Establishing Traceability and Comparability for GRUAN Measurements

Tom Gardiner
Environmental Measurement Group
National Physical Laboratory, UK

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Talk Contents

- Concepts and Definitions
- Quality Assurance Strategy within CEOS
- Intercomparisons
- Instrumental Type Testing and Proficiency Testing Schemes
- Summary and Discussion

Concepts and Definitions

- Focus on traceability, uncertainty and equivalence.

- 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

As defined by the International Vocabulary of Basic and General Terms in Metrology (VIM) — Third edition (2006)

What is uncertainty?

VIM definition

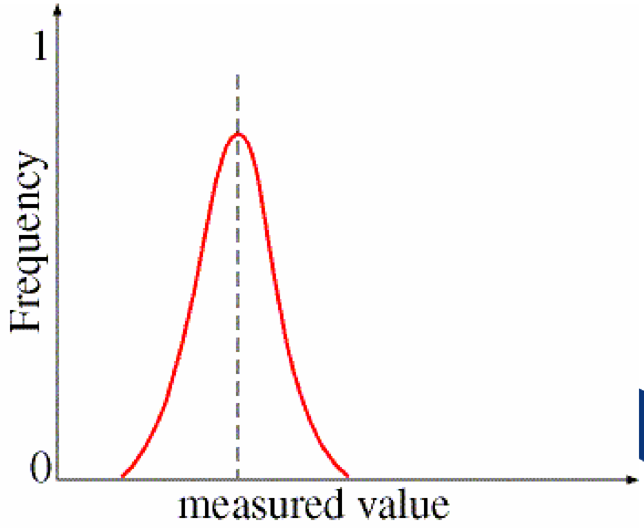
'Parameter, associated with the result of a measurement, that characterises the dispersion of the values that could reasonably be attributed to the measurand'

From which we can conclude:

- Uncertainty is a topic which seems to attract the most obscure and convoluted definitions
- Uncertainty is a **property of a result**
- Indicates the likely range within which we think the 'true' value of a measured quantity lies, **given all the information we have**
- Measurement uncertainty is a single value, expressed in terms of the measurand, either as a percentage or in units or the measurement

$x \pm U$

(with a given confidence interval defined by a coverage factor, k))



What isn't it

- Mistakes
  - Uncertainty doesn't (can't) cover mistakes and errors
- The error in the result
  - An error is the difference between a result and the true answer – we don't know what the 'true' answer is
  - Better to think of measurement uncertainty as a figure of merit, an indication of what values the true answer might have
- An absolute fact
  - It is an estimate, at best we are saying that 95 times out of a hundred the result is (probably) within our uncertainty bounds.

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Why evaluate uncertainty

- Allows us to assess methods and results against data quality requirements
- Fitness for purpose
- Interpretation of results
- Equivalency of results
- Provides an understanding of the measurement and which parameters should be given most consideration
  - Informs method optimisation

As usual the trouble's in the small print

The uncertainty (on a 95 % confidence interval) of the assessment methods will be evaluated in accordance with the principles of the ISO Guide to the Expression of Uncertainty in Measurement (1993) or the methodology of ISO 5725:1994 or equivalent. The percentages for uncertainty in the above table are given for individual measurements averaged over the period considered by the limit value, for a 95 % confidence interval. The uncertainty for the fixed measurements should be interpreted as being applicable in the region of the appropriate limit value.

Illustration of the concept of uncertainty

Repeated measurements
(of the same thing)

Average

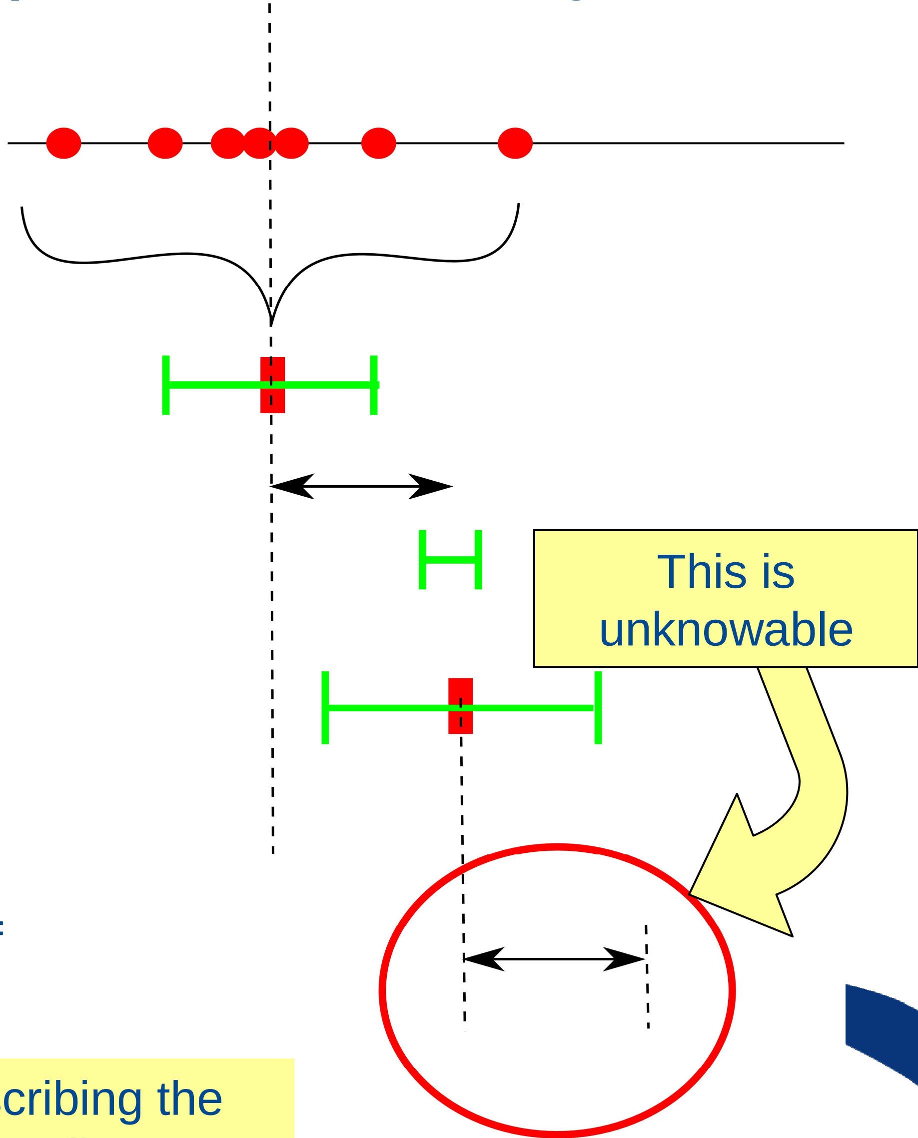
Uncertainty due to repeatability

Correction for standard conditions

Uncertainty due to correction

Measurement result and
estimate of uncertainty

However, ‘true’ result may be
outside the uncertainty because of
unknown effects



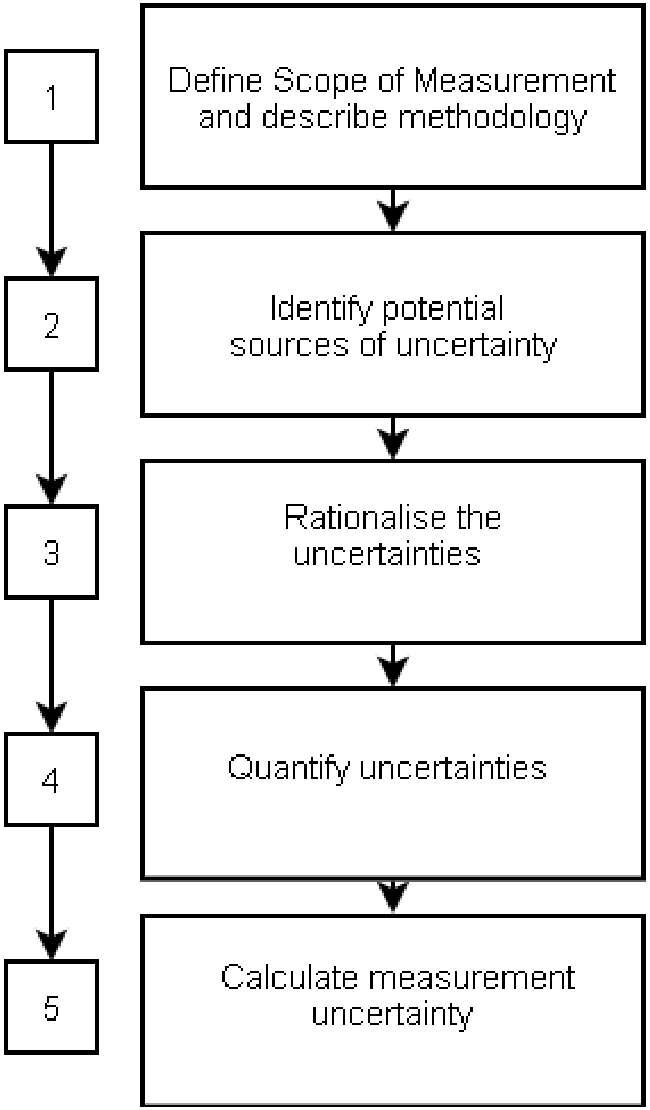
We minimise this by describing the
method as fully as possible

Guidance and Standards

- In the air quality field there are a large number of guides and standards which deal with uncertainty evaluation
- Guide to Expression of Uncertainty in Measurement [GUM] ENV 13005)
- Within CEN and ISO standardisation
  - CR 14377 Approach to uncertainty estimation for ambient air reference measurement results
  - CEN reference methods ISO/DIS 20988 – Guidelines for estimating measurement uncertainty
- In analytical chemistry
  - ILAC – G17,
  - Eurochem/CITAC Guides, G4
- Guides for using validation data to evaluate uncertainty
  - ISO/TS 21748

Guide to Uncertainty in Measurement (GUM)

- GUM has been adopted as an overarching methodology
- Approach can be summarised as
  - Describe measurement steps
  - Identify uncertainties associated with these and all inputs
  - Combine them
  - Assign known level of confidence to this uncertainty



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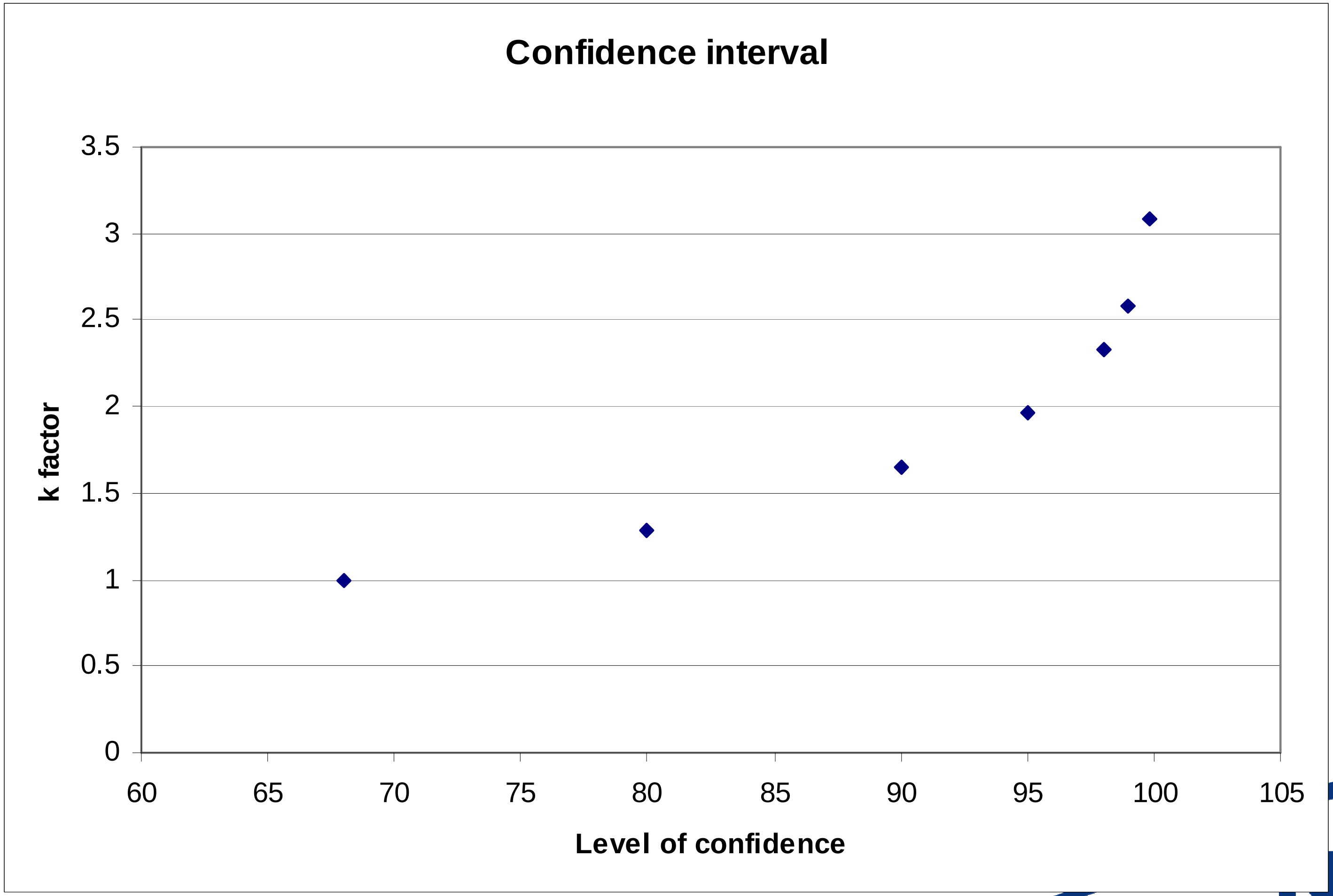
GUM approach to determining uncertainty

- Define the measurement process
    - In principle we should know the 'measurement equation'

$$Y = f(X_1, X_2 .. X_N)$$

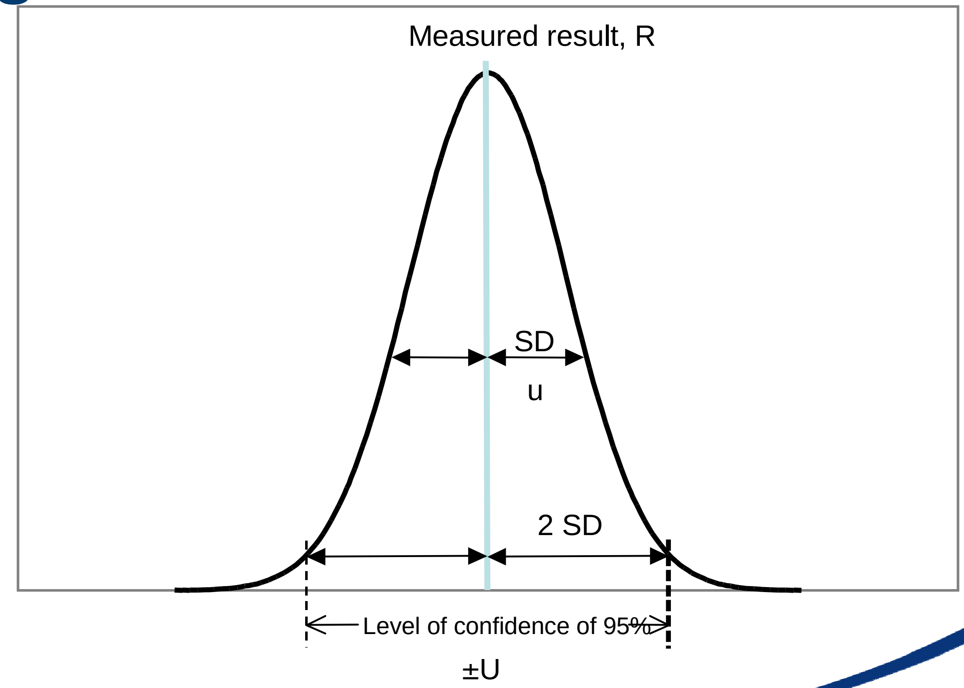
- Quantify uncertainties of each X_i these as standard uncertainties (in units of measurand)
    - by repeated measurement - Type A
    - by estimation - Type B
    - Insignificant contributions may be ignored
- Combine these as square root of the sum of the variances – for random uncorrelated sources
- Expand the combined uncertainty to give an estimate of the uncertainty with a required level of confidence by multiplying by a coverage factor (k)

Relationship between k and level of confidence



Normal Distribution

- Simplest model of uncertainty for repeated measurements with random uncertainty
- Estimated by standard deviation of the results



Standard uncertainties

- We convert uncertainty sources to standard uncertainties
  - For random terms this is the standard deviation of the set of repeated results
  - For quantities which we believe lie within a range, but with equal probability of being anywhere in that range (often things like drift or certain influence quantities)
    - This is a rectangular distribution, width R
    - The equivalent standard deviation is $\frac{R}{\sqrt{3}}$
    - You'll see this in uncertainty spreadsheets quite often

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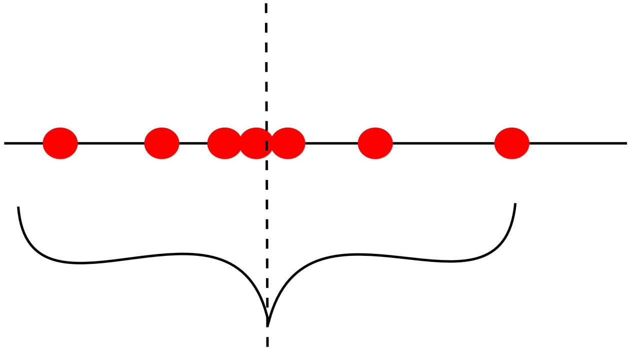
Repeatability in atmospheric measurements



- One key issue in atmospheric measurements is that in general we can't make repeated measurements of the measurand
- If what we are measuring is an annual mean, then we can't look at the scatter of results as a measure of the uncertainty in the measurement
- Need to characterise the repeatability from validation measurements – usually by repeated measurements of a CRM
- Of course the measurement we make of the mean will improve with more results

Don't confuse variability of the measurand with uncertainty of the measurement

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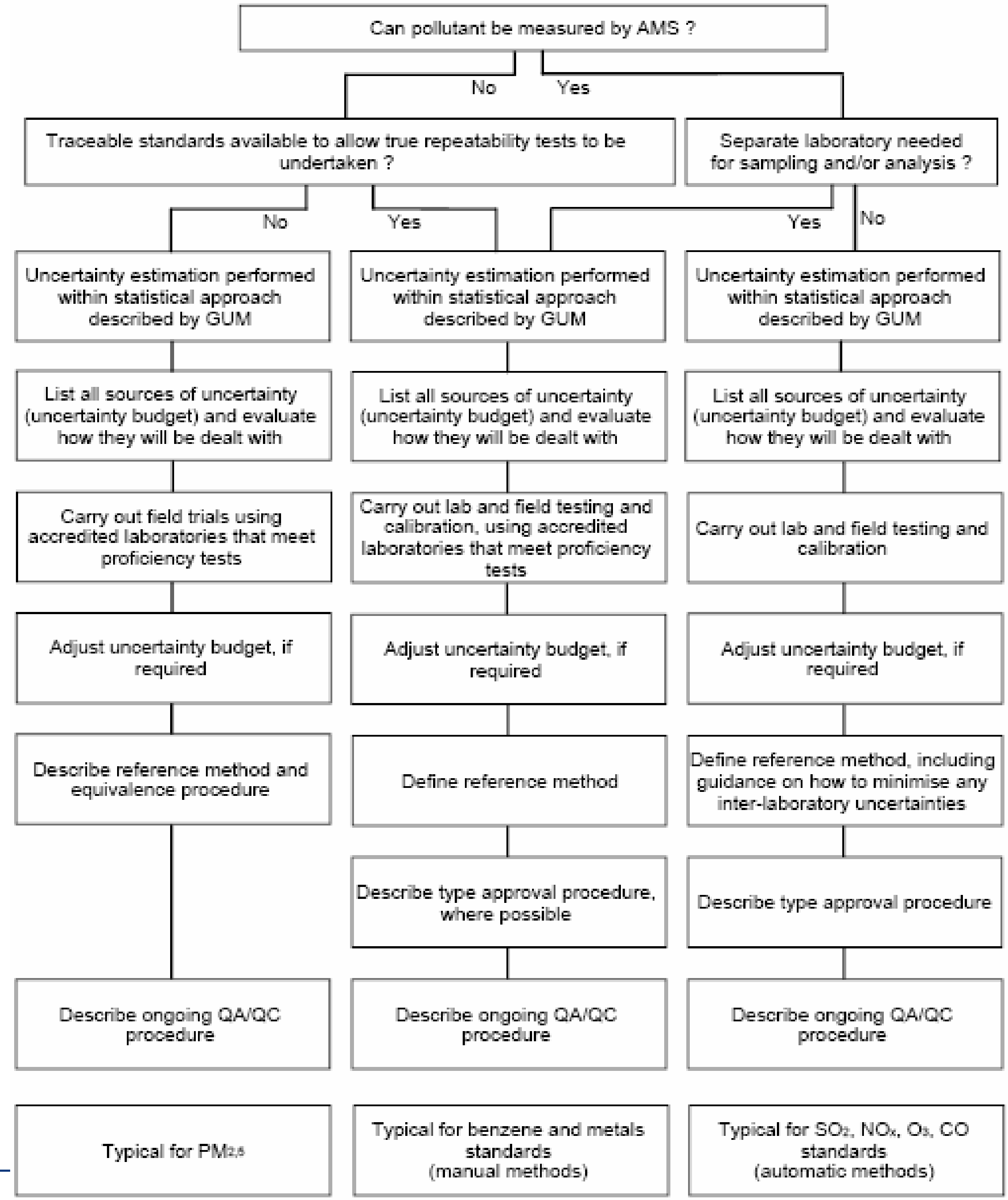
CR 14377

Approach to uncertainty for CEN reference methods

Aimed to produce harmonised uncertainty evaluation

Based on GUM

Table 1 — Methodology used for the development of European Standards for measurements of ambient air quality



EN ISO 20988

- Guidelines for measuring measurement uncertainty
- Provides eight models of ‘experiment’ which may provide input data to an uncertainty evaluation, and statistical approaches to assess these.
  - A1: simple random sampling;
  - A2: repeated observation of a reference material by a measuring system;
  - A3: observation of different reference materials in a calibration procedure;
  - A4: repeated observation of different reference materials by identical measuring systems;
  - A5: parallel measurements with a reference method of measurement;
  - A6: paired measurements of two identical measuring systems;
  - A7: inter-laboratory comparison of identical measuring systems;
  - A8: parallel measurement of identical measuring systems.
- **Not the easiest standard to apply**

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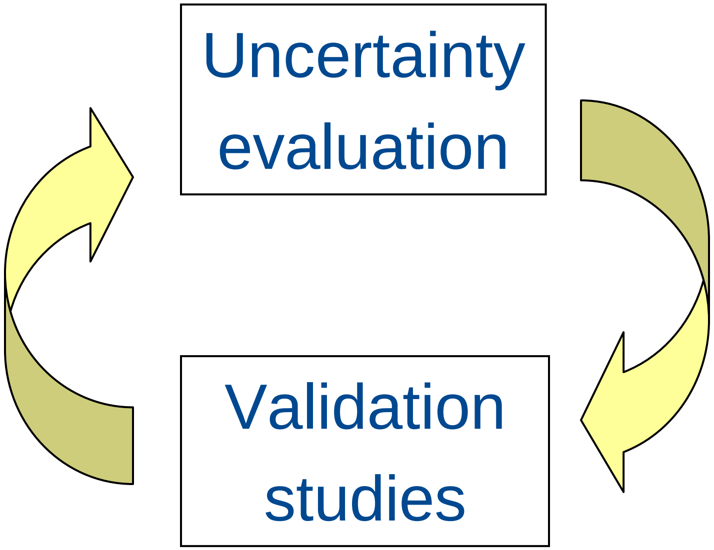
Uncertainty of a method

- Measurement uncertainty is a property of a result
- Ideally this would be evaluated for every result
- There is general acceptance that it is possible to evaluate the uncertainty of a standardised method – and assume this uncertainty applies to future measurements made with the method
- Need to be sure the uncertainty evaluation is appropriate for all applications of the method – ie conditions and scope of validation experiments cover the ongoing use
- QA/QC requirements within method become important
- Ideally a method would provide both results of validation including the ‘method’ uncertainty, and a procedure for a user to evaluate the measurement uncertainty of results they have obtained

Validation

- Validation provides evidence that a method is fit for purpose
- Often takes the form of inter-laboratory studies and intra-laboratory method assessment
- Should include all QA/QC and other procedures used to control the method
- EU project norman – providing a standard approach to the development of new methods for emerging pollutants
  - Levels of validation from research method to method appropriate for standardisation by CEN



Validation studies can be used to check uncertainty evaluations or to provide input into them.

Uncertainty evaluation can be used to help plan validation studies

Ideally the two processes should be iterated

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Controlling uncertainty - calibration

- Calibration ties down the uncertainties at the conditions present during calibration
- Influence quantities which don't change from the conditions of calibration won't contribute to the uncertainty
- Only things which are either uncontrolled by calibration (ie interferent gases) or change (ambient temperature) should be included
- Of course the calibration itself introduces an uncertainty

Repeatability or Trueness?

- Always define the scope of the measurement that you are determining the uncertainty of
- What may appear as a systematic term (bias) in one context may be a random term in another (and vice versa)
- For example over a year the use of different calibrations will randomise some uncertainties.
- If you can randomise a systematic (bias) term then it can be reduced (ie use multiple independent calibration artefacts)

Equivalence

- Two ways to determine equivalence

Showing EM meets performance requirements

Showing EM gives same results as SM(within some defined criteria)

'An Equivalent Method to the Standard Method for the measurement of a specified air pollutant, is a method meeting the Data Quality Objectives for continuous or fixed measurements specified in the relevant air quality directive'

Equivalence procedure

- Equivalence procedure for ambient monitoring
- Allows for full evaluation (different principles) or ‘variation on a theme’
- Requires assessment of scope of equivalence – ie what range of conditions and locations are covered
- Assessment based on uncertainty assessment – based on laboratory tests, field comparison against RM
- Different test plans depending on type of instrument – specifically related to traceability
  - Ie for PM instruments traceability is to a reference instrument

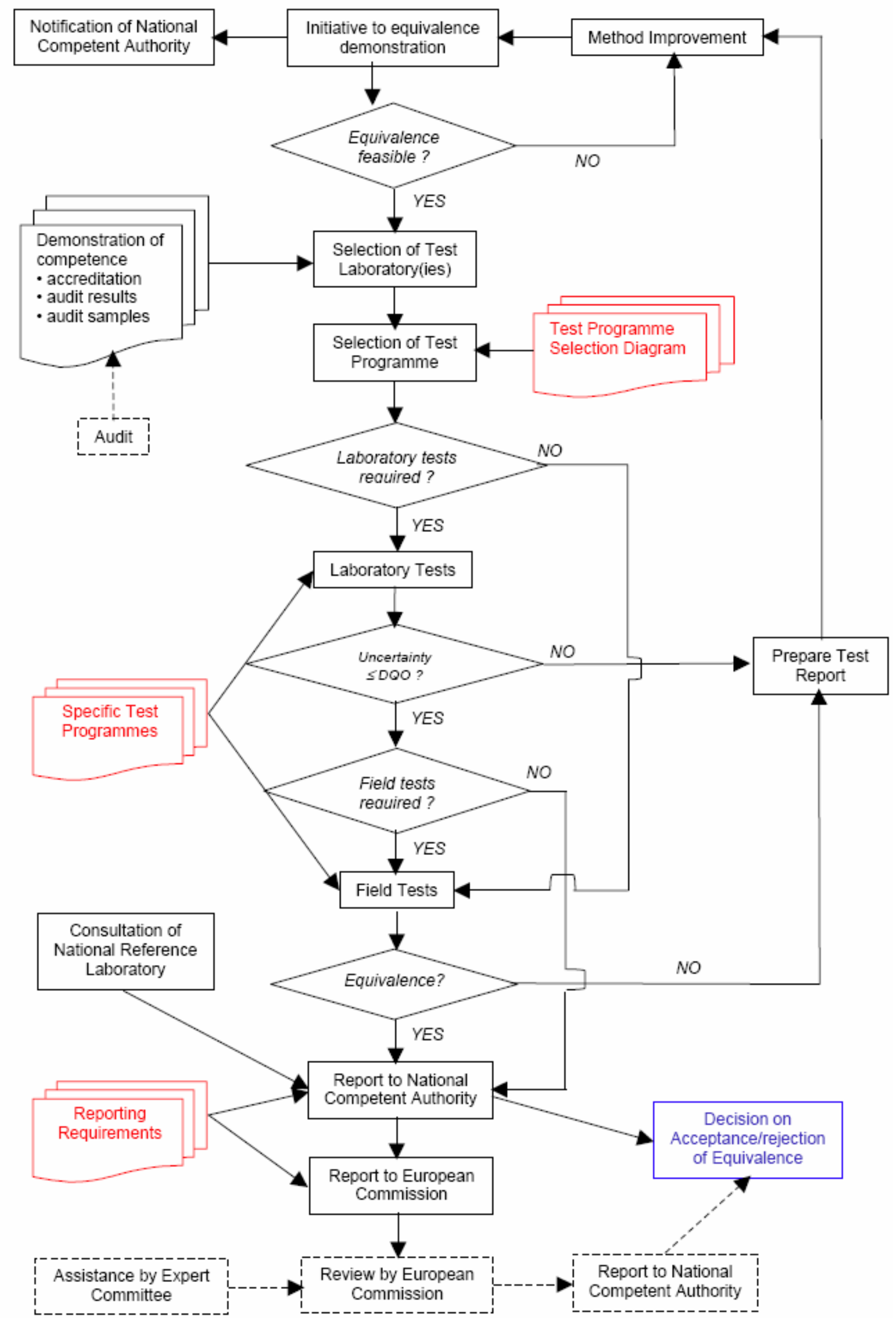
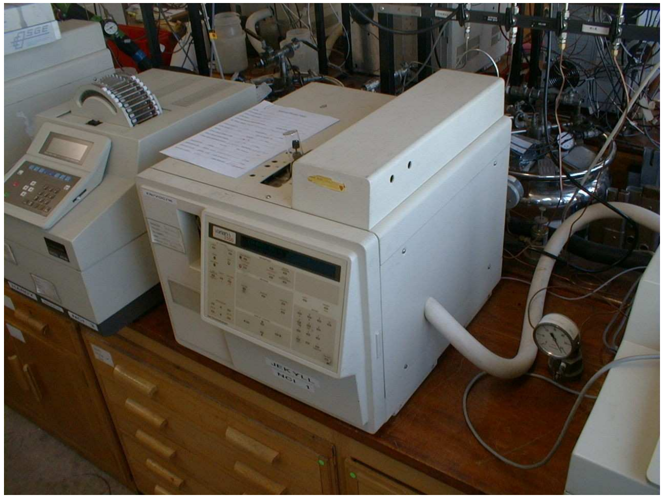


Figure 2. Flow scheme of the procedure for demonstration of equivalence

Example Uncertainty – HC network

Source	Value / description	Value	Probability Distribution	Divisor	% Standard Uncertainty LV
Volume of sampled air					
Sample time	2%	2%	Rectangular	√3	1.155
Flow rate accuracy		5%	Rectangular	√3	2.887
Flow rate repeatability	0.2% FSD on a flow rate of 10cc	0.40%	Normal	1	0.4
Drift in flow	2% in six months	2%	Rectangular	√3	1.155
Pressure correction	0.02%FSD / psi, assume a 3% range	0.02%	Normal	1	0.02
Temperature correction	0.13%FSD / deg c, assume a 10C range	2.60%	Normal	1	2.6
Analytical					
Sampling efficiency	Insignificant	0			0
Stability of benzene / sample matrix	Max allowable by Std	1%	Normal	1	1
Recovery of Benzene on desorption	Insignificant	0	Normal		0
Standards repeatability	13118 measurements	462	Normal	1	3.522
Linearity	5%	0.05	Rectangular	√3	2.887
Interference		2%	Rectangular	√3	1.155
Blank	<2ng ≡ 0.01PPB, assume limit value measured (1.5 PPB)	0.67%	Rectangular	√3	0.386
Total Combined Standard Uncertainty					6.414
Total Combined Expanded Uncertainty				K=2 95%	**12.829**



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Quality Assurance Strategy within CEOS

- The QA4EO initiative provides a Quality Assurance Framework for Earth Observation and presents the guiding principles and key guidelines of the three themes:
  - Data Quality (DQ),
  - Data Policy (DP)
  - Communication and Education (CE).
- This framework has been approved by CEOS for the space element of GEO, and is likely to be extended across all of the GEO areas in the future.

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Requirement

- **The Group on Earth Observations (GEO)'s Global Earth Observation System of Systems (GEOSS) <u>must</u> deliver comprehensive "knowledge / information products" worldwide and in a timely manner to meet the needs of its nine "societal benefit areas".**

This will be achieved through the synergistic use and combination of data derived from a variety of sources (satellite, airborne and *in-situ*) through the coordinated resources and efforts of the GEO members.

Achieving this vision requires the establishment of an operational framework to facilitate interoperability and harmonisation.

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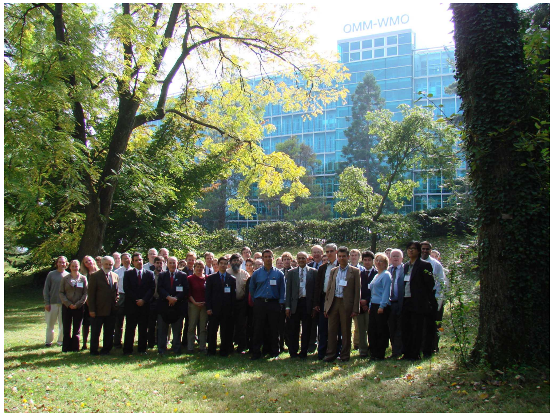
Strategy development: community engagement

Strategy development led by small CEOS team through two community workshops, CEOS sub-groups and ad-hoc meetings

“GEO/CEOS workshop on quality assurance of calibration and validation processes:



guiding principles”
(*Geneva Oct 07)*

Establishing an operational framework”
(*Washington May 08)*

Peer review completed Sep 08

CEOS approval given Nov 08

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Operational framework: Principles

This framework, in the context of data and derived products, is dependent on the successful implementation of two principles:

- **Accessibility / Availability**
- **Suitability / Reliability**

And the means to efficiently communicate these attributes to all stakeholders.

GEOSS: Seamless & continuous delivery of information products to meet needs of societal benefit areas

Interoperability arrangements to allow combinations of disparate sources of data

Data Quality

Accessibility Availability

Suitability Reliability

Fit For purpose

Strategy:
Establish set of guidelines based on "best practices" to be endorsed by CEOS, under auspices of GEO and implemented by the agencies

All data and derived products must have associated with them a Quality Indicator based on a documented quantitative assessment of its traceability to an agreed reference standard (ideally tied to SI).

Comparisons

Procedures

Reference standards (with method of use): including designation of "test sites"

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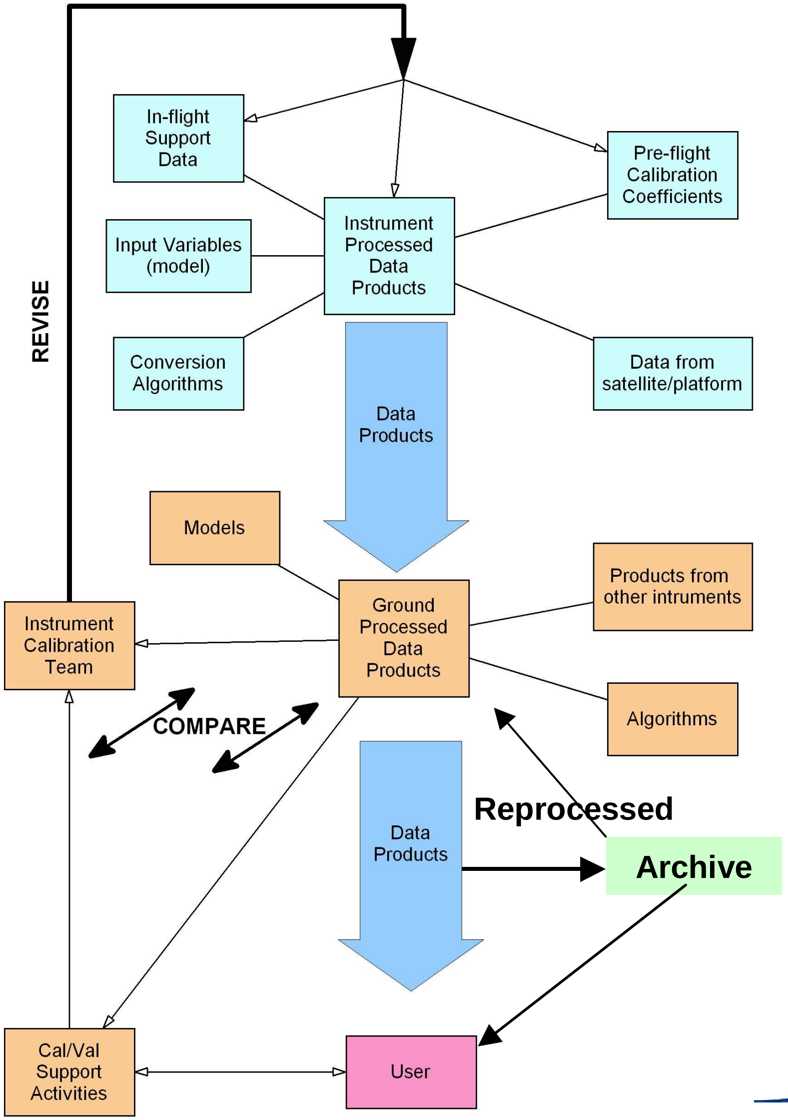
Operational framework: scope



Its scope encompasses the whole EO sector:

- **All sensor types & operational domains**
- **Data collection**
- **Processing (Level 1 to Level n)**
- **Distribution**

Operational framework: Structure

To enable these principles to be implemented in a harmonised manner, the Committee on Earth Observation Satellites (CEOS), the space arm of GEOSS, following discussion at two international workshops of Cal/Val experts, has established a quality assurance (QA) framework.

This framework consists of a set of operational guidelines derived from "best practices" for implementation by the community. These guidelines have been collated into three theme areas:

- **Data Quality**,
- **Data Policy** *and*
- **Communication & Education**

Each theme has an overarching "guiding principle" towards achieving interoperability with a minimal set of "key guidelines" to aid harmonisation.

Data Quality

All data and derived products must have associated with them a Quality Indicator (QI) based on documented quantitative assessment of its traceability to community agreed reference standards. This requires all steps in the data and product delivery chain (collection, archiving, processing and dissemination) to be documented with evidence of their traceability.

- **Guidelines are generic in scope to cover all data-related "activities".**
- **Provide guidance (and indicative templates) on how to establish a QI and means to obtain and document associated evidence.**

- **Content / writing of a "procedure"**
- **Validating models & Algorithms**
- **Selecting "Reference standards"**
- **Evaluating Uncertainties**
- **Organising and analysing comparisons**
- **Evidence of traceability**

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Data Policy

The data must be freely and readily available / accessible / useable in an unencumbered manner for the good of the GEOSS community, for both current and future users. This necessitates that all Cal/Val data and associated support information (metadata, processing methodologies, Quality Assurance, etc.) is associated with the means to effectively implement a Quality Indicator. In return, the data provider must be consistently acknowledged.

Guidelines are based on the adoption of existing "best" and commonly-used practises

- **Common metadata content and its linkage with datasets**
- **Domain harmonised formats for Cal/Val data exchange**
- **"Code of practise" for Cal/Val data providers & users**

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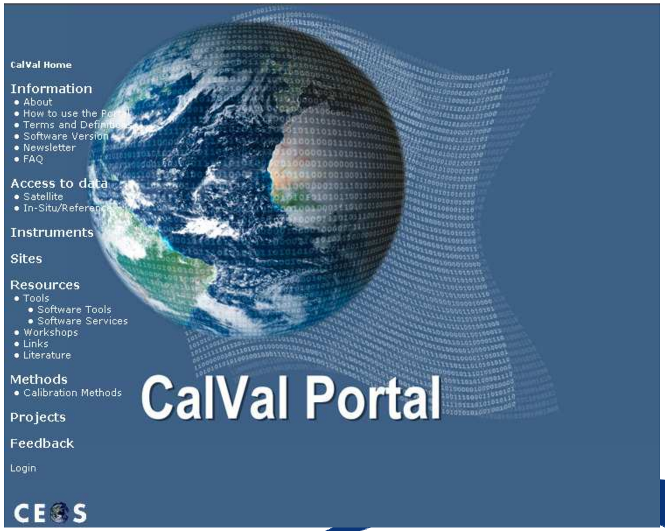
Communication and Education

Interoperability requires all stakeholders to have a clear understanding of the adequacy of the information that they are accessing and using for their specific application, i.e. its "fitness for purpose". The evidence for this clarity will be accessible through a [single portal](http://calvalportal.ceos.org) (http://calvalportal.ceos.org) and will be fully traceable to its origins. The traceability and interoperability process must be understandable by any appropriately trained individual throughout GEOSS and efforts must be made to encourage the wider usage of information and facilitate the training of GEOSS users.

- **Dictionary of terminology**
- **Maintenance / evolution & utilisation of a Cal/Val Portal for all EO sensor domains**
- **Document management system**
- **Facilitate education and capacity building to promote use of QA4EO**



QA4EO - Guidelines

- A series of key guidelines have been written to support the implementation of QA4EO :
  - Establish QI for a sensor delivered data product (QA4EO-CEOS-GEN-DQK-001)
  - Content of a documentary procedure to meet the QA requirements of QA4EO (QA4EO-CEOS-GEN-DQK-002)
  - Establishing reference standards (QA4EO-CEOS-GEN-DQK-003)
  - Organisation and analysis of “comparison of measurements” (QA4EO-CEOSGEN-DQK-004)
  - Writing and validating models, algorithms & software (QA4EO-CEOS-GENDQK-005)
  - Evaluating uncertainty of measurement (QA4EO-CEOS-GEN-DQK-006)
  - Establishing and assessing “quantitative evidence of traceability” (QA4EOCEOS-GEN-DQK-007)

QA4EO – Quality Indicator

"a means of providing a user of a product (which is the result of a process) sufficient information to assess its suitability for a particular application. This "information" should be based on a quantitative assessment of its traceability to an agreed reference standard (ideally SI)."

QA4EO – Documentary Procedures (I)

- The core headings for a documented procedure are as follows :
  - Identifier: alphanumeric, following QA4EO-CEOS-GEN-CEK-001
  - Title: concise but explanatory
  - Author: owner, point of contact (POC)
  - Authority: authority under which the document is issued
  - Issue/version number/date: indicate if superseding a previous version
  - Abstract: concise overview, one or two paragraphs, includes keywords to aid in automated searching
  - Overview/scope: extension of abstract, to enable rapid assessment of purpose and content of the document
  - Terminology/definitions: key terms used; not for establishing new definitions
  - Background/context/requirement: information to place the activity in the context of addressing a requirement

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QA4EO – Documentary Procedures (II)

- The core headings for a documented procedure are (cont.):
  - Outcomes: possible/expected results of the activity, with uncertainty, and referenced to standards
  - Inputs: the entities upon/with, which the activity operates
  - Standards and Traceability: the “standards” to which the outcomes are referenced, and the linkage/comparison pathway
  - Task Description: details of the activity, to enable reproduction and assess its suitability for a particular purpose
  - Evaluation of Performance: quantitative assessment of the results of the activity, to establish confidence levels for the outcomes
  - Evidence to support a Performance Indicator: documentation to justify/support the Evaluation of Performance
  - Review of Process: results of internal/external user evaluations

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QA4EO - Standards

- Definitions
  - **Measurement Standard**: Realization of the definition of a given quantity, with stated quantity value and associated measurement uncertainty, used as a reference
  - **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 standard**: Measurement standard that is used routinely to calibrate or verify measuring instruments or measuring systems
  - **Intrinsic standard**: Measurement standard based on a sufficiently stable and reproducible property of a phenomenon or substance. The quantity value of an intrinsic standard is assigned by consensus and does not need to be established by relating it to another measurement standard of the same type.

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Data Quality: Implementation

- Following the key guidelines within QA4EO should allow all stakeholders to have confidence in any assigned Quality Indicator (QI).
- Where appropriate, sensor- or application- specific guidelines/procedures may be endorsed by CEOS on behalf of the community to facilitate harmonisation.
    - **The structure / content of these additional guidelines should follow that of the Key guidelines**
    - **Ideally based on agreed "mature" best practise**
    - **Are not necessarily unique**
    - **"peer review" and endorsement through CEOS WGCV sub-groups**
- Individual agencies will be responsible for implementation in their "domain of influence" although CEOS WGCV will provide technical support and a forum for ensuring inter-agency consistency.
- The key requirement is "documented evidence and quantification of traceability to an agreed reference"
- Evolution of guidelines as a result of feedback and to encompass full GEOSS community

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Intercomparisons

- One of the main routes for establishing and maintaining measurement traceability and uncertainty is through intercomparisons.
- Comparisons need to be carefully designed so that they can be carried out “blind” but avoid issues due to simple typographical errors and recognise the potentially large cost of organisation and participation.
- In many cases there is no “a-priori” correct answer and so a process needs to be adopted to establish a “comparison reference value” (CRV) for the comparison to which all results can be compared, in a fair but scientifically appropriate manner.
- They are not the same as scientific studies into the comparability of two different instruments.

Typical reporting procedure of a formal intercomparison

- Pilot receives all the results with uncertainty budgets and finishes all the measurements.
- Pilot distributes the uncertainty budgets of all the participants to all participants.
- Pilot sends out Relative Data to each participant and their reported values as recorded by the pilot for checking.
- Responses to Relative Data from all participants due
- Comments on the uncertainty budgets closed.
- Responses to comments on uncertainty budgets and revision of uncertainty closed.
- Draft A (internal report) distributed.
- Comments on draft A.
- Draft B (external report) submitted to approval authority. Or, Draft A-2 distributed to participants.
- Draft B approved by approval authority (Or, comments sent to Pilot, requesting revision)
- Final Report published.

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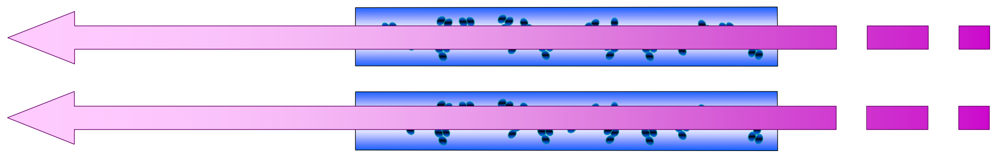
Ozone reference method: UV photometry

ATTENUATED LIGHT INTENSITY *I*



LIGHT INTENSITY I_0

OZONE SAMPLE

***x* mole fraction of ozone in dry air (nmol/mol)**

$$x = \frac{-1}{2\sigma L_{opt}} \frac{T}{P} \frac{R}{N_A} \ln(D)$$

T Temperature in the cells

P Pressure in the cells

L_{opt} light path length

σ Ozone absorption cross-section at 253.64 nm under standard conditions of temperature and pressure

D Product of transmittance of the two cells

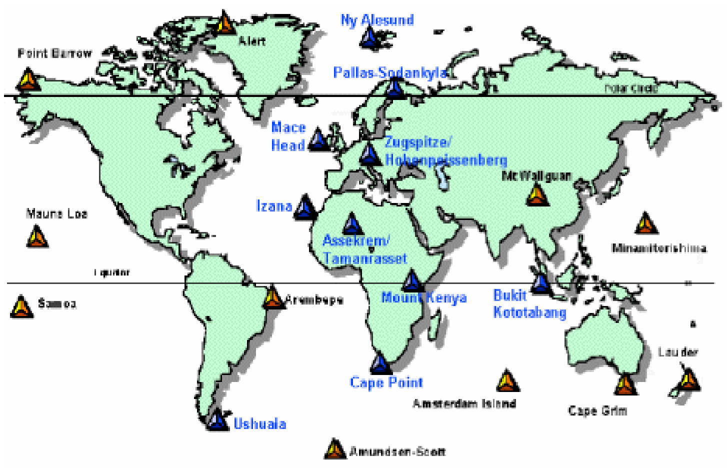
R Gas constant

N_A Avogadro constant

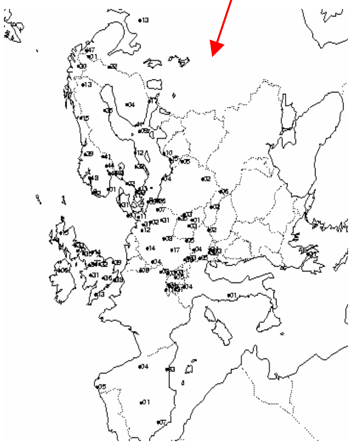
Global measurements of ambient ozone

Global, regional and national ozone measurement networks :

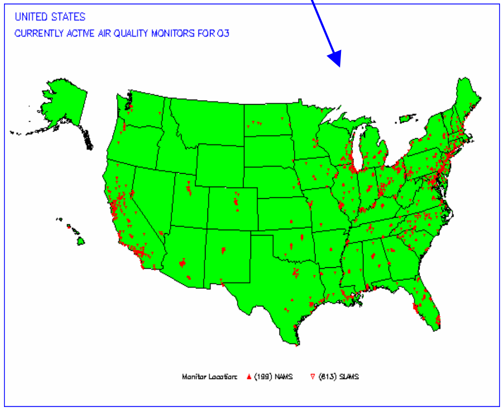
regulation and long term trends in air quality and climate



WMO Global Atmospheric Watch network



European Union network

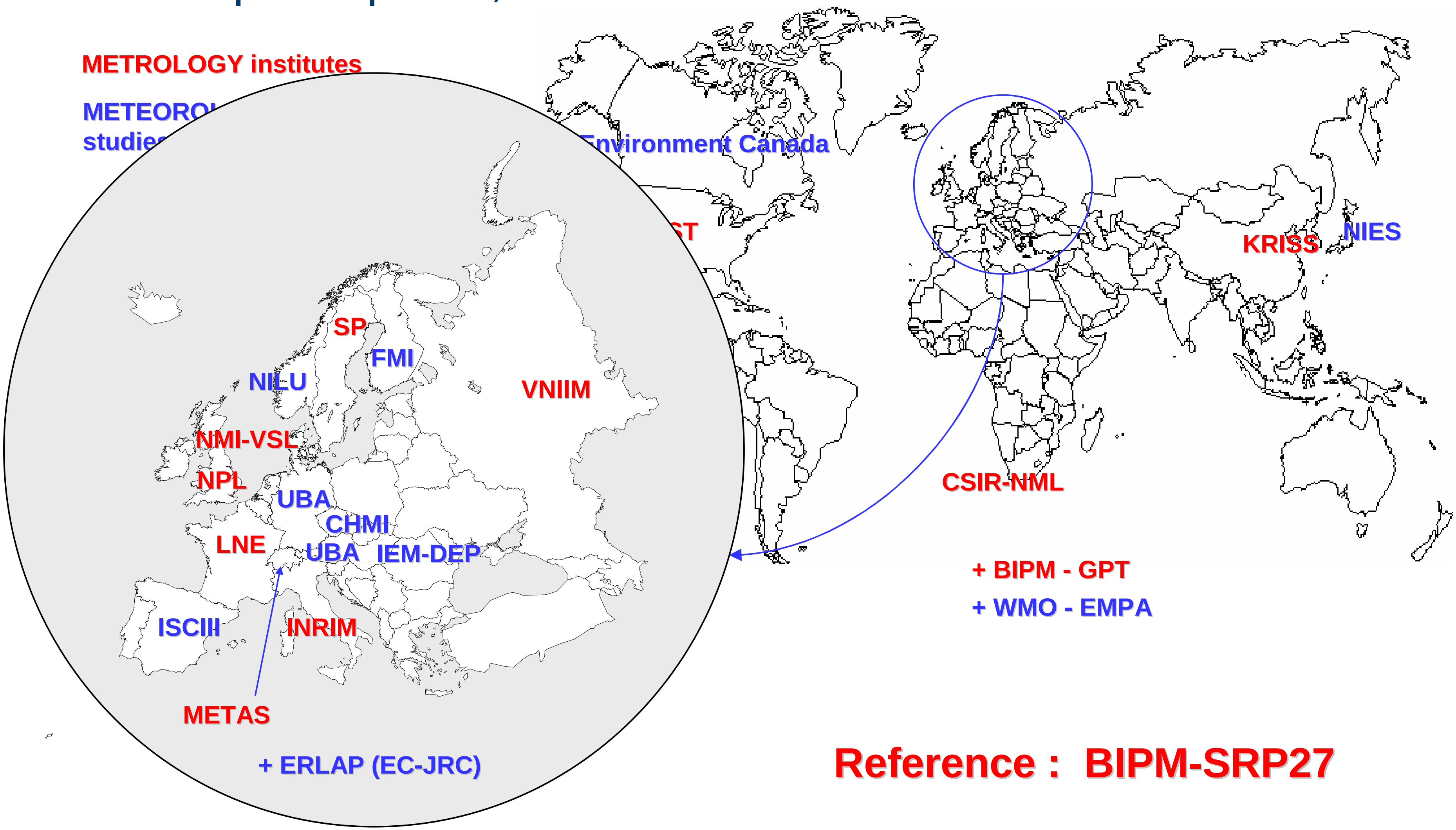


USA air quality monitoring for O_3

Measurements have to be comparable, referenced to points that are constant and reproducible.

CCQM "pilot" study P28

- 23 participants, 18 months



Protocol for Intercomparison

Protocol A – Primary Standards

- Transport of instruments to and from the BIPM
- Handling of instruments sent to the BIPM
- Comparison description
- Quantities and Units
- Pre-comparison requirements
- Comparison procedure
- Uncertainty budgets
- Linear regression fits
- Degrees of equivalence
- Data acquisition and backup
- Reporting of results

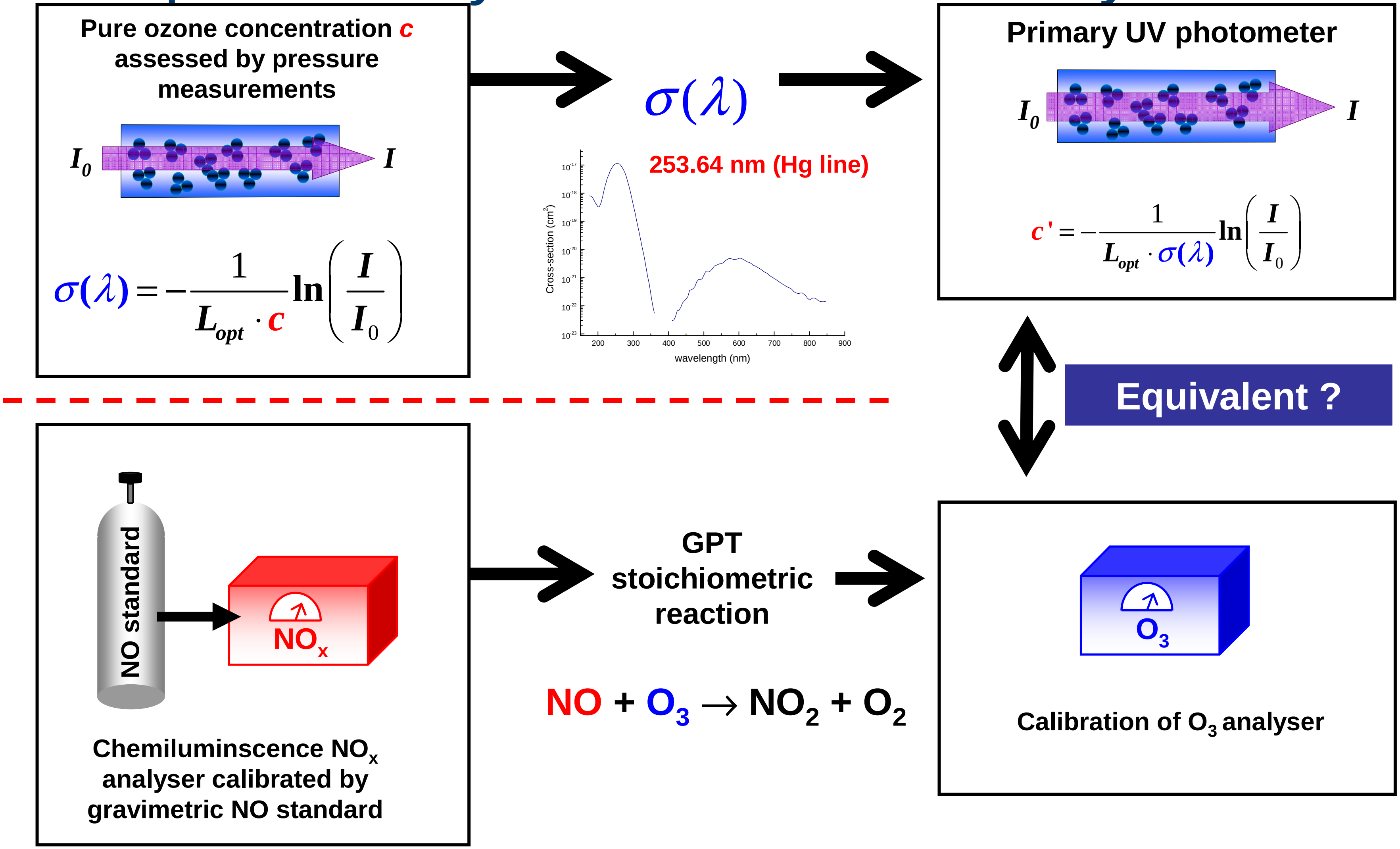
"Guidelines for key comparisons" at
http://www.bipm.org/utils/en/pdf/guidelines.pdf

Protocol for Intercomparison

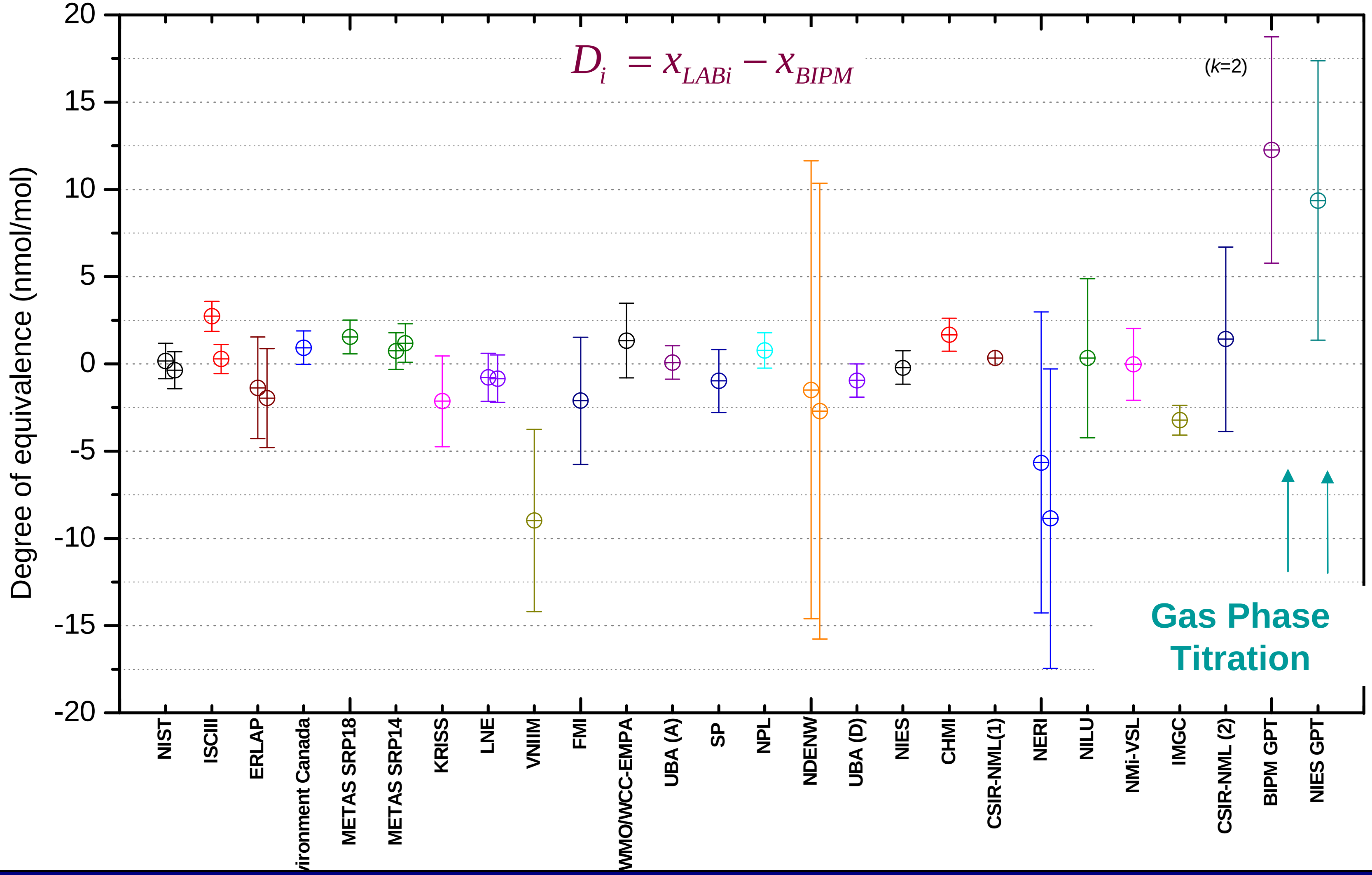
Protocol B – Transfer Standards

- Transport of instruments to and from the BIPM
- Handling of instruments sent to the BIPM
- Stability and characteristics of transfer standards
- Comparison description
- Quantities and Units
- Comparison between the national standard and the transfer standard before travelling with the transfer standard
- Comparison between the transfer standard and BIPM-SRP27 at the BIPM
- Subsequent comparison between the national standard and the transfer standard at the laboratory of the participating institute
- Uncertainty budgets
- Calculation of the relationship between the national standard and the reference standard
- Degrees of equivalence
- Comparability of the two degrees of equivalence for each nominal value
- Reporting of results

UV photometry and GPT traceability chains

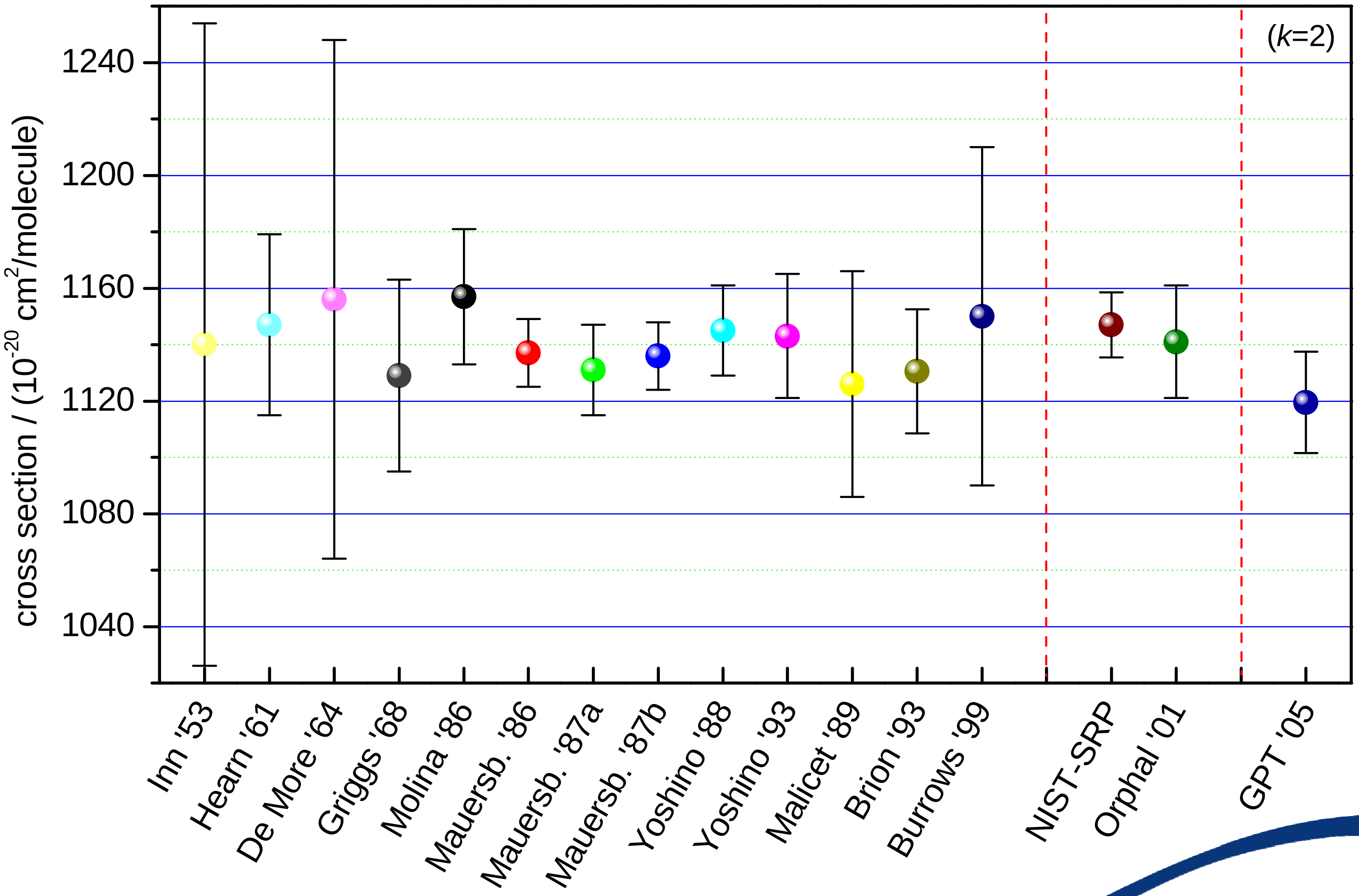


Results of CCQM-P28 (at 420 nmol/mol)



UV absorption of ozone at 253.7 nm

Cross-section measured by different groups since 1953 (by UV spectroscopy)



Courtesy of Michael Essler, BIPM.

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Future directions for Ozone network

- Absolute cross-section measurements
- Resolution of discrepancy between GPT and UV methods
- Reduce uncertainty due to transfer standards
- Current network based on a standard reference method, aiming to move toward full SI traceabilty.

Intercomparison of atmospheric profile measurements

- Clearly the GRUAN requirements lead to a need for ongoing intercomparisons of atmospheric profile measurements.
- This significantly adds to the complexity of analysing a intercomparison dataset, primarily because the true atmospheric state is unknown and variable.

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Profile Intercomparison Covariance

- In its simplest form, the error covariance of the difference between a reference instrument and the instrument being validated is

$$\mathbf{S}_{\mathrm{diff}} = \mathbf{S}_{\mathrm{s+r,val}} + \mathbf{S}_{\mathrm{s+r,ref}} + \mathbf{S}_{\mathrm{coinc.}} + \mathbf{S}_{\mathrm{smooth,diff,}}$$

where :

$\mathbf{S}_{\mathrm{s+r,val}}$ is the combined systematic and random error covariance of the validation instrument

$\mathbf{S}_{\mathrm{s+r,ref}}$ is the combined systematic and random error covariance of the reference instrument

$\mathbf{S}_{\mathrm{coinc.}}$ is due to the coincidence mismatch in space and time of the two measurements

$\mathbf{S}_{\mathrm{smooth,diff,}}$ is due to the smoothing error in the difference including the effect of mapping *a piori* information onto the results

T. Von Clarmann, ACP, 6, 4311-4320, 2006

Profile Intercomparison

- Correlation between the reference and validation measurements (eg. through the use of the same temperature profiles or spectroscopic data) and between the coincidence and smoothing covariances further complicate the issue.
- Despite this various quality metrics can be determined through x^2 testing including
  - the significance of any bias in the comparison.
  - the consistency of the bias with the original estimates of the systematic errors.
  - determination of the precision of the comparison.

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Instrumental Type Testing and Proficiency Testing Schemes

- Type testing (or type approval) establishes that a particular type of instrument is fit for a specific application
- Proficiency testing schemes are design to establish organisation / laboratory performance in a specified area of testing, measurement or calibration.

The MCERTS type-approval and certification scheme

- Rationale for establishing an internationally acceptable type-approval and certification scheme for industrial monitoring instruments
  - Measurements of industrial emissions and air quality are widespread and are mainly carried out for regulatory purposes
  - There is a requirement to demonstrate independently that such measurements are fit for purpose and of the required accuracy
  - There was no certification and type-approved scheme which is acceptable across the European Union or on a wider international basis

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Overview of Laboratory and Field Tests

- Laboratory Tests
  - Range of tests carried out using specialised facilities to demonstrate that the instrument meets the MCERTS performance standards
  - Performance characteristics evaluated which are intrinsic to the instrumental technique evaluated
  - Most laboratory tests have mandatory pass/fail criteria
  - Remainder of tests will report on results obtained (eg the accuracy of the CEM - as delivered by the manufacturer)

Overview of Laboratory and Field Tests

- Field Tests
  - Direct assessment of the instrument's 'fitness for purpose' on a representative industrial plant
  - Comparisons with well-characterised SRM results
  - Evaluation of maintainance intervals, etc.

Instrument performance characteristics to be tested

- Laboratory tests :
  - accuracy of measurements of the determinand
  - zero and span drift
  - linearity and short-term drift tests
  - cross-sensitivity to likely components of the stack gas other than the determinand
  - influence of sample pressure and temperature
  - response time and delay time
  - lower detection limit
  - repeatability
  - influence of ambient environmental conditions on zero and span readings

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Instrument performance characteristics to be tested

- Field tests :
  - performance and accuracy of the CEM against a Standard Reference Method under field conditions (using Integral Performance criteria)
  - reproducibility under field conditions (for particulate monitoring instruments)
  - availability and maintenance interval under field conditions
  - time dependent zero and span drift under field conditions

- Other Tests
  - susceptibility to physical disturbances

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Summary and Discussion

- Define clear set of data quality objectives with related uncertainty requirements.
- QA4EO provides a potential framework for this.
- Should QA4EO procedures be applied to GRUAN datasets ?
  - Define appropriate Quality Indicators for outputs.
- Validation activities to ensure quality objectives are met
  - Are type-testing (of instruments) and/or proficiency testing (of sites/ personnel) needed ?
- Intercomparisons will be important element of overall QA.
  - Formalised procedures for blind intercomparisons.
  - Robust uncertainty analysis for comparing atmospheric profile measurements.

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