World Meteorological Organization

Weather • Climate • Water

The Quality Assurance System of WMO/GAW and the role of NMIs

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What is the GAW Programme?

- WMO/GAW was established 1989 by merging GO_3OS and BAPMoN.
- GAW is a partnership involving contributors from about 100 countries.

Surface-based *in situ* and remote sensing observations are the backbone of the GAW network, which consists of Global and Regional stations and stations working within contributing networks.

Currently GAW coordinates activities and data from 30 Global stations, 400 Regional stations, and 100 Contributing stations (http://gaw.empa.ch/gawsis/)

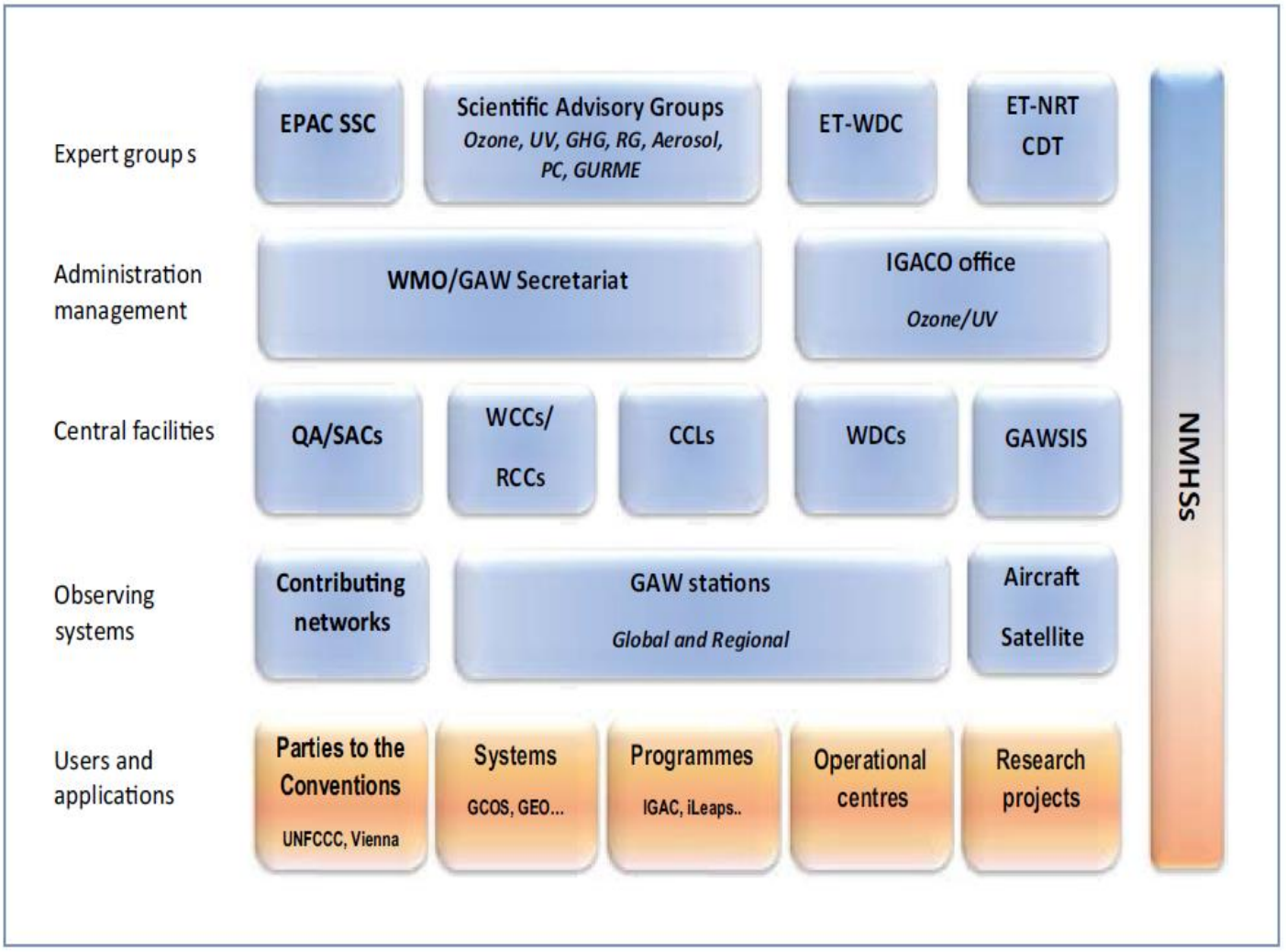
GAW requires that the stations are not **directly impacted** by pollution sources

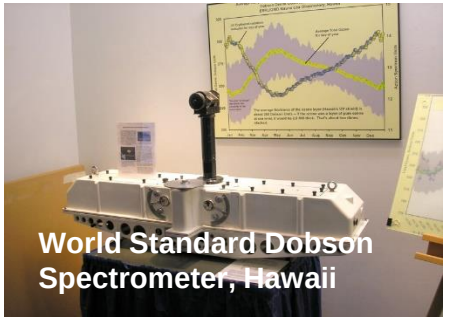
GAW focal areas

- Stratospheric Ozone and vertical ozone distribution
- Greenhouse Gases (*CO_2 and its isotopes , CH_4 and its isotopes, N_2/O_2 ratio, N_2O, SF_6, CFCs and substitutes*)
- Reactive Gases (*O_3, CO, VOCs, NO_x, SO_2*)
- Precipitation Chemistry
- Aerosols (*chemical and physical properties, AOD*)
- UV Radiation
- GAW Urban Meteorology (GURME) project

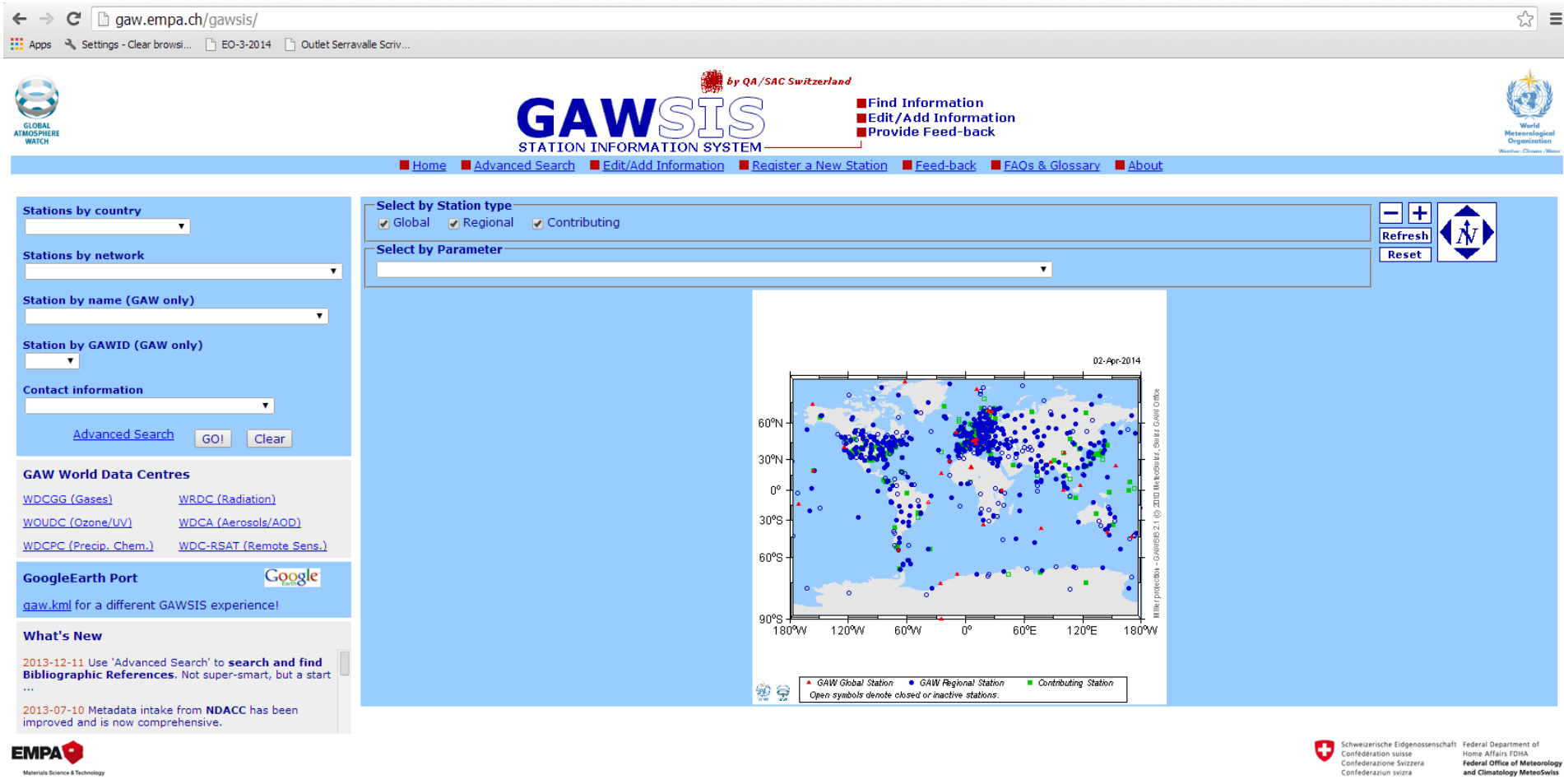
Variables important for climate studies: GHG, aerosols, ozone

The GAW Programme Elements




World Standard Dobson Spectrometer, Hawaii

GAW Station Information System (GAWSIS)



General requirements to GAW stations

1. The station location is chosen such that, for the variables measured, it is regionally representative and is normally free of the influence of significant local pollution sources.

2. There are adequate power, air conditioning, communication and building facilities to sustain long term observations with greater than 90% data capture (i.e. <10% missing data).

3. The technical support provided is trained in the operation of the equipment.

4. There is a commitment by the responsible agency to long term observations of at least one of the GAW variables in the GAW focal areas (ozone, aerosols, greenhouse gases, reactive gases, UV radiation, precipitation chemistry).

5. **The GAW observation made is of known quality and linked to the GAW Primary Standard.**

6. The data and associated metadata are submitted to one of the GAW World Data Centres no later than one year after the observation is made. Changes of metadata including instrumentation, traceability, observation procedures, are reported to the responsible WDC in a timely manner.

7. If required, data are submitted to a designated data distribution system in near-real-time.

8. Standard meteorological *in situ* observations, necessary for the accurate determination and interpretation of the GAW variables, are made with known accuracy and precision.

9. The station characteristics and observational programme are updated in the GAW Station Information System (GAWSIS) on a regular basis.

10. A station logbook (i.e. record of observations made and activities that may affect observations) is maintained and is used in the data validation process.

Why does GAW have its QA principles

Adequate gathering of data related to state of the global atmosphere – and analysis of anthropogenic impact on a global scale – would require that all measurements **be expressed in the same units and on the same scale,** such that measurements performed by different countries are comparable.

For GAW **network compatibility** is MORE important than absolute calibration:

- We need to define small spatial gradients (including gradients between the countries)
- We need to have trend estimates by different countries relative to the same reference
- GAW primary standards are supported by Central Calibration Labs for long time, hence the whole network has the same reference independent of the point when new stations join the Programme. GAW has an experience with multiple scales which created unnecessary complexity in QA system.
- Only harmonized data sets can be used to calculation of global averaged mole fraction and be used for inverse modelling and comparison with model simulations

Network compatibility is different from measurement uncertainty and absolute traceability

QMF principles

✓Network-wide use of only one reference standard or scale (***primary standard***). In consequence, there is only one institution that is responsible for this standard.
✓ Full traceability to the ***primary standard*** of all measurements made by Global, Regional and Contributing GAW stations.
✓ The definition of data quality objectives (DQOs).
✓ Establishment of guidelines on how to meet these quality targets, i.e., harmonized measurement techniques based on Measurement Guidelines (MGs) and Standard Operating Procedures (SOPs).
✓ Establishment of MGs or SOPs for these measurements.
✓ Use of detailed log books for each parameter containing comprehensive meta information related to the measurements, maintenance, and 'internal' calibrations.
✓ Regular independent assessments (system and performance audits).
✓ Timely submission of data and associated metadata to the responsible World Data Centre as a means of permitting independent review of data by a wider community.

How GAW QA and NMI concepts differ

1) GAW has one reference for the whole network. If the scale is reviewed it impacts the whole network, rather than individual country results. References of individual countries do not depend on results of key comparisons.

2) Difference between National Standards introduces additional uncertainty to measurements, hence makes it more difficult to reach strict GAW Data Quality objectives

3) GAW reference scale is supported for a long-period of time, hence allow for the trends estimate in the atmospheric concentrations

4) **Theoretically**, if National standards are treated and supported by different countries the same way for a long time, regularly compared to each other and are *compatible to the degree much better than network compatibility requirements*, we can accept the NMI concept of standards redundancy, but it is a long way to go to that point

Complexity of the GAW approach

- GAW has six groups of variables with completely different properties (long-lived gases, short-lived gases, total column, physical properties of aerosols, chemical properties of aerosols, chemical composition of aerosols and rain water)
- Different variables allow for different traceability chain
- Different groups express requirements in a different way

Within GAW Central Calibration Laboratories are responsible for support of the network reference (standard or scale)

Central Facilities

Five types of central facilities:

- Central Calibration Laboratories (CCLs)
- Quality Assurance/Science Activity Centres (QA/SACs)
- World Calibration Centres (WCCs)
- Regional Calibration Centres (RCCs)
- World Data Centres (WDCs)

GAW World Central Facilities

Variable	QA/SAC	Central Calibration Laboratory (CCL) (Host of Primary Standard)	World Calibration Centre (WCC)	Regional Calibration Centre (RCC)	World Data Centre (WDC)
CO_2	JMA (A/O)	ESRL	ESRL (round robin) Empa (audits)		JMA
carbon isotopes		MPI-BGC			JMA
CH_4	Empa (Am, E/A) JMA (A/O)	ESRL	Empa (Am, E/A) JMA (A/O)		JMA
N_2O	UBA	ESRL	IMK-IFU		JMA
CFCs, HCFCs, HFCs					JMA
SF_6		ESRL			JMA
H_2		MPI-BGC			JMA
Total Ozone	JMA (A/O)	ESRL[1], EC[2]	ESRL[1], EC[2]	BoM[1], ESRL[1], IZO[2] JMA[1], MOHp[1], MGO[3], OCBA[1], SAWS[1], SOO-HK[1]	EC[5], DLR[6]
Ozone Sondes	IEK-8	IEK-8	IEK-8		EC
Surface Ozone	Empa	NIST	Empa	OCBA	JMA
Precipitation Chemistry	NOAA-ARL	ISWS	ISWS		NOAA-ARL
CO	Empa	ESRL	Empa		JMA
VOC	UBA	NPL	IMK-IFU		JMA
SO_2					JMA
NO_x	UBA		IEK-8 (NO)		JMA
Aerosol	UBA (physical properties)		IfT (physical properties)		NILU[5], DLR[6]
Optical Depth		PMOD/WRC[4]	PMOD/WRC		NILU
UV Radiation				ESRL (Am), EUVC/PMOD (E)	EC
Solar Radiation		PMOD/WRC	PMOD/WRC		MGO

[1]Dobson, [2]Brewer, [3]Filter instruments, [4]Precision Filter Radiometers (PFR), [5]ground-based, [6]satellite-based

Central Calibration Laboratories (CCLs)

Box 5. Terms of Reference for GAW Central Calibration Laboratories (CCLs)

(a) Host in the long term (many decades) the GAW primary standard and scale for a particular variable.

(b) Serve the needs of the other quality assurance facilities and activities of GAW.

(c) Prepare or commission laboratory standards required by the GAW network members for calibration purposes.

(d) Supply well-calibrated air to GAW analytical laboratories as needed for conducting inter-comparisons (in collaboration with the World or Regional Calibration Centres).

Role of NMIs in support of the GAW Central Calibration Laboratories (CCLs)

Variable	WMO/GAW CCL (non NMI)	WMO/GAW CCL (supported by NMIs)
CO_2	NOAA/ESRL	Included in MoU
carbon isotopes	MPI-BGC	
CH_4	NOAA/ESRL	Included in MoU
N_2O	NOAA/ESRL	Included in MoU
CFCs, HCFCs, HFCs		
Total Ozone	NOAA/ESRL(Dobson), Environment Canada (Brewer)	
Ozone Sondes	FZ-Jülich	
Surface Ozone		NIST
Precipitation Chemistry	Illinois State Water Survey, Champaign IL, USA (ISWS)	
CO	NOAA/ESRL	
VOC		NPL, NIST
SO_2		
NOx		CCQM
Aerosol		
Optical Depth	Physikalisch-Meteorologisches Observatorium Davos/World Radiation Centre, Davos, Switzerland (PMOD/WRC)	Included in MoU
UV Radiation		
Solar Radiation	Physikalisch-Meteorologisches Observatorium Davos/World Radiation Centre, Davos, Switzerland(PMOD/WRC)	Included in MoU
H_2	MPI-BGC	

World/Regional Calibration Centres (WCCs/RCCs)

Box 7. Terms of Reference for World and/or Regional Calibration Centres (WCCs, RCCs)

(a) Assist Members operating GAW stations to link their observations to the GAW primary standard.

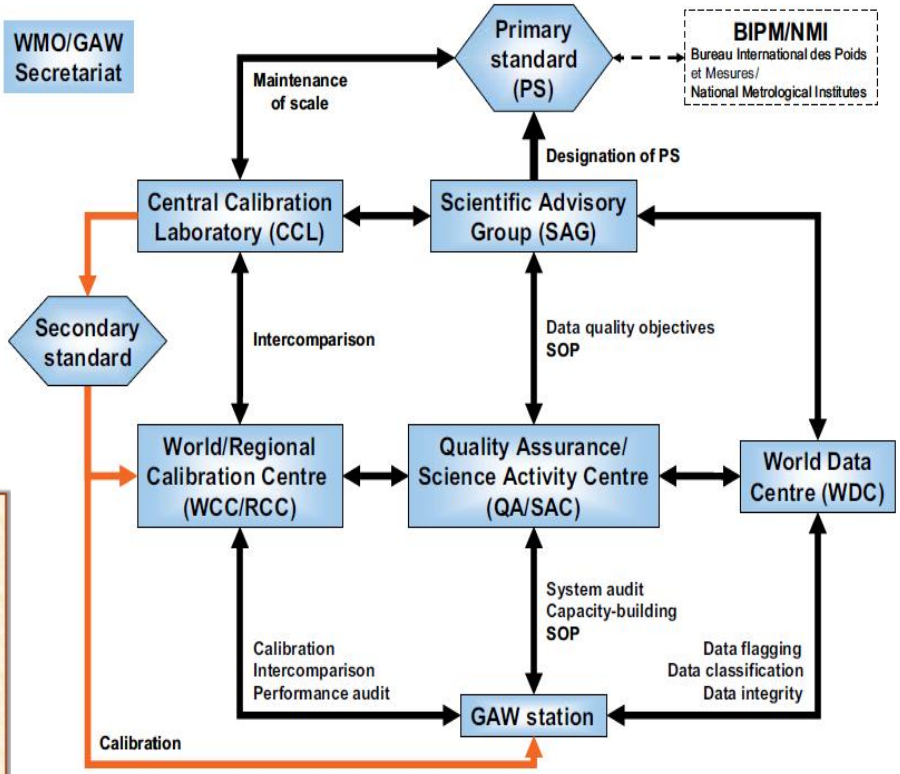
(b) Develop quality control procedures following the recommendations by the SAGs, support the QA of specific measurements and ensure the traceability of these measurements to the corresponding primary standard.

(c) Maintain laboratory and transfer standards that are traceable to the primary standard.

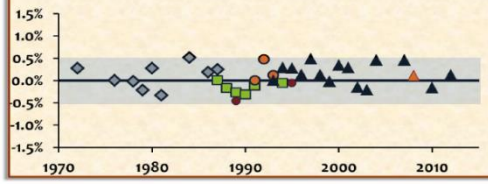
(d) Perform regular calibrations and performance audits at GAW sites using transfer standards in co-operation with the established RCCs.

(e) Provide, in co-operation with the QA/SACs, training and long-term technical help for stations.

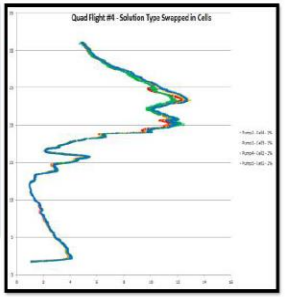
GAW Quality Assurance system



This is a display of the stability of the World Standard D083, based on results of the Langley plot campaigns at Mauna Loa Observatory. The results are expressed as a percentage difference from the "real" value when total ozone is calculated.



Four of the weekly Boulder balloon flights during November, 2012 carried four ozonesonde instruments to compare different ozone sensing solutions.



DQOs for GHG

Component	Compatibility goal	Extended compatibility goal	Range in unpolluted troposphere	Range covered by the WMO scale
CO_2	± 0.1 ppm (Northern hemisphere) ± 0.05 ppm (South. hemisphere)	± 0.2 ppm	360 - 450 ppm	250 – 520 ppm
CH_4	± 2 ppb	± 5 ppb	1700 – 2100 ppb	300 – 2600 ppb
CO	± 2 ppb	± 5 ppb	30 – 300 ppb	20 -500 ppb
N_2O	± 0.1 ppb	± 0.3 ppb	320 – 335 ppb	260 – 370 ppb
SF_6	± 0.02 ppt	± 0.05 ppt	6 – 10 ppt	1.1 – 9.8 ppt
H_2	± 2 ppb	± 5 ppb	450 – 600 ppb	140 −1200 ppb
$\delta^{13}C\text{-}CO_2$	± 0.01‰	± 0.1‰	-7.5 to -9‰ vs. VPDB	
$\delta^{18}O\text{-}CO_2$	± 0.05‰	± 0.1‰	-2 to +2‰ vs. VPDB	
$\Delta^{14}C\text{-}CO_2$	± 0.5‰	± 3‰	0-70‰	
$\Delta^{14}C\text{-}CH_4$	± 0.5‰		50-350‰	
$\Delta^{14}C\text{-}CO$	± 2 molecules cm^{-3}		0-25 molecules cm^{-3}	
$\delta^{13}C\text{-}CH_4$	± 0.02‰	± 0.2‰		
$\delta D\text{-}CH_4$	± 1‰	± 5‰		
O_2/N_2	± 2 per meg	± 10 per meg	-250 to -800 per meg (vs. SIO scale)	

Reviewed at GGMT-2013

Current WMO Scales for GHG

- WMO CO_2 X2007
- WMO CH_4 X2004
- WMO CO X2004 (*new CO scale has been recently released -> WMO CO X2014)*
- WMO N_2O X2006A
- WMO SF_6 X2006 (*new SF6 scale has been recently released -> WMO SF_6 X2014)*
- WMO H_2 X2009

Central Calibration Laboratories

Host of WMO World Reference Standards for long-lived GHG

- CO_2, CH_4, N_2O, SF_6

NOAA ESRL USA

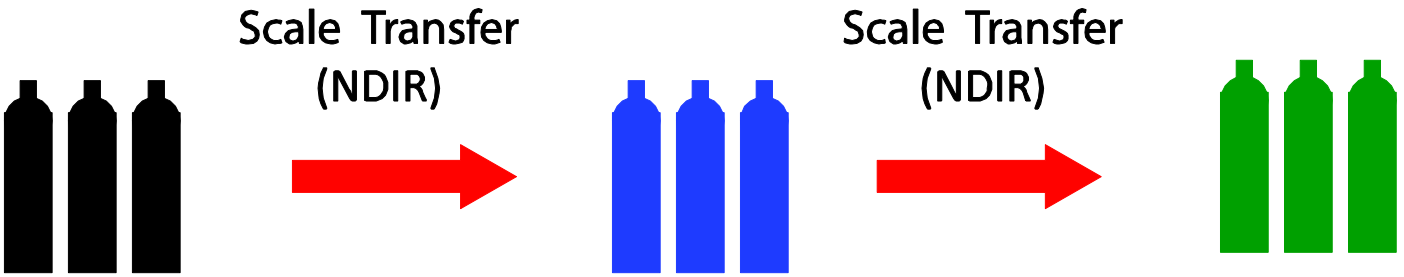
Collaboration under the CIPM MRA includes collaboration with the Consultative Committee for Amount of Substance (CCQM), Gas Analysis Working Group (GAWG) that held its annual meeting in NOAA, Boulder, CO, USA on 27 September 2011. MRA allows NOAA to represent WMO in the following recent key comparisons:

- CCQM-K82 (Methane in air at ambient level)
- CCQM-K83 (Halocarbons in air at ambient levels)
- CCQM-K84 (Ambient CO)

Propagation of WMO Mole Fraction Scale for CO_2

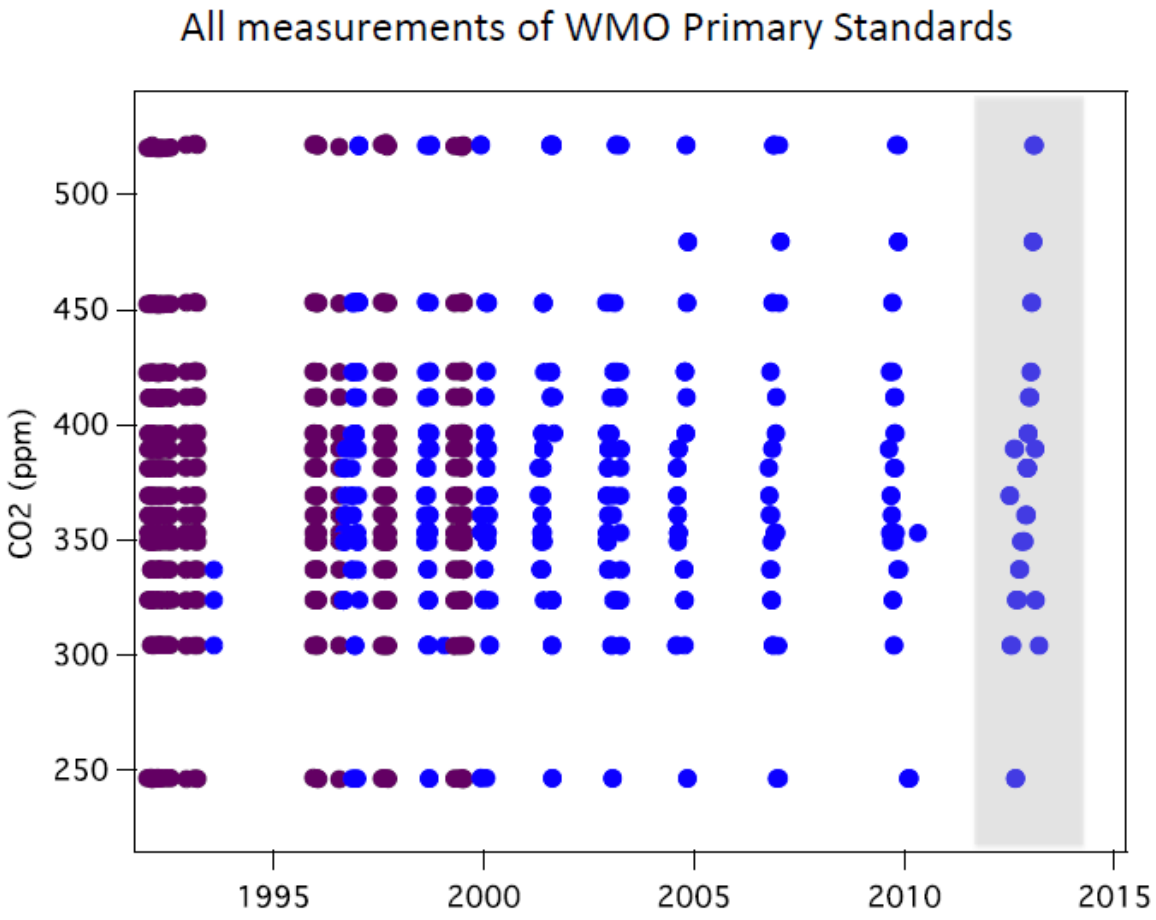
WMO CO_2 scale

- Reference scale for CO_2 in dry air, maintained by NOAA/GMD
- Defined by 15 primary standards (~ 250 – 520 ppm)



Courtesy of B.Hall

Stability of WMO Mole Fraction Scale for CO_2



Courtesy of B.Hall

World Calibration Centres

Linking Observations to World Reference Standards and Ensuring Network Comparability through comparison campaigns and regular audit

CO_2	- NOAA ESRL USA - EMPA, Switzerland (audits)
CH_4	- EMPA, Switzerland (Am,E/A) - JMA, Japan (A/O)
N_2O	Karlsruhe Institute of Technology (KIT), Institute for Meteorology and Climate Research, IMK-IFU, Garmisch-Partenkirchen, Germany
SF_6	Korea Meteorological Administration

WMO Round-Robin comparisons

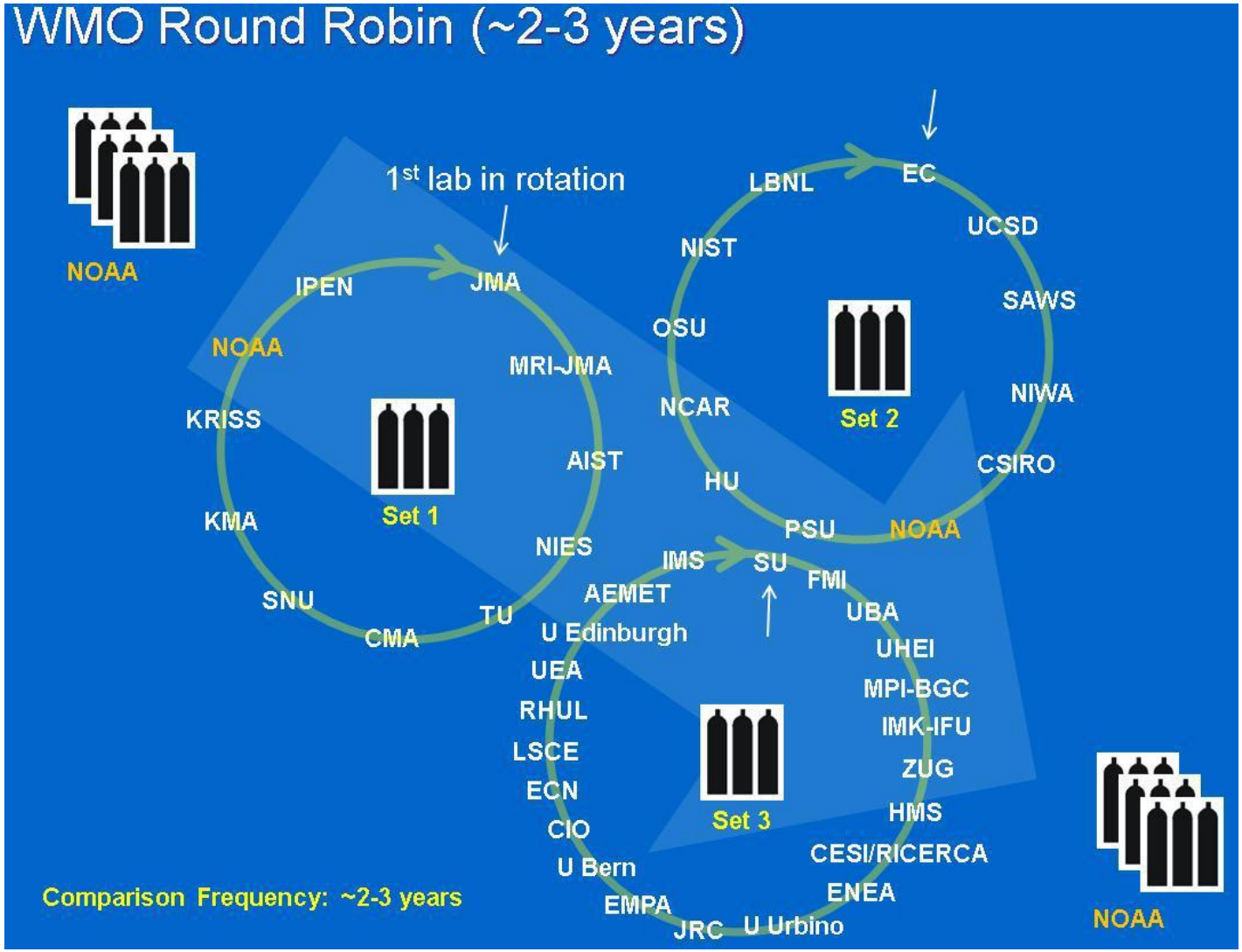
- In reference to WMO goals for compatibility, the purpose of the WMO Round-Robin (RR) reference gas intercomparison would be NOT to distribute calibration scales, but to verify how well the WMO scale is propagated to each of the participating lab, and to the relevant field measurements if they routinely uses WMO standards directly.

WMO Round-Robin comparisons

- **NOAA ESRL prepared 9 high pressure cylinders (3 sets) of clean dry air, collected at Niwot Ridge for the intercomparison.**
- **Labs were divided into 3 globally-distributed groups.**

6th Round-robin (2014 -): 43 Labs registered

Comparison campaigns



WMO Round-Robin comparisons

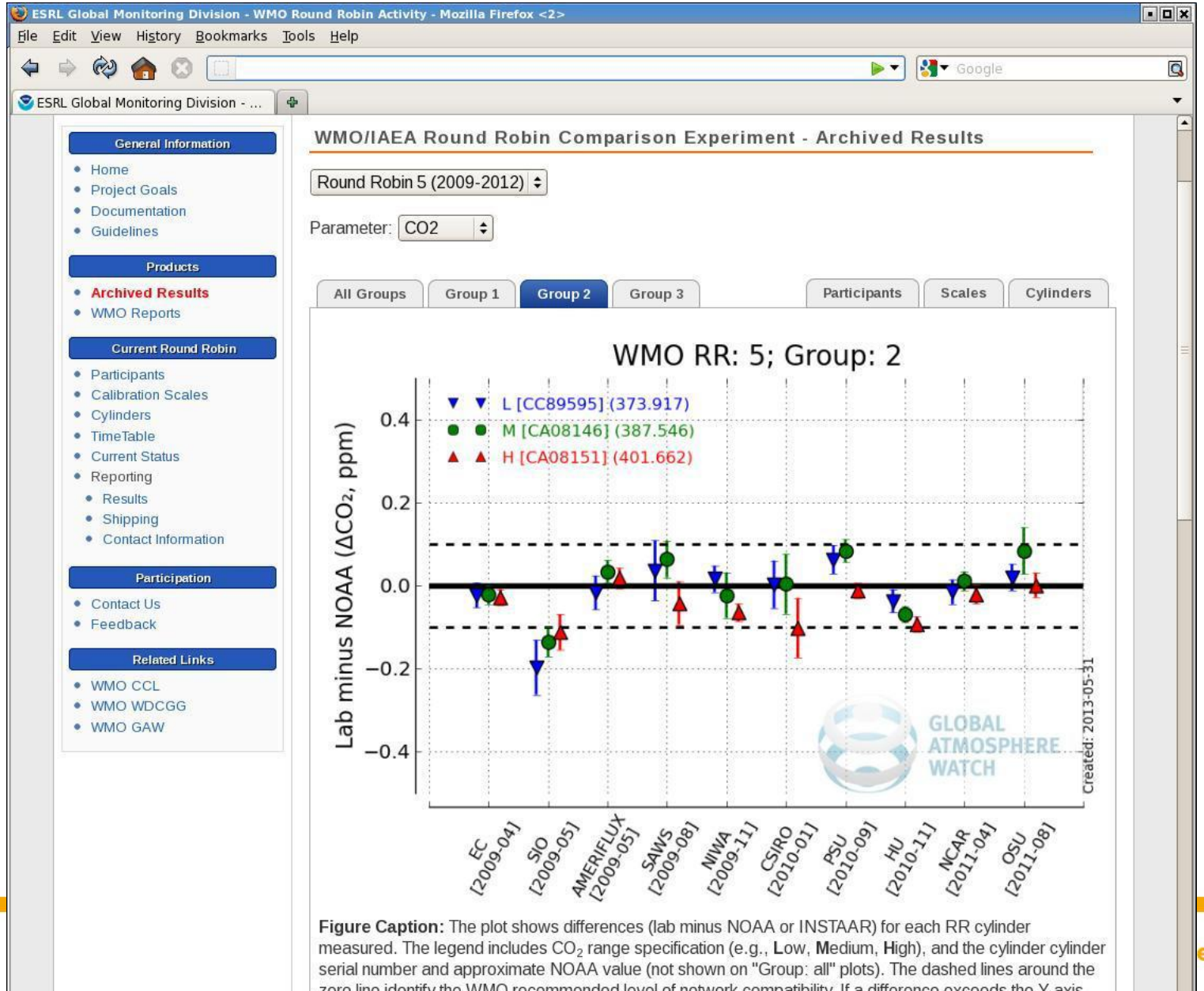


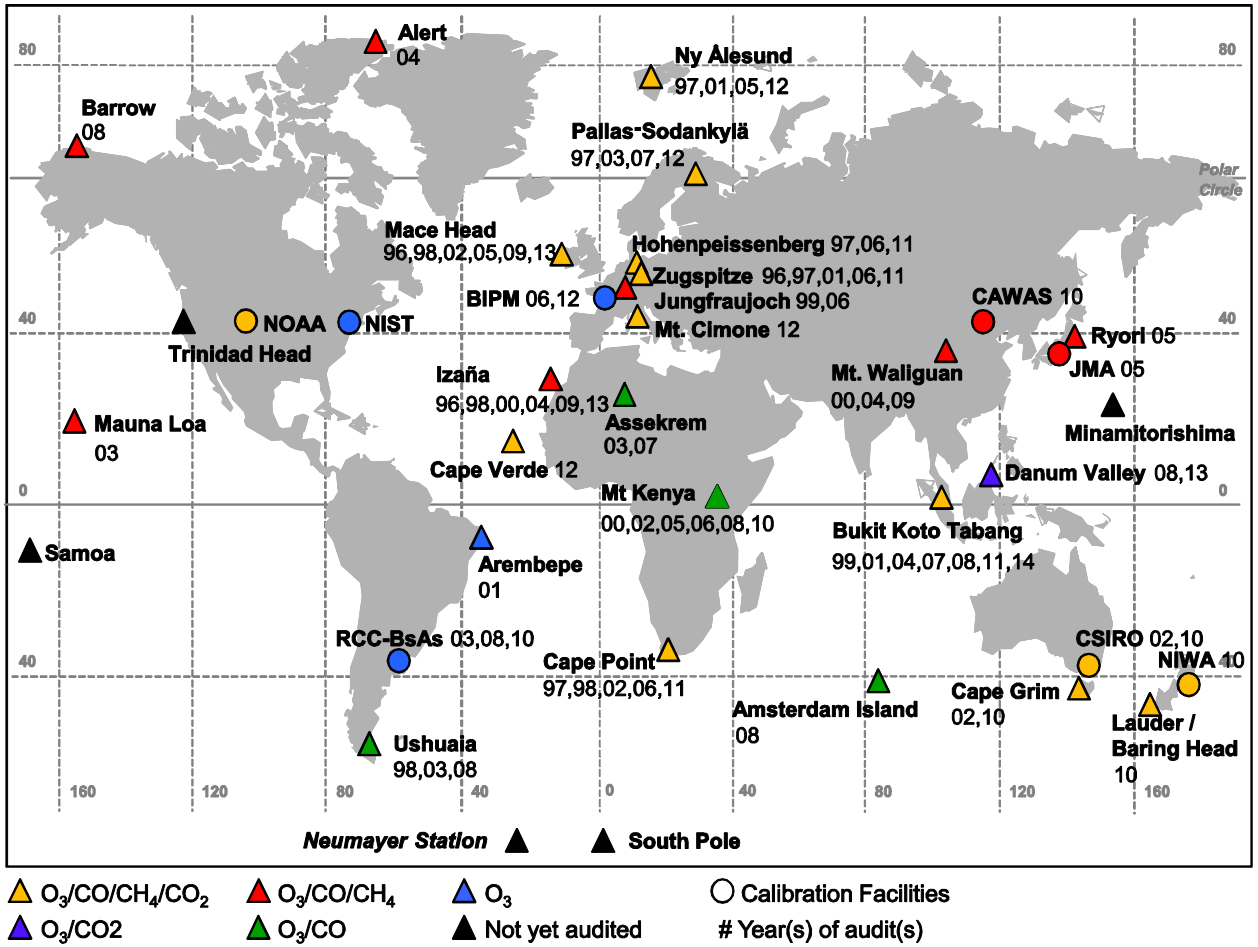
Figure Caption: The plot shows differences (lab minus NOAA or INSTAAR) for each RR cylinder measured. The legend includes CO_2 range specification (e.g., **L**ow, **M**edium, **H**igh), and the cylinder cylinder serial number and approximate NOAA value (not shown on "Group: all" plots). The dashed lines around the zero line identify the WMO recommended level of network compatibility. If a difference exceeds the Y axis

Regional GHG comparisons

Laboratory and Location	Date of Measurement	Cylinder Number						Instrument
		CPB31288			CPB31289			
		Mole fraction (ppb)	SD (ppb)	No	Mole fraction (ppb)	SD (ppb)	No	
JMA Tokyo, Japan	Jun. 25, 2013	1738.3	1.0	10	1878.0	1.6	10	SHIMADZU GC-14BPF
CSIRO Aspendale, Australia	Aug. 15-16, 20-21, 27-28, 2013	1738.2	0.5	107	1878.7	0.5	128	CARLE (EG&G) Series 400
NIWA Wellington, New Zealand	Oct. 10, Oct. 14, 2013	1738.9	1.2	20	1878.3	1.4	20	Hewlett-Packard (Agilent) 5890
NOAA/ESRL Boulder, U.S.A.	Jan. 21-Feb. 10, 2014	1740.0	0.7	5	1879.7	1.0	5	Hewlett-Packard (Agilent) 6890
JMA Tokyo, Japan	Apr. 8, 2014	1738.1	1.6	10	1877.9	1.2	10	SHIMADZU GC-14BPF

Stations audits by Empa

WCC-Empa Audits 1996 – 2014



Reactive Gas measurements

	Central Calibration Laboratory	World Calibration Center
Surface Ozone	NIST	Empa
CO	NOAA ESRL	Empa
VOC	NPL (NMHCs) NIST (monoterpens)	IMK-IFU
SO_2		
NOx		IEK-8 (NO) tentative

- Traceability in for CO and VOCs is ensured via distribution of the gas standards by assigned CCLs and audits by WCCs at Empa and Karlsruhe Institute of Technology (IMK-IFU).
- CO is part of the GHG Round-Robin campaign

CCQM-GAWG NMIs and CCLs

Ethane	Acetone
Propane	DMS
Acetylene	Benzene
Isoprene	Toluene
Formaldehyde	Iso-Butane
Monoterpenes	n-Butane
Acetonitrile	Iso-Pentane
Methanol	n-Pentane
Ethanol	

NMHC — NPL

MTs — NIST, NPL, VSL

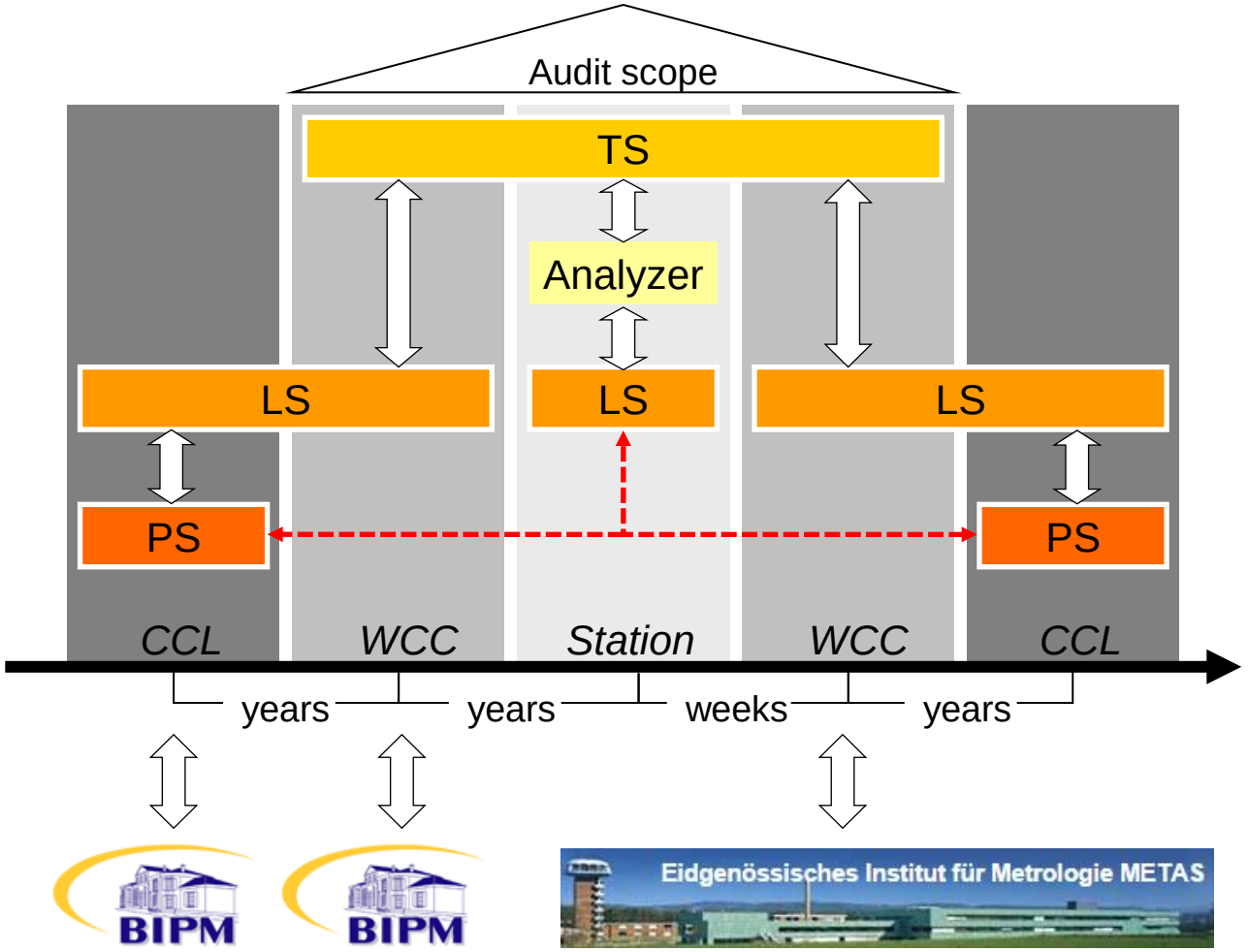
oxyVOC — NIST, NPL, VSL

DMS, ACT — KRISS

HCHO — BIPM

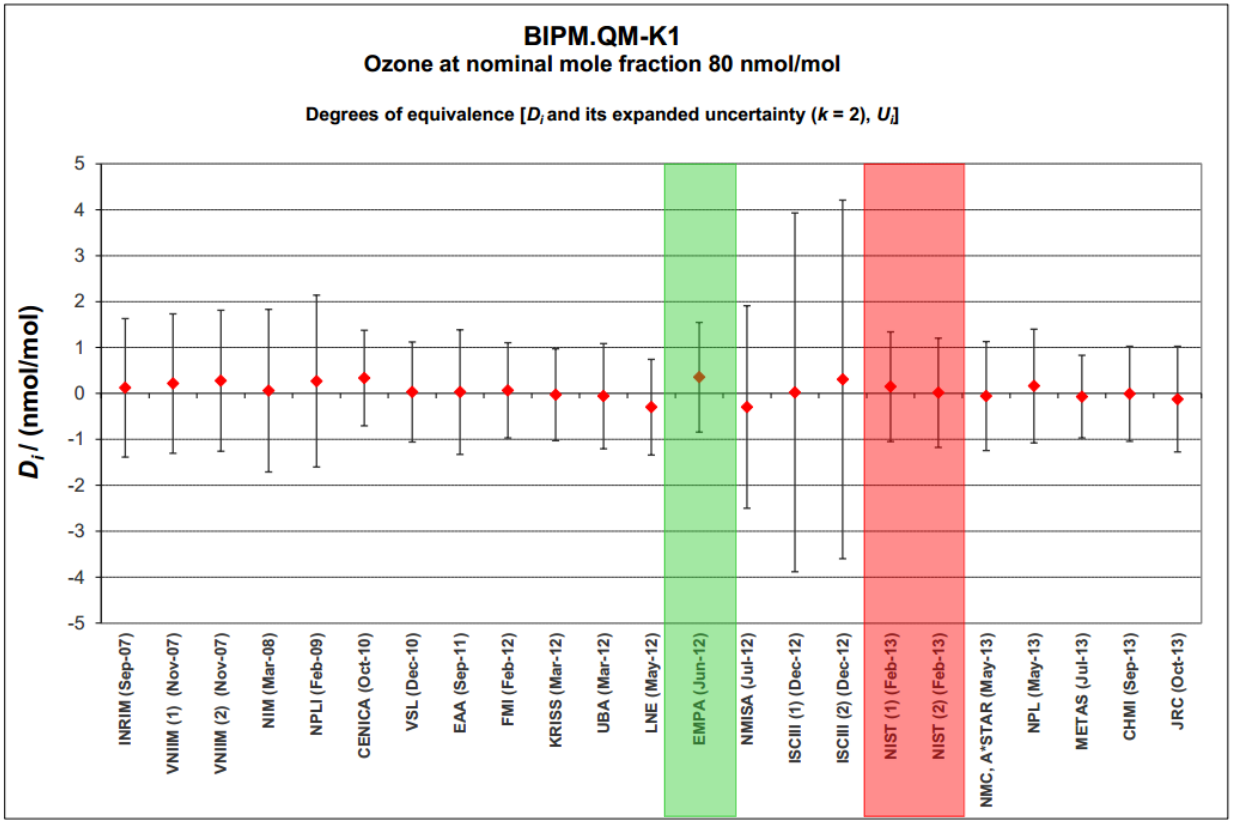
O_3 Traceability Chain

- In the case of ozone: CCL = NMI (NIST).
- WCC-Empa is designated laboratory of WMO for surface ozone calibrations.
- Both CCL and WCC-Empa are participating in the international comparisons of ozone standards (BIPM.QM-K1) along with a large number of NMIs.
- WMO/GAW is able to demonstrate degrees of equivalence for surface ozone measurements.



Compatibility of surface O_3 measurements

- From the BIPM key comparison database (http://kcdb.bipm.org/).
- WMO/GAW is able to demonstrate degree of equivalence through participation of the designated institute (Empa).
- Results are available for nominal mole fractions of 80 and 420 nmol/mol.
- Demonstration of traceability to internationally accepted standards is a clear advantage for the GAW programme.



WMO/GAW facilities Empa (WCC) and NIST (CCL) are linked to international accepted standards through the BIPM key comparison for surface ozone.

Summary

- NMIs play an important role in support of the group of reactive gases
- Currently in the other areas the role of NMIs is limited (NOTE: GAW QA is not a responsibility of NMIs)
- GAW has different approach to the quality assurance of observations and traceability for a good reason
- NMIs assigned a role of Central Calibration Laboratory for GAW have monopoly right to provide standards to the network, but have a responsibility to support the network reference for unlimited period of time

Collaboration between GAW and BIPM should aim at helping GAW in the areas where we lack expertize rather than at attempting to substitute GAW Quality Assurance system by NMI's concept

Thank you for your attention!