°F])
J-type thermocouples:	±(0.1% of T1-T2 reading + 1.2°C) (±[0.1% of T1-T2 reading + 2.2°F])

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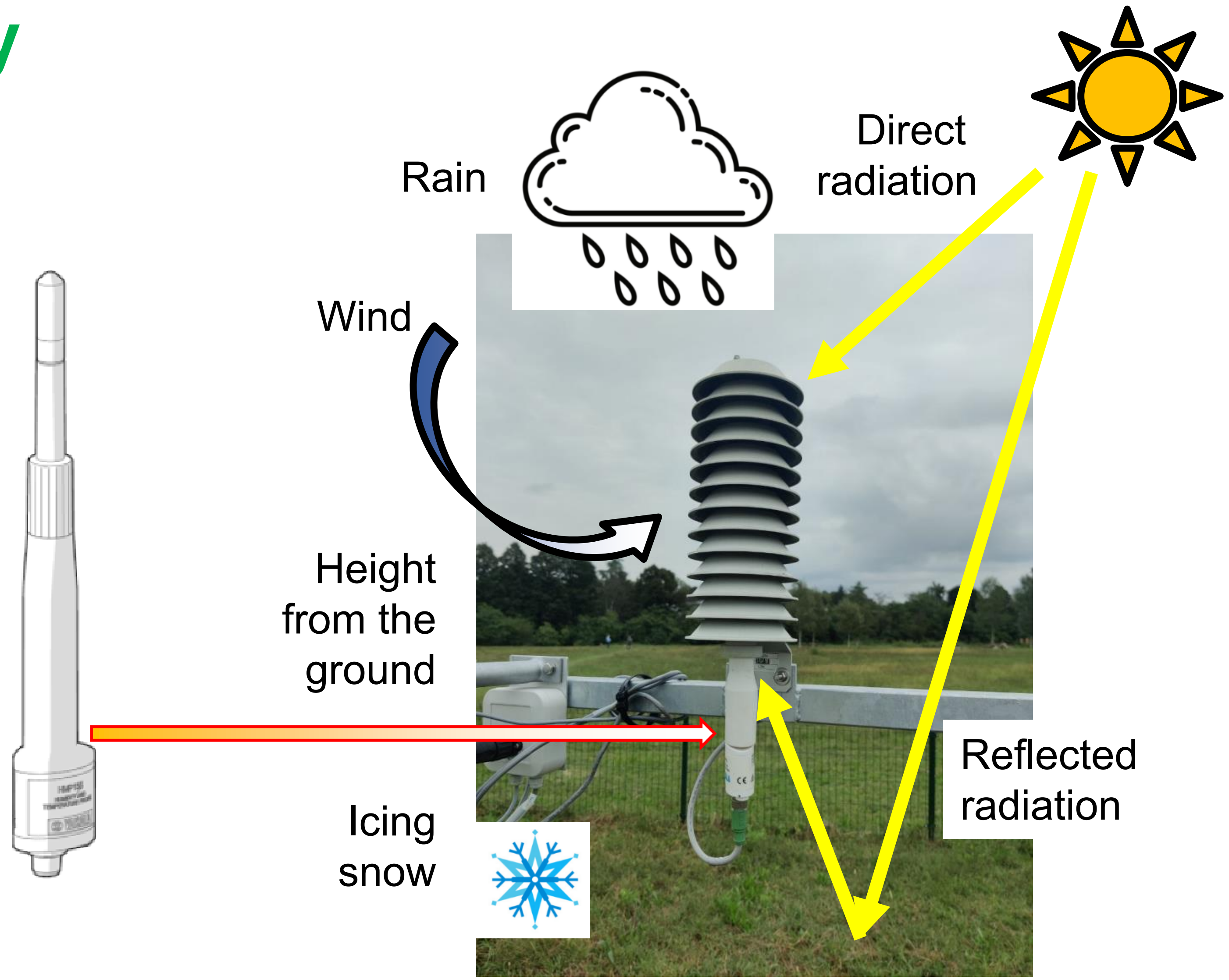
Type B components of uncertainty

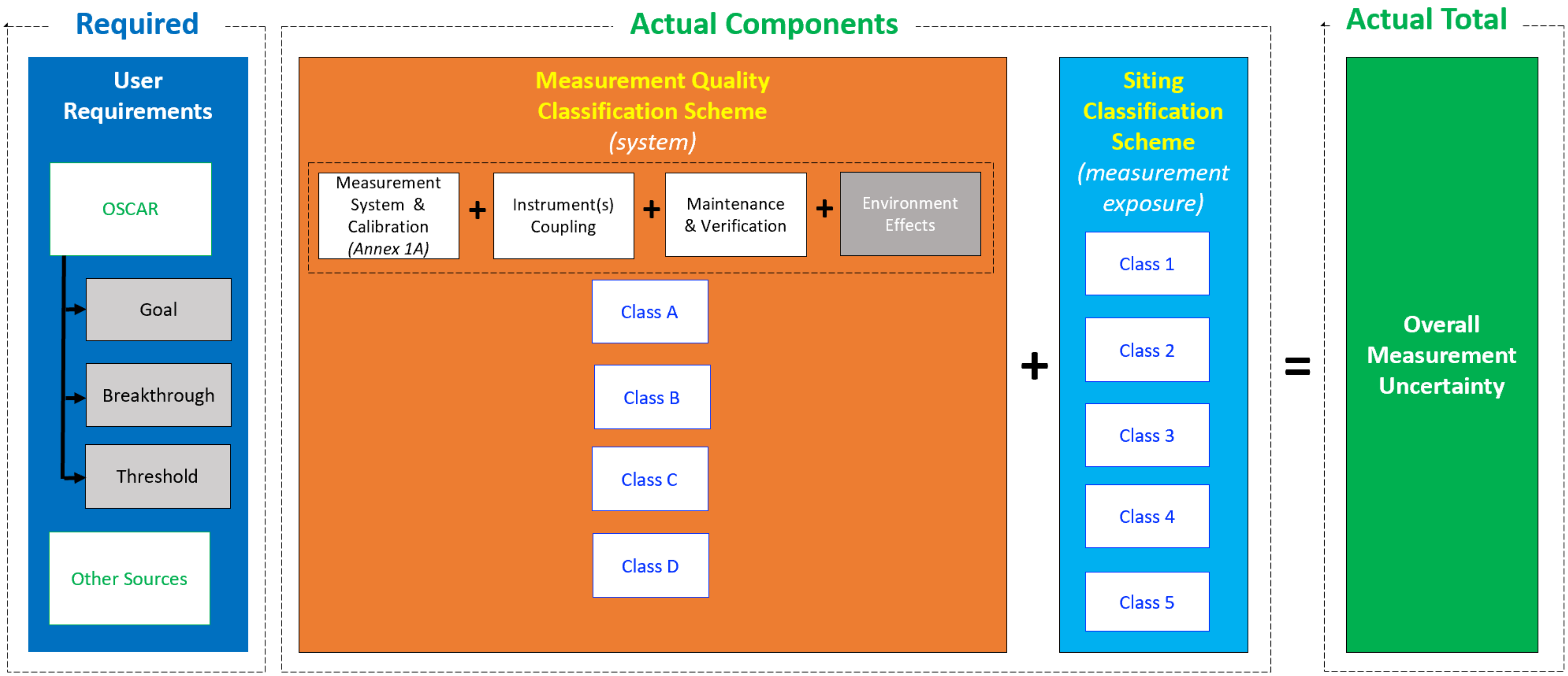
Instrument components

Calibration
Resolution
Drift
Logger
Sensitivity
Hysteresis
Repeatability

Environmental AQIs



MEASUREMENT QUALITY CLASSIFICATIONS
FOR SURFACE OBSERVING STATIONS ON LAND



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Sources of Uncertainty for surface-based measurement systems (from the new classification scheme in WMO-No.8)

(Each one should generate a component in the uncertainty budget)

Measurement System and Calibration:

- Construction quality,
- Resolution,
- Instrument and logger calibration,
- Linearity,
- Hysteresis,
- Time constant,
- Drift with temperature,
- Sampling method,
- Sampling frequency,
- Processing algorithm,
- Digitization and rounding,
- Response time,
- Definition of the measurand

Instrument Coupling:

- Radiation screen,
- Static pressure head,
- Rain gauge fence screen.

Maintenance and Verification:

- Frequency of maintenance,
- Instrument and system drift with time,
- Instrument and system aging,
- Instrument and system faults (that affect data but do not cause failure),
- Cleanliness of instrument and site.

Environment Effects:

- Sensor mechanical stress during transport and operation,
- Evaporation of precipitation on screen,
- Wind effects on measurement,
- Condensation on temperature instrument,
- Solar radiation effects on measurement.

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Also the un-complete knowledge of the **measurand** or its definition is a component of the overall measurement uncertainty.

Example: air temperature

- Do we measure air temperature or the heat transfer between the air and the thermometer?
- How well can we evaluate this heat equilibrium?
- How well can we describe the heat transfer model, including materials, convection, conduction, radiation…?

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Uncertainties on the measurand

- incomplete definition of the measurand;
- imperfect realization of the definition of the measurand;
- non representative sampling — the sample measured may not represent the defined measurand;
- inadequate knowledge of the effects of **environmental conditions (AQIs)** on the measurement or imperfect measurement of environmental conditions;
- inexact values of measurement standards and reference materials;
- approximations and assumptions
- variations in repeated observations of the measurand under apparently identical conditions.

Play a relevant role in field observations

Thank you.

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