SYSTEM AND PERFORMANCE AUDIT OF SURFACE OZONE, CARBON MONOXIDE, METHANE AND CARBON DIOXIDE AT THE

GLOBAL GAW STATION MT. KENYA KENYA JANUARY 2015

World Meteorological Organization

GLOBAL ATMOSPHERE WATCH

HARAMBEE

Empa
Materials Science and Technology

WCC-Empa Report 15/1b

Submitted to the World Meteorological Organization by

C. Zellweger, M. Steinbacher and B. Buchmann

WMO World Calibration Centre WCC-Empa

Empa Dübendorf, Switzerland

Versions:

This report supersedes WCC-Empa Report 15/1, which contained a typo in Equation (1a), page 6. Equation (1a) was X_{O3} (ppb) = ([OA] + 18 ppb) / 0.9941 in WCC-Empa Report 15/1; the correct Equation (1a) is X_{O3} (ppb) = ([OA] + 0.18 ppb) / 0.9941.

WCC-Empa Report 15/1b

Contact Information:

GAW World Calibration Centre WCC-Empa
GAW QA/SAC Switzerland
Empa / Laboratory Air Pollution - Environmental Technology
CH-8600 Dübendorf, Switzerland
mailto:gaw@empa.ch

CONTENTS

EXECUTIVE SUMMARY AND RECOMMENDATIONS

The seventh system and performance audit by WCC-Empa[1] at the Global GAW station Mt. Kenya was conducted from 16 - 23 January 2015 in agreement with the WMO/GAW quality assurance system (WMO, 2007b). Measurements at the Mt. Kenya (MKN) GAW station are coordinated by the Kenya Meteorological Department (KMD).

Previous audits at Mt. Kenya GAW station were conducted in January 2000 (Herzog et al., 2000), February 2002 (Zellweger et al., 2002), February 2005 (Zellweger et al., 2005), January 2006 (Klausen et al., 2006), November 2008 (Zellweger et al., 2008) and June 2010 (Zellweger et al., 2010).

The following people contributed to the audit:

Dr. Christoph Zellweger	Empa Dübendorf, WCC-Empa
Mr. Peter Graf	Empa Dübendorf, National Air Pollution Monitoring Network
Mr. Kennedy K. Thiong'o	KMD Nairobi, GAW Country Contact
Mr. Constance C. Okuku	KMD Nanyuki, Station Manager
Mr. Charles Kioko	KMD Nanyuki, Station Operator
Mr. Zablon W. Shilenje	KMD Nairobi, Scientist

This report summarises the assessment of the Mt. Kenya GAW station in general, as well as the surface ozone, carbon monoxide, methane and carbon dioxide measurements in particular.

The report is distributed to the MKN station, the Kenyan GAW Country Contact and the World Meteorological Organization in Geneva. The report will be posted on the internet.

The recommendations found in this report are graded as minor, important and critical and are complemented with a priority (*** indicating highest priority) and a suggested completion date.

Station Location and Access

The Global GAW station Mt. Kenya is located at high altitude in equatorial Africa. This location provides a unique opportunity to monitor background air as well as to conduct research in a data-sparse region of the world. This location is regarded as very important to fill gaps in the global coverage of the GAW programme.

Access to the site is by a dirt road and requires a 4WD vehicle and a 30-minute hike. The road improved significantly since the last audit in 2010 with the support from the external aid programme of the European Union. When completed, the access road will be upgraded to bitumen (10 km) and all-weather gravel standard (18 km). The construction work was still ongoing but access up to Old Moses Camp (approx. 2 km below the station) was already much easier compared to the past.

Further information about the MKN station is available from the GAW Station Information System (GAWSIS) (http://gaw.empa.ch/gawsis).

Station Facilities

The station consists of two containers that provide small but adequate laboratory space. At the time of the audit, construction of a new additional container providing office space was just about to commence. The containers were not air-conditioned at the time of the audit and the diurnal temperature variation inside the laboratory could exceed 10 K. This was inadequate for high quality

[1] WMO/GAW World Calibration Centre for Surface Ozone, Carbon Monoxide, Methane and Carbon Dioxide. WCC-Empa was assigned by WMO and is hosted by the Laboratory for Air Pollution and Environmental Technology of the Swiss Federal Laboratories for Materials Testing and Research (Empa). The mandate is to conduct system and performance audits at Global GAW stations every 2 – 4 years based on mutual agreement.

atmospheric monitoring as it potentially compromises the measurements. An air conditioning system was installed after the audit, which should significantly improve temperature stability.

The power supply to the station was severely damaged by a bushfire in March 2009. As a consequence, power became extremely unreliable since November 2009, and the line was permanently cut off in 2010. The power line was finally replaced by an improved construction with concrete poles in 2014. Since then, power is available for most of the time.

A new UPS system was provided to KMD by MeteoSwiss, and this unit was installed in February 2015 after the WCC-Empa audit by Günther Wehrle from the Paul Scherrer Institute (Switzerland) during implementation of new measurements of aerosol optical properties as part of the CATCOS (Capacity Building and Twinning for Climate Observing Systems) project. This system however was again disconnected afterwards, and re-installation by Günther Wehrle is scheduled for January 2016.

The station has been equipped with internet connectivity during the audit (D-Link 4G LTE router). Currently, only a pre-paid data plan is available (10 GB). Connectivity is through the 3G network, and signal coverage is sufficient at MKN.

The facilities at the station are complemented by an office in Nanyuki where administrative matters are handled. However, these facilities are not adequately equipped. Further computers and a reliable internet connection with sufficient bandwidth are needed.

Recommendation 1 (*, critical, 2016, ongoing)**
To protect the instruments from power surges, the UPS unit needs to be operational at all times. It has been bypassed shortly after installation due to issues with the electrical wiring at the station. It is recommended that all electrical installations are checked and repaired or replaced when necessary (Partly completed January 2016, but still issues with the electrical wiring).
Recommendation 2 (*, important, immediately)**
It is recommended to change from pre-paid to post-paid internet at MKN.
Recommendation 3 (*, important, immediately)**
Internet access with sufficient bandwidth (10 Mbps or more) needs to be installed at the Nanyuki office.
Recommendation 4 (, important, ongoing)**
KMD needs to allocate a budget for the Mt. Kenya station / Nanyuki office:
- Clothing, other equipment for operators.
- New office computers that are needed to work with data.
Recommendation 5 (, important, 2016)**
KMD must ensure that access to the station is possible at all times. The current 4WD vehicle has reached the end of its lifetime, and replacement is needed.

Measurement Programme

Measurements from three different WMO/GAW focal areas are performed at MKN. An overview of the measurement programme is available from GAWSIS. It was noticed during the audit that the measurements of the meteorological parameters are discontinued.

Recommendation 6 (, minor, 2016)**
GAWSIS needs to be updated to reflect the recent change in the aerosol instrumentation.
Recommendation 7 (*, critical, immediately)**
Measurements of the meteorological parameters need to be re-established.

Air Inlet System

The air inlet system is adequate for the measurements performed, although no additional ports are available at the main manifold. The greenhouse gas measurements are using their own dedicated inlets on the meteo mast.

Station Management and Operation

In the beginning of continuous operations the station was usually visited weekly by officers of the Kenya Meteorological Department (KMD) who reside in nearby Nanyuki (1.5 h from the station). Since 2009 these visits were less regular due to prolonged power outages and the lack of an appropriate vehicle. In the meantime, regular visits resumed. The station staffs consist of one meteorologist and a technician. The station technician will retire in January 2016. It is regarded of highest importance that the technical expertise to operate and maintain the equipment is transferred to his successor James Karuiki, who commenced at MKN in November 2015. It is further regarded as important that also staff with a scientific background is directly involved in the daily operation of the MKN station. A twinning relationship between KMD, Mt. Kenya staff and QA/SAC Switzerland is ongoing, but communication remains difficult. Collaboration with external partners is important for the future of the station, and the recently established co-operation between KMD and the University of Nairobi (UoN) should be intensified. The web presence of the Mt. Kenya GAW station is currently still limited. In order to improve the visibility of KMD's GAW activities within Kenya and abroad, a better web coverage should be considered. Some of the recommendations made after the last audit remain still valid, and are given below:

Recommendation 8 (*, important, ongoing)**
KMD should explore all possibilities for training of station operators and scientists. Participation in GAWTEC as well as other training courses is highly recommended, and the knowledge needs to be shared between KMD staff.

Recommendation 9 (*, important, 2016)**
Since the measurement programme at MKN is now considerably larger with the addition of greenhouse gas and aerosol measurements, KMD should consider hiring additional technical and scientific staff to maintain the operations at MKN.

Recommendation 10 (*, important, ongoing)**
KMD still needs to intensify technical and scientific exchange with existing and new external partners, and to participate more actively in such partnerships.

Recommendation 11 (, important, ongoing)**
KMD successfully established collaboration with the University of Nairobi. Such activities are important for the station and should be continued.

Recommendation 12 (*, important, on-going)**
Technical expertise must be transferred to the new station technician. It is of highest priority that the knowledge of the former technicians will still be available; KMD is encouraged to facilitate this process.

Recommendation 13 (*, critical, on-going)**
The financial planning for the MKN operation must include a budget for maintenance and repair of the existing instrumentation, as well as provisions for future instrument replacements and measurement programme expansions.

Surface Ozone Measurements

The surface ozone measurements at Mt. Kenya were established in 1999, but measurements commenced in May 2002 due to the lack of electrical power before that period. Continuous time series are available since then until the end of 2009, but also with large gaps due to unstable power. Measurements were re-established after the current audit.

Instrumentation. The station is equipped with one ozone analyser (TEI 49C). The instrumentation is adequate for its intended purpose. At the time of the audit, the original ozone instrument (TEI49C #58106-318) was found to be damaged due to a power surge. The instrument was replaced by another TEI 49C ozone analyser (#0330102716) by WCC-Empa. The TEI49C #58106-318 could be repaired by exchanging one of the electronic boards, and a quick check showed that it is still in a good condition. However, no comparison with the WCC-Empa travelling standard was performed due to the fact that the repair could only be completed at the end of the audit. A further TEI 49i ozone analyser is available at KMD Nairobi for ozone monitoring at the KMD head office in Nairobi. The instrument was installed by MeteoSwiss in 2014, and was also compared against the WCC-Empa reference during this audit.

Standards. An ozone standard (TEI 49i-PS) is available at KMD in Nairobi. This instrument was installed by MeteoSwiss as part of the ozone sounding programme in 2014, and replaced the old TEI 49PS calibrator which was decommissioned.

Intercomparison (Performance Audit). The ozone analyser of MKN and the calibrator and analyser of KMD were compared against the WCC-Empa travelling standard (TS) with traceability to a Standard Reference Photometer (SRP). The result of the comparisons is summarised below with respect to the WMO GAW Data Quality Objectives (DQOs) (WMO, 2013). The data was acquired by the WCC-Empa data acquisition system, and no further corrections were applied. The following equations characterise the bias of the instruments:

Station analyser:

TEI 49C #0330102716 (BKG +0.0 ppb, COEF 1.015):

Unbiased O_3 mixing ratio (ppb): X_{O3} (ppb) = ([OA] + 0.18 ppb) / 0.9941 (1a)

Standard uncertainty (ppb): u_{O3} (ppb) = sqrt (0.30 ppb^2 + 2.61e-05 * X_{O3}^2) (1b)

KMD instruments:

TEI 49i-PS #1127049769 (BKG +0.0 ppb, COEF 1.014):

Unbiased O_3 mixing ratio (ppb): X_{O3} (ppb) = ([OC] + 0.03 ppb) / 0.9923 (1c)

Standard uncertainty (ppb): u_{O3} (ppb) = sqrt (0.29 ppb^2 + 2.58e-05 * X_{O3}^2) (1d)

TEI 49i #1122849256 (BKG -0.1 ppb, COEF 1.016):

Unbiased O_3 mixing ratio (ppb): X_{O3} (ppb) = ([OA] + 0.21 ppb) / 0.9861 (1e)

Standard uncertainty (ppb): u_{O3} (ppb) = sqrt (0.28 ppb^2 + 2.79-05 * X_{O3}^2) (1f)

The result of the comparison is further illustrated in the figures below.

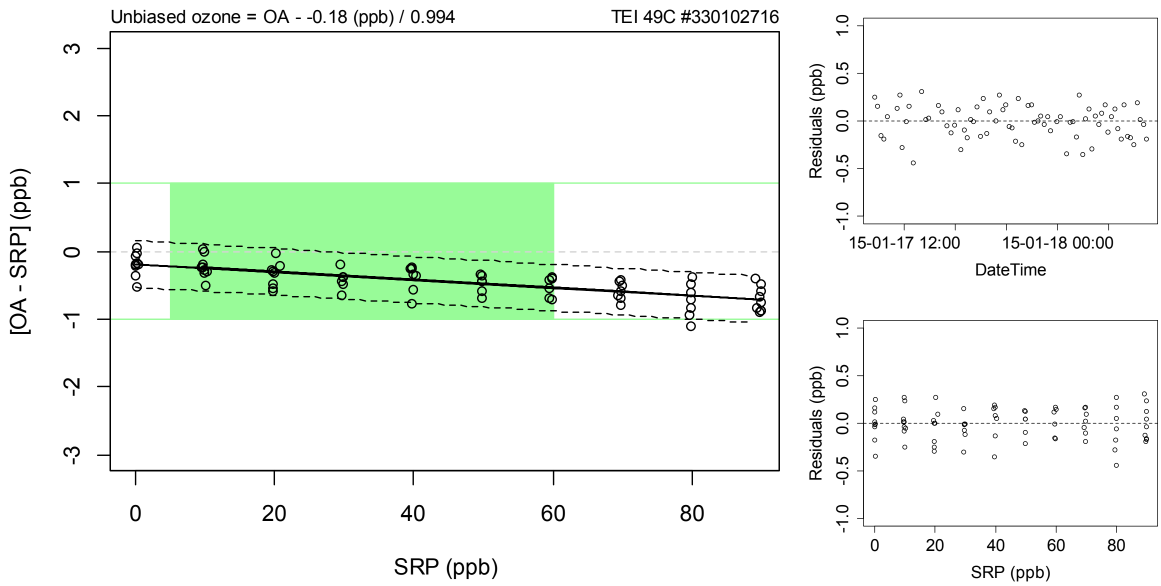

Figure 1. *Left: Bias of the MKN ozone analyser (TEI 49C #0330102716) with respect to the SRP as a function of mole fraction. Each point represents the average of the last 10 one-minute values at a given level. The green lines correspond to the DQOs, and the green area to the mole fraction range relevant for MKN. The dashed lines about the regression lines are the Working-Hotelling 95% confidence bands. Right: Regression residuals of the ozone comparisons as a function of time (top) and mole fraction (bottom).*

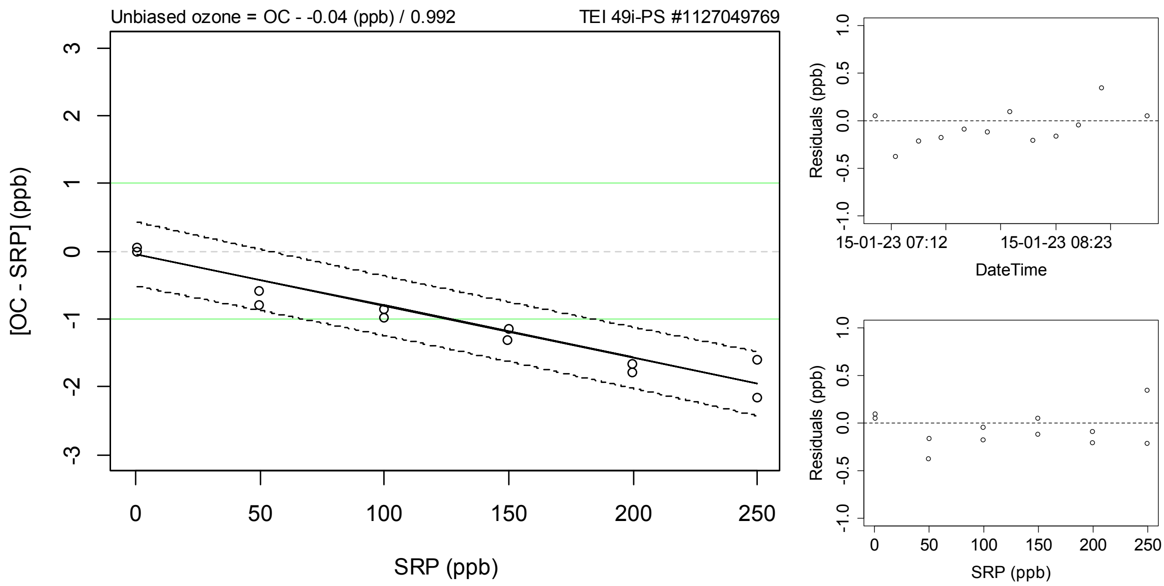

Figure 2. *Same as above for the KMD ozone calibrator TEI 49i-PS #1127049769. No relevant mole fraction range is shown because it is an ozone calibrator.*

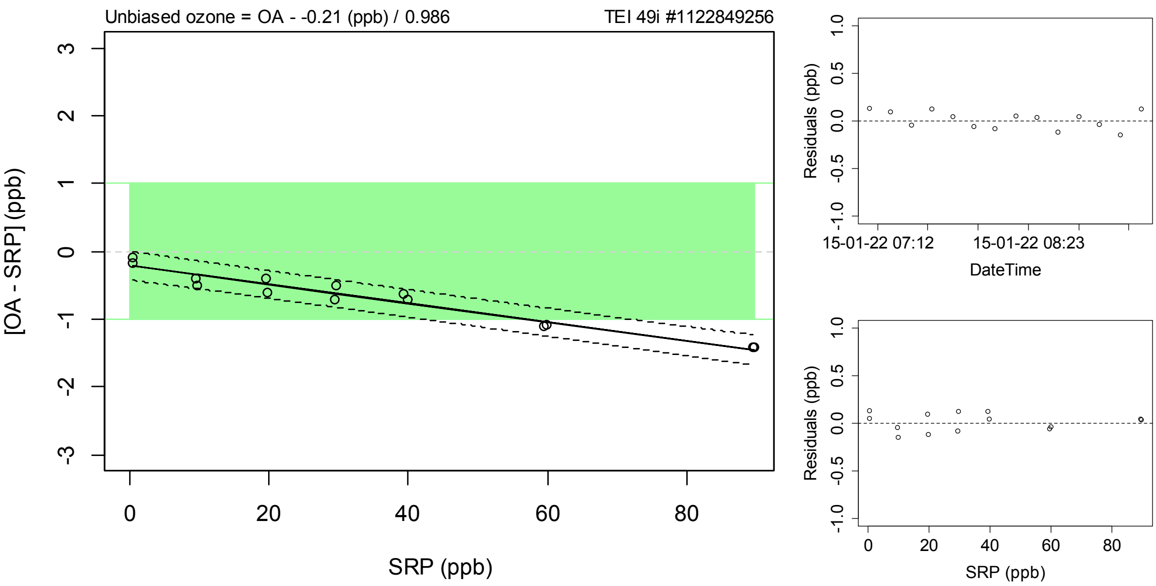

Figure 3. *Same as above for the KMD ozone analyser TEI 49i #1122849256. Relevant mole fraction range for polluted sites.*

The results of the comparison can be summarised as follows:

At MKN, the TEI 49C #0330102716 ozone analyser is in good calibration and the bias is within the WMO/GAW DQOs for the relevant mole fraction range. The calibrator and analyser from KMD were both reading slightly lower compared to the WCC-Empa reference. Due to the short comparison period, no adjustments were made. If these low reading will be confirmed by future comparisons, WCC-Empa recommends the adjustment of the calibration settings.

Carbon Monoxide Measurements

Carbon monoxide measurements at Mt. Kenya were established in 1999, but measurements commenced in May 2002 due to the lack of electrical power before that period. Continuous time series are available since then until the end of 2009, but also with large gaps due to unstable power. Measurements were re-established after the current audit.

Instrumentation. Mt. Kenya is equipped with a Horiba APMA 360 NDIR CO analyser. The instrument was found to be unstable during the last audit by WCC-Empa in 2010, and issues were also found during the current audit. Therefore, the instrumentation can no longer to be regarded as adequate, and replacement needs to be initiated.

> **Recommendation 14 (***, critical, as soon as possible)**
> *The performance of the NDIR CO analyser does not comply with the WMO/GAW compatibility goals. The instrument needs therefore to be replaced, preferably with a more sensitive measurement technique (e.g. CRDS).*

Standards. The station is equipped with two carbon monoxide standards. One standard has a mole fraction of approx. 1 ppm CO in air and is used for direct calibrations of the instrument. The other standard has a mole fraction of approx. 50 ppm CO in air and is used for automatic span checks after dilution with zero air. With this equipment, adequate calibration of the carbon monoxide measurements is possible. All standards have been delivered to the station by WCC-Empa, and no local supplier is available.

> **Recommendation 15 (***, critical, ongoing)**
> *It is highly recommended that the manual span checks are made in at least 3-monthly intervals. This also must be documented in the log file.*

Intercomparison (Performance Audit). The comparison involved repeated challenges of the MKN instruments with randomised carbon monoxide levels using dilution of a 50 ppm cylinder with CO free air generated by a zero air unit. The comparison was repeated twice with different calibration settings. The following equations characterise the instrument bias, and the results are further illustrated in Figure 4 and 5 with respect to the WMO GAW DQOs (WMO, 2014):

Horiba APMA360 #890617035 (Zero -8, SPAN 1.0300):

Unbiased CO mixing ratio: X_{CO} (ppb) = (CO + 2.8) / 0.9382 (2a)

Remaining standard uncertainty: u_{CO} (ppb) = sqrt (335.0 ppb^2 + 1.01e-04 * X_{CO}^2) (2b)

Horiba APMA360 #890617035 (Zero -16, SPAN 1.0900):

Unbiased CO mixing ratio: X_{CO} (ppb) = (CO + 36.2) / 0.9838 (2c)

Remaining standard uncertainty: u_{CO} (ppb) = sqrt (375.3 ppb^2 + 1.01e-04 * X_{CO}^2) (2d)

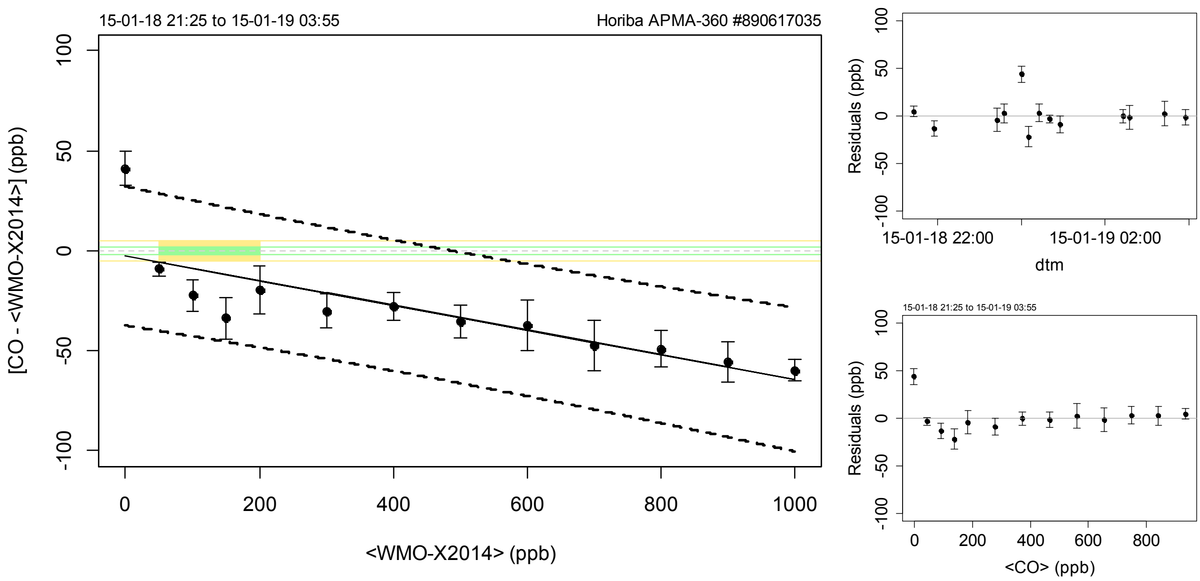

Figure 4. *Left: Bias of the MKN Horiba APMA360 carbon monoxide instrument with respect to the WMO-X2014 reference scale as a function of mole fraction. Each point represents the average of data at a given level from a specific run. The error bars show the standard deviation of individual measurement points. The green and yellow lines correspond to the WMO compatibility and extended compatibility goals, and the green and yellow areas to the mole fraction range relevant for MKN. The dashed lines around the regression lines are the Working-Hotelling 95% confidence bands. Right: Regression residuals (time dependence and mole fraction dependence).*

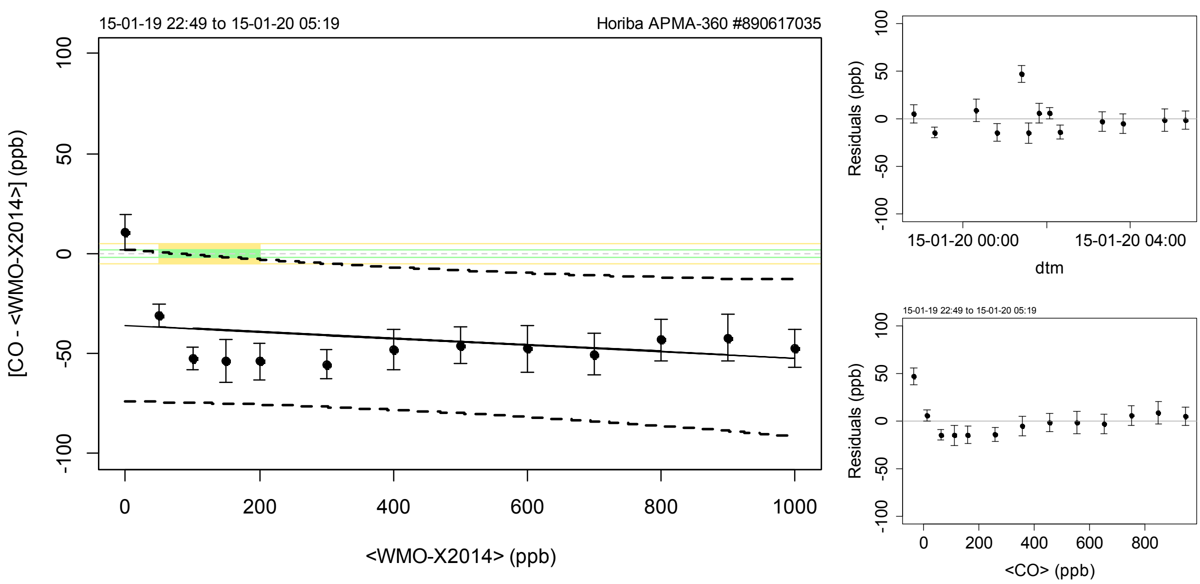

Figure 5. *Same as above, after adjustments of the calibration settings.*

The results of the comparisons can be summarised as follows:

The instrument seems to be non-linear in the lower measurement range between 0-200 ppb CO, and also suffers from significant drift. The change in sensitivity is also clearly indicating that the instrument has reached the end of its expected lifetime. Furthermore, the repeatability is clearly insufficient to reach the WMO/GAW compatibility goals, which should be the target for measurements at a remote site as MKN. However, it would be beneficial if these findings could also be confirmed by regular direct measurements of standards on the instrument. Therefore, re-establishing the manual span checks as recommended above is of utmost importance.

Due to the above findings, the instrument needs to be replaced. However, careful evaluation of the new instrument type is required prior to purchase, since not all CO analysers are suitable for long-term reliable measurements. WCC-Empa and QA/SAC Switzerland should be contacted before the purchase of a new instrument.

Methane and Carbon Dioxide Measurements

The analyser for the continuous measurements of methane and carbon dioxide at MKN was installed in June 2010 by WCC-Empa and QA/SAC Switzerland. Due to lack of electrical power, the measurements never commenced, and the instrument was damaged by a power surge after the re-establishment of power in 2014. The instrument was diagnosed during the present audit, but on-site repair was not possible. The instrument was then shipped via Empa to Picarro Inc. in California for repair. The motherboard of the built-in computer as well as the wave length monitor were damaged and needed to be replaced. The repaired instrument returned to Empa in September 2015, and several tests were made before shipping to Kenya. During these tests, the user calibration settings were changed. Details are given in the Appendix. Re-installation was completed at MKN in December 2015 based on detailed installation instructions provided by WCC-Empa. However, the calibration gases have not yet been connected to the instrument.

> **Recommendation 16 (***, critical, 2016)**
> *The calibration gases need to be connected to the Picarro instrument following the instructions provided by WCC-Empa. The operators of the MKN station should contact WCC-Empa or QA/SAC Switzerland if further clarification is needed.*

Instrumentation. Picarro G1301, including a custom built valve box for automatic measurements of standard gases.

Standards. A set of 4 NOAA standards is available for the calibration of the Picarro instrument. Furthermore, a working standard provided by WCC-Empa is available. In addition, the National Center for Atmospheric Research (NCAR) installed CO_2 measurements at MKN in 2009. These measurements never became operational. In the meantime, the NCAR instrument (AIRCOA) was decommissioned. The standards however are still at MKN, and may be used as working standards for the Picarro instrument (B. B. Stephens, personal communication). A list of the available standards is given in the Appendix.

> **Recommendation 17 (**, important, 2016)**
> *The NCAR standards should be calibrated against the NOAA standards for future use as working standards.*

Intercomparison (Performance Audit). The comparison involved repeated challenges of the MKN instruments with randomised CH_4 and CO_2 levels from laboratory and working standards at WCC-Empa during instrument testing in September 2015. The instrument was initially calibrated (change of user calibration settings) using one WCC-Empa calibrated tank on actual NOAA scales and zero air. 72 hours after this initial calibration a set of standards was measured, and no further correction was applied to the data. The results of the comparison measurements for the individual measurement parameters are summarised and illustrated below.

The following equation characterises the instrument bias. The result is further illustrated in Figure 6 and 7 with respect to the relevant mole fraction range (white area) and the WMO/GAW compatibility goals (green area) and extended compatibility goals (yellow area) (WMO, 2014).

PICARRO G1301 #334-CFADS080:

Unbiased CH_4 mixing ratio:	X_{CH4} (ppb) = (CH_4 -0.42 ppb) / 0.99999	(1a)
Remaining standard uncertainty:	u_{CH4} (ppb) = sqrt (0.3 ppb^2 + 1.30e-07 * X_{CH4}^2)	(1b)
Unbiased CO_2 mixing ratio:	X_{CO2} (ppm) = (CO_2 - 0.08 ppm) / 0.99987	(2a)
Remaining standard uncertainty:	u_{CO2} (ppm) = sqrt (0.002 ppm^2 + 3.28e-08 * X_{CO2}^2)	(2b)

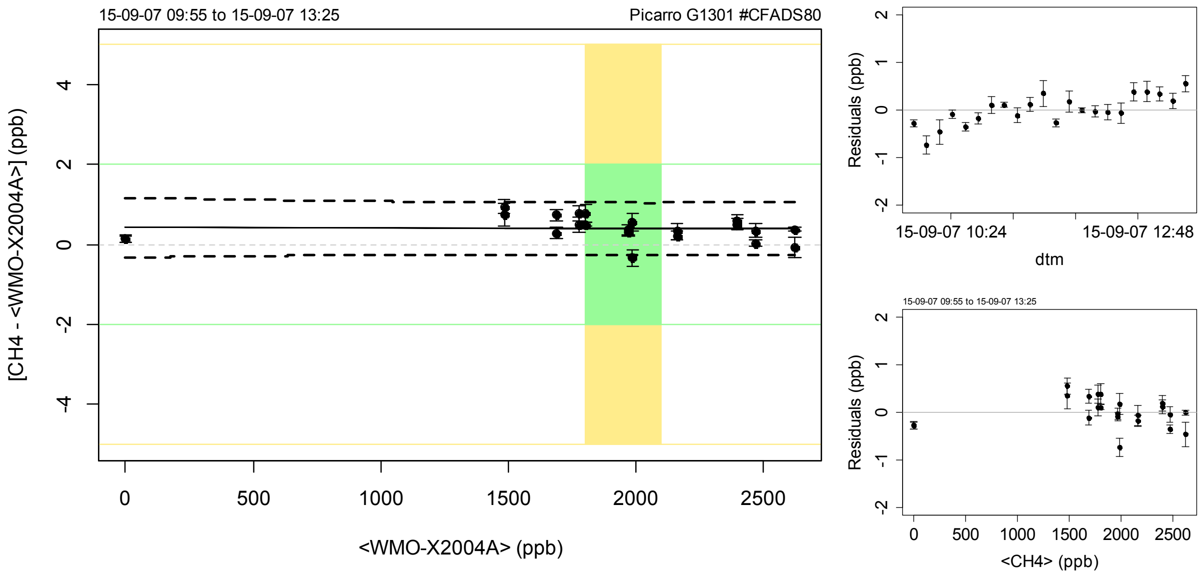

Figure 6. *Left: Bias of the PICARRO G1301 #334-CFADS080 methane instrument with respect to the WMO-X2004A CH_4 reference scale as a function of mole fraction. Each point represents the average of data at a given level from a specific run. The error bars show the standard deviation of individual measurement points. The green and yellow lines correspond to the WMO compatibility and extended compatibility goals, and the green and yellow areas to the mole fraction range relevant for MKN. The dashed lines around the regression lines are the Working-Hotelling 95% confidence bands. Right: Regression residuals (time dependence and mole fraction dependence).*

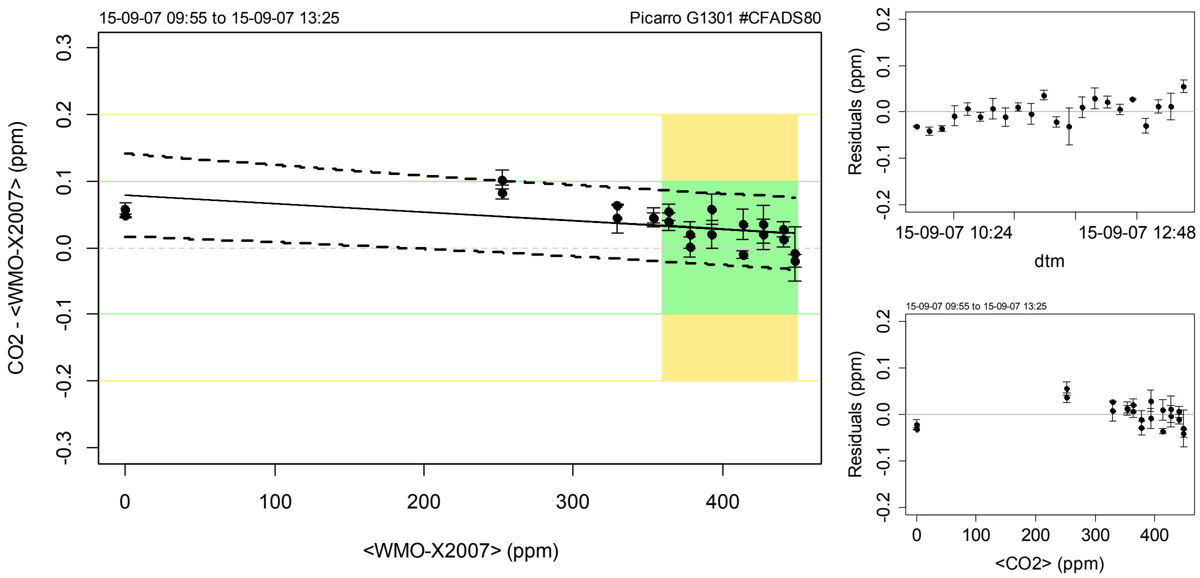

Figure 7. *Same as above for CO_2.*

The results of the comparisons can be summarised as follows:

Agreement within the WMO/GAW compatibility goals of ±2 ppb (CH_4) and ±0.1 (CO_2) ppm was found in the relevant mole fraction range. This result was achieved 3 days after the last calibration. However, the comparison was performed at Empa in a well air conditioned environment. It will be necessary to run standard gases in regular intervals at MKN to ensure stability over time, and allow potential drift correction.

The results of the comparisons show that the instrumentation is fully adequate for the planned CO_2/CH_4 at MKN.

Data Acquisition and Management

The LabView-based data acquisition system developed by QA/SAC-Switzerland was replaced by a commercial system from Breitfuss GmbH (EasyComp, Anacomp4 and Anavis) during the current WCC-Empa audit. Drivers for all monitoring instruments are installed. The system stores 1-min data. Currently, the data is manually transferred to Empa by TeamViewer access. CO_2 and CH_4 data will further be acquired using the LabView based Picarro data acquisition system. Final data validation is still made at Empa as part of the twinning between KMD and QA/SAC Switzerland.

Recommendation 18 (*, important, 2016)**
It is regarded of highest importance that the KMD staffs gets more involved in the data validation process. KMD is further encouraged to actively use the available data for scientific purposes.
Recommendation 19 (, important, 2016)**
An automatic data transfer to both Empa and KMD should be established, which also would serve a redundant back-up of the data.

For each instrument, hand written and electronic log files are available. It is important that all relevant events and observations are recorded in these log files. WCC-Empa reviewed these files during the audit. It was found that these files were only partly comprehensive.

Recommendation 20 (, important, 2016)**
Documentation is an important aspect of the QA procedures, and it must be made sure that all relevant observations are entered in the corresponding log files.

Data Submission

Surface O_3 and CO data (both from May 2002 – July 2010) have been submitted to the World Data Centre for Greenhouse Gases (WDCGG). No data is available after this period until January 2015. It is recommended that the future data is submitted in at least yearly intervals.

Recommendation 21 (, important, ongoing)**
Data submission is one of the obligations of GAW stations. Available data should be submitted to the corresponding data centres, with a submission delay of maximum one year.
Recommendation 22 (*, minor, as soon as possible)
GAWSIS needs to be updated to reflect the addition of continuous GHG measurements. Updates of GAWSIS should be made after changes of the station staff or the measurement programme.

Conclusions

The Global GAW station Mt. Kenya is situated in a strategically important location for the GAW programme, which makes the available data a very significant contribution to GAW.

Compared to the last audit by WCC-Empa in 2010, significant progress has been made concerning the infrastructure at the site. However, funding issues remain a problem for the sustainable operation of the measurements, and some of the instruments need immediate replacement (CO, meteorological parameters).

It was recognized that the scientific use of the available data is now of highest priority. In a first step, data need to be regularly analysed, and quality controlled data sets need to be submitted to the corresponding data centres in yearly intervals. Beyond this, more scientific use of the data by KMD staff should be envisaged. This requires ongoing education and training of the existing staff as well as collaboration with both national and international partners.

The continuation of the Mt. Kenya measurement series is highly recommended and important for GAW.

Summary Ranking of the Mt. Kenya GAW Station

System Audit Aspect	Adequacy[#]	Comment
Access	(4)	Improved road, transport of heavy equipment still difficult.
Facilities		
Laboratory and office space	(3)	Basic facilities only; no sanitary installations
Internet access	(3)	Available through 3G modem, currently only prepaid
Air Conditioning	(0)	Not available at the time of audit, installed after the audit
Power supply	(3)	Replaced power line, re-connection of UPS needed
General Management and Operation		
Organisation	(3)	Communication with external partners difficult at times, funding issues
Competence of staff	(3)	Ongoing technical and scientific training of staff needed
Air Inlet System	(5)	Adequate system
Instrumentation		
Ozone	(4)	Adequate instrumentation
Carbon monoxide	(1)	Instable instrument, replacement needed
CO_2/CH_4 (Picarro G1301)	(5)	Adequate instrumentation
Standards		
Ozone	(4)	TEI 49i-PS available at KMD
CO, CO_2, CH_4	(4)	NOAA standards / working standards available, no local supplier
Data Management		
Data acquisition	(5)	New system fully adequate
Data processing	(3)	Relies on support of twining partners
Data submission	(3)	Data partly submitted, long delays and large data gaps

[#]0: inadequate thru 5: adequate.

Dübendorf, March 2016

Dr. C. Zellweger WCC-Empa	Dr. M. Steinbacher QA/SAC Switzerland	Dr. B. Buchmann Head of Department

APPENDIX

Global GAW Station Mt. Kenya

Site description and measurement programme

Information about the Mt. Kenya GAW station is available from GAWSIS.

http://gaw.empa.ch/gawsis/reports.asp?GAWID=MKN

Organisation and Contact Persons

An overview of the organisation as well as contact persons is available from GAWSIS

Surface Ozone Measurements

Monitoring Set-up and Procedures

Air Conditioning

At the time of the audit the station was not air conditioned, and the lab temperature showed a significant diurnal variation. In the meantime, an air conditioning system was installed.

Air Inlet System

Unchanged since the last audit. The air inlet is adequate for surface ozone measurements.

Instrumentation

Ozone analyser (TEI 49C). The original TEI49C analyser was decommissioned after an instrument failure in 2014, and a refurbished TEI 49C instrument was installed at the site during the audit. Instrumental details are summarised in Table 1.

Standards

An ozone standard (TEI 49i-PS) is available at KMD Nairobi. Instrumental details are summarised in Table 1.

Operation and Maintenance

Check for general operation:	Weekly during station visits.
Zero / Span check:	None.
Calibration/checks with standard:	None.
Inlet filter exchange:	Usually every 2 months, sometimes longer, more often in case of pollution episodes.
Other (cleaning, leak check etc.):	As required.

Data Acquisition and Data Transfer

New Breitfuss data acquisition system.

Data Treatment

Final data validation is still made at Empa as part of the twinning between KMD and QA/SAC Switzerland. It is important that more effort is made by the station staff concerning data validation.

Documentation

An electronic log book is available, but the information was only partly comprehensive and up-to-date. The instrument manuals were available at the site.

Comparison of the Ozone Analyser and Ozone Calibrator

All procedures were conducted according to the Standard Operating Procedure (WCC-Empa SOP) and included comparisons of the travelling standard with the Standard Reference Photometer at Empa before and after the comparison of the analyser.

Setup and Connections

The internal ozone generator of the WCC-Empa transfer standard was used for generation of a randomised sequence of ozone levels ranging from 0 to 90 ppb. Zero air was generated using a custom built zero air generator (Silicagel, activated charcoal, Purafil). The TS was connected to the station analyser using approx. 1.5 m of PFA tubing. Table 1 details the experimental setup during the comparisons of the travelling standard with the station analysers. The data used for the evaluation was recorded by the WCC-Empa data acquisition system.

Table 1. Experimental details of the ozone comparison.

Travelling standard (TS)	
Model, S/N	TEI 49C-PS #56891-310 (WCC-Empa)
Settings	BKG -03, COEF 1.008
Station Analyser (OA)	
Model, S/N	TEI 49C #0330102716
Principle	UV absorption
Range	0-1 ppm
Settings	BKG +0.0 ppb, COEF 1.015
Pressure readings (hPa)	Ambient 657.3; OA 657.3
KMD Calibrator (OC)	
Model, S/N	TEI 49i-PS #1127049769
Principle	UV absorption
Range	0-1 ppm
Settings	BKG = +0.0; COEFF = 1.014
Pressure readings (mmHg)	Ambient 826.3; OC 825.03, adjusted to 826.3 before comparisons
KMD Analyser (OA)	
Model, S/N	TEI 49i #1122849256
Principle	UV absorption
Range	0-1 ppm
Settings	BKG -0.1 ppb, COEF 1.016
Pressure readings (mmHg)	Ambient 826.8; OA 829.5, adjusted to 826.8 before comparisons

Results

Each ozone level was applied for 13 minutes, and the last 5 one-minute averages were aggregated. These aggregates were used in the assessment of the comparison. All results are valid for the calibration factors as given in Table 1 above. The readings of the travelling standard (TS) were compensated for bias with respect to the Standard Reference Photometer (SRP) prior to the evaluation of the ozone analyser (OA) and calibrator (OC) values.

The results of the assessment is shown in the following Tables (individual measurement points) and further presented in the Executive Summary (Figure and Equations).

Table 2. Ten-minute aggregates computed from the last 10 of a total of 15 one-minute values for the comparison of the MKN ozone analyser (OA) TEI 49C #0330102716 with the WCC-Empa travelling standard (TS).

Date - Time (UTC)	Run #	Level (ppb)	TS (ppb)	OA (ppb)	sdTS (ppb)	sdOA (ppb)	OA-TS (ppb)	OA-TS (%)
2015-01-17 09:43	1	0	0.04	0.24	0.18	0.17	0.20	NA
2015-01-17 09:58	1	30	29.34	29.25	0.04	0.05	-0.09	-0.3
2015-01-17 10:13	1	60	59.41	58.81	0.15	0.14	-0.60	-1.0
2015-01-17 10:28	1	90	89.61	88.78	0.09	0.28	-0.83	-0.9
2015-01-17 10:43	1	10	9.46	9.39	0.17	0.09	-0.07	-0.7
2015-01-17 11:28	1	50	49.40	49.16	0.14	0.20	-0.24	-0.5
2015-01-17 11:43	1	20	20.02	20.10	0.67	0.75	0.08	0.4
2015-01-17 11:53	1	80	79.44	78.59	0.21	0.22	-0.85	-1.1
2015-01-17 12:13	2	0	0.22	0.16	0.13	0.16	-0.06	NA
2015-01-17 12:25	2	40	39.32	39.17	0.17	0.17	-0.15	-0.4
2015-01-17 12:43	2	80	79.74	78.72	0.12	0.30	-1.02	-1.3
2015-01-17 13:24	2	90	89.03	88.70	0.89	0.47	-0.33	-0.4
2015-01-17 13:43	2	10	9.42	9.32	0.17	0.17	-0.10	-1.1
2015-01-17 13:58	2	20	19.37	19.22	0.13	0.31	-0.15	-0.8
2015-01-17 14:43	3	0	0.01	0.12	0.12	0.19	0.11	NA
2015-01-17 14:58	3	20	20.68	20.58	0.99	0.79	-0.10	-0.5
2015-01-17 15:21	3	10	10.08	9.91	0.49	0.45	-0.17	-1.7
2015-01-17 15:43	3	90	89.29	88.52	0.04	0.12	-0.77	-0.9
2015-01-17 15:57	3	70	69.21	68.66	0.04	0.10	-0.55	-0.8
2015-01-17 16:13	3	60	59.30	58.97	0.11	0.30	-0.33	-0.6
2015-01-17 16:28	3	30	29.44	28.90	0.11	0.18	-0.54	-1.8
2015-01-17 16:43	3	50	49.62	49.14	0.11	0.07	-0.48	-1.0
2015-01-17 16:58	3	80	79.66	78.90	0.12	0.26	-0.76	-1.0
2015-01-17 17:13	4	0	-0.01	-0.04	0.06	0.14	-0.03	NA
2015-01-17 17:28	4	30	29.73	29.47	0.08	0.24	-0.26	-0.9
2015-01-17 17:43	4	60	59.82	59.52	0.05	0.16	-0.30	-0.5
2015-01-17 17:58	4	90	89.84	89.04	0.11	0.17	-0.80	-0.9
2015-01-17 18:13	4	10	9.78	9.90	0.09	0.15	0.12	1.2
2015-01-17 18:28	4	40	39.71	39.26	0.10	0.15	-0.45	-1.1
2015-01-17 18:43	4	70	69.77	69.35	0.15	0.18	-0.42	-0.6
2015-01-17 19:13	4	20	19.90	19.71	0.37	0.41	-0.19	-1.0
2015-01-17 19:28	4	80	79.94	79.63	0.13	0.16	-0.31	-0.4
2015-01-17 19:43	5	0	-0.14	-0.07	0.08	0.17	0.07	NA
2015-01-17 19:56	5	40	39.64	39.50	0.09	0.13	-0.14	-0.4
2015-01-17 20:13	5	80	79.73	79.09	0.07	0.12	-0.64	-0.8
2015-01-17 20:27	5	30	29.51	29.19	0.21	0.19	-0.32	-1.1
2015-01-17 20:42	5	50	49.68	49.08	0.07	0.27	-0.60	-1.2
2015-01-17 20:58	5	90	89.74	89.33	0.10	0.15	-0.41	-0.5
2015-01-17 21:13	5	10	9.95	9.58	0.16	0.18	-0.37	-3.7
2015-01-17 21:43	5	70	69.47	69.12	0.47	0.53	-0.35	-0.5
2015-01-17 21:58	5	60	59.73	59.45	0.04	0.16	-0.28	-0.5

2015-01-17 22:13	6	0	-0.05	-0.11	0.08	0.17	-0.06	NA
2015-01-17 22:28	6	20	19.56	19.38	0.06	0.16	-0.18	-0.9
2015-01-17 22:43	6	40	40.17	39.90	0.77	0.63	-0.27	-0.7
2015-01-17 22:58	6	10	9.69	9.53	0.12	0.14	-0.16	-1.7
2015-01-17 23:13	6	90	89.69	89.10	0.07	0.12	-0.59	-0.7
2015-01-17 23:28	6	70	69.70	69.09	0.11	0.18	-0.61	-0.9
2015-01-17 23:57	6	30	29.68	29.43	0.05	0.13	-0.25	-0.8
2015-01-18 00:13	6	50	49.66	49.32	0.03	0.09	-0.34	-0.7
2015-01-18 00:43	7	0	0.04	-0.35	0.15	0.09	-0.39	NA
2015-01-18 00:58	7	30	29.66	29.40	0.05	0.07	-0.26	-0.9
2015-01-18 01:13	7	60	59.37	58.92	0.55	0.50	-0.45	-0.8
2015-01-18 01:28	7	90	89.74	88.93	0.04	0.16	-0.81	-0.9
2015-01-18 01:43	7	10	9.65	9.81	0.09	0.34	0.16	1.7
2015-01-18 01:58	7	40	39.62	38.95	0.13	0.13	-0.67	-1.7
2015-01-18 02:13	7	70	69.70	69.21	0.15	0.12	-0.49	-0.7
2015-01-18 02:28	7	50	49.68	49.42	0.04	0.13	-0.26	-0.5
2015-01-18 02:41	7	20	19.64	19.17	0.15	0.12	-0.47	-2.4
2015-01-18 02:58	7	80	79.82	79.29	0.11	0.22	-0.53	-0.7
2015-01-18 03:13	8	0	-0.07	-0.15	0.10	0.18	-0.08	NA
2015-01-18 03:28	8	40	39.72	39.48	0.10	0.17	-0.24	-0.6
2015-01-18 03:43	8	80	79.75	79.34	0.07	0.25	-0.41	-0.5
2015-01-18 03:58	8	30	29.76	29.39	0.08	0.22	-0.37	-1.2
2015-01-18 04:13	8	50	49.76	49.42	0.09	0.07	-0.34	-0.7
2015-01-18 04:28	8	90	89.79	89.27	0.07	0.11	-0.52	-0.6
2015-01-18 04:43	8	10	9.71	9.52	0.06	0.13	-0.19	-2.0
2015-01-18 04:58	8	20	19.69	19.32	0.08	0.23	-0.37	-1.9
2015-01-18 05:13	8	70	69.67	69.33	0.15	0.16	-0.34	-0.5
2015-01-18 05:28	8	60	59.67	59.06	0.06	0.22	-0.61	-1.0
2015-01-18 05:43	9	0	-0.07	-0.30	0.11	0.18	-0.23	NA
2015-01-18 05:58	9	20	19.58	19.14	0.10	0.26	-0.44	-2.2
2015-01-18 06:13	9	40	39.62	39.50	0.17	0.21	-0.12	-0.3
2015-01-18 06:28	9	10	9.61	9.51	0.08	0.11	-0.10	-1.0
2015-01-18 06:43	9	90	89.70	89.01	0.09	0.12	-0.69	-0.8
2015-01-18 06:58	9	70	69.69	68.99	0.19	0.17	-0.70	-1.0

Table 3. Ten-minute aggregates computed from the last 10 of a total of 15 one-minute values for the comparison of the KMD ozone calibrator (OC) TEI 49i-PS #1127049769 with the WCC-Empa travelling standard (TS).

Date - Time (UTC)	Run #	Level (ppb)	TS (ppb)	OC (ppb)	sdTS (ppb)	sdOC (ppb)	OC-TS (ppb)	OC-TS (%)
2015-01-23 07:05	1	0	0.67	0.81	0.02	0.04	0.14	NA
2015-01-23 07:14	1	50	49.70	49.00	0.06	0.19	-0.70	-1.4
2015-01-23 07:24	1	250	249.56	247.34	0.11	0.14	-2.22	-0.9
2015-01-23 07:34	1	100	99.64	98.73	0.07	0.19	-0.91	-0.9
2015-01-23 07:44	1	200	199.57	197.90	0.09	0.12	-1.67	-0.8
2015-01-23 07:54	1	150	149.63	148.35	0.05	0.12	-1.28	-0.9
2015-01-23 08:04	2	0	0.54	0.72	0.07	0.05	0.18	NA
2015-01-23 08:14	2	200	199.54	197.75	0.11	0.19	-1.79	-0.9
2015-01-23 08:24	2	50	49.80	49.31	0.06	0.06	-0.49	-1.0
2015-01-23 08:34	2	100	99.74	98.95	0.11	0.28	-0.79	-0.8
2015-01-23 08:44	2	250	249.69	248.04	0.06	0.10	-1.65	-0.7
2015-01-23 09:04	2	150	149.77	148.65	0.08	0.17	-1.12	-0.7

Table 4. Ten-minute aggregates computed from the last 10 of a total of 15 one-minute values for the comparison of the KMD ozone analyser (OA) TEI 49i #1122849256 with the WCC-Empa travelling standard (TS).

Date - Time (UTC)	Run #	Level (ppb)	TS (ppb)	OC (ppb)	sdTS (ppb)	sdOC (ppb)	OC-TS (ppb)	OC-TS (%)
2015-01-22 07:08	1	0	0.27	0.32	0.07	0.14	0.05	NA
2015-01-22 07:18	1	20	19.40	19.13	0.08	0.15	-0.27	-1.4
2015-01-22 07:28	1	10	9.44	9.18	0.09	0.14	-0.26	-2.8
2015-01-22 07:38	1	40	39.27	38.74	0.11	0.10	-0.53	-1.3
2015-01-22 07:48	1	90	89.30	87.95	0.10	0.12	-1.35	-1.5
2015-01-22 07:58	1	60	59.32	58.31	0.02	0.13	-1.01	-1.7
2015-01-22 08:08	1	30	29.39	28.80	0.05	0.16	-0.59	-2.0
2015-01-22 08:18	2	0	0.24	0.21	0.08	0.08	-0.03	NA
2015-01-22 08:28	2	90	89.61	88.25	0.10	0.13	-1.36	-1.5
2015-01-22 08:38	2	20	19.67	19.18	0.05	0.10	-0.49	-2.5
2015-01-22 08:48	2	40	39.74	39.12	0.09	0.16	-0.62	-1.6
2015-01-22 08:58	2	60	59.81	58.82	0.11	0.09	-0.99	-1.7
2015-01-22 09:08	2	10	9.65	9.29	0.13	0.12	-0.36	-3.7
2015-01-22 09:18	2	30	29.56	29.18	0.16	0.14	-0.38	-1.3
2015-01-22 09:18	2	30	29.56	29.18	0.16	0.14	-0.38	-1.3

Carbon Monoxide Measurements

Monitoring Set-up and Procedures

Air Conditioning

Same as for surface ozone.

Air Inlet System

Unchanged since the last audit. The air inlet is adequate for CO measurements.

Instrumentation

Mt. Kenya is equipped with a AMPA360NDIR analyser. Instrumental details are listed in Table 6.

Standards

The following Table gives an overview of the current and past standards for the calibration of the CO instrument. Automatic span checks are made using a dilution system. In addition, regular manual span checks (3-monthly) should be made.

Table 5. CO Standards available at MKN.

Cylinder ID	Manufacturer	Use	CO (ppb)	U_{CO} (ppb)	Start of use	End of use
080304_CA06112	Empa	Dilution	51021.0	510.0	Jul 08	cont.
080304_CA04549	Empa	Direct calibration	1288.0	13.0	Jun 10	cont.
080808_CA08202	Empa	Dilution	59772.0	598.0	Stock	NA
080808_CA08210	Empa	Direct calibration	859.5	8.6	Stock	NA

Operation and Maintenance

Same as for surface ozone.

Data Acquisition and Data Transfer

Same as for surface ozone.

Data Treatment

Same as for surface ozone.

Documentation

Same as for surface ozone.

Comparison of the Carbon Monoxide Analyser

All procedures were conducted according to the Standard Operating Procedure (WMO, 2007a) and included comparisons of the travelling standards at Empa before the comparison of the analysers. Details of the traceability of the travelling standards to the WMO/GAW Reference Standard at NOAA/ESRL are given in the appendix.

Setup and Connections

Table 6 shows details of the experimental setup during the comparison of the transfer standard and the station analysers. The data used for the evaluation was recorded by the MKN data acquisition system.

Table 6. Experimental details of MKN CO comparison.

Travelling standard (TS)	
A CO in air standard (080304_CA06112, 51.02 ppm CO, 1300 psi) prepared by WCC-Empa and calibrated against the WMO- X2014 carbon monoxide scale at WCC-Empa has been used in combination with a dilution system. Levels of 0, 50, 100, 150, 200, 300, ..., 1000 ppb were generated with this system.	
Station Analyser MKN (AL)	
Model, S/N	Horiba APMA360 #890617035
Principle	NDIR, cross flow modulation
Drying system	PERMAPURE Nafion drier
Comparison procedures	
Connection	The output of the dilution system was connected to the sample inlet of the Horiba APMA360

Results

The results of the assessment are shown in the Executive Summary (figures and equations), and the individual measurements of the TS are presented in the following Tables.

Table 7. CO aggregates computed from single analysis (mean and standard deviation of mean) for each level during the comparison of the Horiba APMA360 #890617035 (Zero -8, SPAN 1. 0300) instrument (AL) with the WCC-Empa TS (WMO-X2014 CO scale).

Date / Time	CO Level (ppb)	TS (ppb)	sdTS (ppb)	AL (ppb)	sdAL (ppb)	N	AL-TS (ppb)	AL-TS (%)
(15-01-19 00:00:35)	0.0	0.0	0.0	41.0	8.4	48.0	41.0	NA
(15-01-18 21:25:45)	1000.0	1000.0	20.0	939.9	5.4	8.0	-60.1	-6.0
(15-01-18 21:55:30)	100.0	100.0	2.0	77.5	7.9	8.0	-22.5	-22.5
(15-01-18 23:35:09)	900.0	900.0	18.0	844.1	10.1	7.0	-55.9	-6.2
(15-01-18 23:25:30)	200.0	200.0	4.0	180.5	12.0	8.0	-19.5	-9.8
(15-01-19 00:25:30)	800.0	800.0	16.0	750.8	9.1	8.0	-49.2	-6.2
(15-01-19 00:55:30)	300.0	300.0	6.0	269.8	8.7	8.0	-30.2	-10.1
(15-01-19 02:35:09)	700.0	700.0	14.0	652.3	12.5	7.0	-47.7	-6.8
(15-01-19 02:25:30)	400.0	400.0	8.0	372.0	7.2	8.0	-28.0	-7.0
(15-01-19 03:25:30)	600.0	600.0	12.0	562.4	12.7	8.0	-37.6	-6.3
(15-01-19 03:55:30)	500.0	500.0	10.0	464.6	8.3	8.0	-35.4	-7.1
(15-01-19 00:10:30)	150.0	150.0	3.0	116.0	10.4	4.0	-34.0	-22.7
(15-01-19 00:40:30)	50.0	50.0	1.0	40.7	3.7	4.0	-9.4	-18.7

Table 8. CO aggregates computed from single analysis (mean and standard deviation of mean) for each level during the comparison of the Horiba APMA360 #890617035 (Zero -16, SPAN 1. 0900) instrument (AL) with the WCC-Empa TS (WMO-X2014 CO scale).

Date / Time	CO Level (ppb)	TS (ppb)	sdTS (ppb)	AL (ppb)	sdAL (ppb)	N	AL-TS (ppb)	AL-TS (%)
(15-01-20 01:24:30)	0.0	0.0	0.0	10.4	8.9	48.0	10.4	NA
(15-01-19 22:49:30)	1000.0	1000.0	20.0	952.6	9.6	8.0	-47.5	-4.8
(15-01-19 23:19:30)	100.0	100.0	2.0	47.5	5.7	8.0	-52.5	-52.5
(15-01-20 00:19:30)	900.0	900.0	18.0	857.7	11.8	8.0	-42.4	-4.7
(15-01-20 00:49:30)	200.0	200.0	4.0	145.8	9.3	8.0	-54.2	-27.1
(15-01-20 01:49:30)	800.0	800.0	16.0	756.5	10.4	8.0	-43.5	-5.4
(15-01-20 02:19:30)	300.0	300.0	6.0	244.5	7.4	8.0	-55.5	-18.5
(15-01-20 03:19:30)	700.0	700.0	14.0	649.5	10.5	8.0	-50.5	-7.2
(15-01-20 03:49:30)	400.0	400.0	8.0	351.9	10.2	8.0	-48.1	-12.0
(15-01-20 04:49:30)	600.0	600.0	12.0	552.1	11.9	8.0	-47.9	-8.0
(15-01-20 05:19:30)	500.0	500.0	10.0	454.0	9.4	8.0	-46.0	-9.2
(15-01-20 01:34:30)	150.0	150.0	3.0	96.2	10.8	4.0	-53.9	-35.9
(15-01-20 02:04:30)	50.0	50.0	1.0	18.7	5.7	4.0	-31.3	-62.6

Methane and Carbon Dioxide Measurements

Monitoring Set-up and Procedures

Air Conditioning

Same as for surface ozone.

Air Inlet System

Location of air intake: Air is sampled from the top of the meteo mast, approx. 8 m above ground.

Inlet protection: Funnel as rainwater protection.

Tubing / Material: Approx. 10 m ¼" tubing (Synflex 1300), flow rate approx4 l/min to the Picarro valve box. From there short (max. 1 m) ¼" tubing to the instrument with a flow rate of approx. 0.25 l/min.

Inlet filter: Swagelok SS-4TF Stainless Steel Tee-Type Particulate Filter, 7 Micron Pore Size.

Humidity trap: Nafion dryer, PD-50T-24SS.

Residence time: Approx. 10 s

Instrumentation

A Picarro G1301 CO_2, CH_4 and H_2O analyser is available at MKN. Instrumental details are listed in Table 10. The instrument was initially calibrated at the WCC-Empa laboratory in September 2015, and the configuration file was changed as follows:

```
[CALIBRATION]
CONCENTRATION_CH4_GAL_INTERCEPT=-0.00014685
CONCENTRATION_CH4_GAL_SLOPE=0.98790371
#CONCENTRATION_CH4_GAL_INTERCEPT=-0.000346858
#CONCENTRATION_CH4_GAL_SLOPE=0.990677619
CONCENTRATION_CH4_USER_INTERCEPT=-0.000777
CONCENTRATION_CH4_USER_SLOPE=1.003539

CONCENTRATION_H2O_CONC_INTERCEPT=0.00
CONCENTRATION_H2O_CONC_SLOPE=1.00
CONCENTRATION_H2O_USER_INTERCEPT=0.000
CONCENTRATION_H2O_USER_SLOPE=1.000

CONCENTRATION_CO2_GAL_INTERCEPT=0.613
CONCENTRATION_CO2_GAL_SLOPE=0.70367062
#CONCENTRATION_CO2_GAL_INTERCEPT=-0.2739
#CONCENTRATION_CO2_GAL_SLOPE=0.707918134
CONCENTRATION_CO2_GAL_H2O_RATIO_SLOPE=0.01244
CONCENTRATION_CO2_USER_INTERCEPT=-0.6533
CONCENTRATION_CO2_USER_CONC_SLOPE=1.007995
```

Before, all USER intercepts and slopes were 0.0000 and 1.0000.

Furthermore, the water vapour correction function was determined at Empa in September 2015 according to the method described by Rella et al. (2013) by WCC-Empa (see Figure 8). The following equations characterise the humidity interference:

$$CO_2(dry) = CO_2(wet) / (1 - 0.01230 * H_{rep} - 0.000183 * H_{rep}^2) \quad (A1)$$

$$CH_4(dry) = CH_4(wet) / (1 - 0.01105 * H_{rep} - 0.000036 * H_{rep}^2) \quad (A2)$$

These equations must be used to correct for the H2O interference.

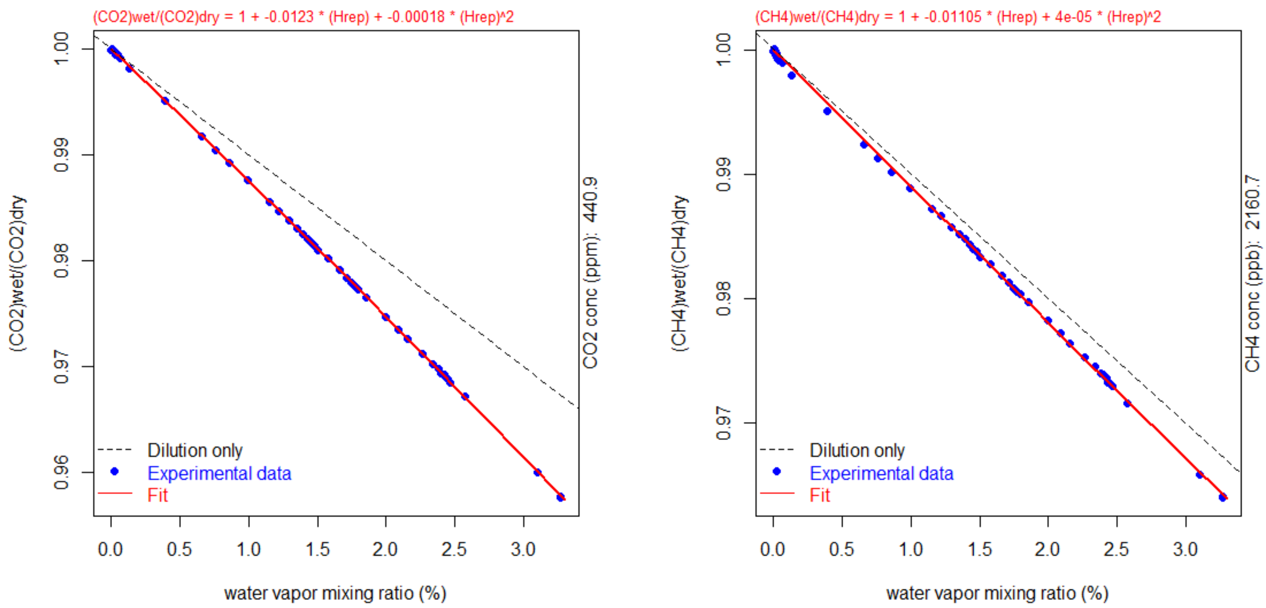

Figure 8. *Quadratic fits for the MKN Picarro G1301 instrument of $(CO_2)wet/(CO_2)dry$ and $(CH_4)wet/(CH_4)dry$ vs. H_2O mixing ratios.*

Standards

Table 9 lists current standards for GHG calibrations available at MKN.

Table 9. Standards available at MKN for the calibration of GHG analyser.
Calibration scales: CH_4: WMO-X2004AA, CO_2: WMO-X2007

Cylinder ID	Type	CH_4 (ppb)	CO_2 (ppm)	Start of use	End of use
CC324480	NOAA/ESRL	1750.09	370.09	2015	cont.
CC324465	NOAA/ESRL	1847.13	390.59	2015	cont.
CC325133	NOAA/ESRL	1801.85	381.03	2015	cont.
CC1788	NOAA/ESRL	1940.73	409.09	2015	cont.
091124_CB08863	Empa WS*	2292.91	538.94	2010	cont.
CA07933	NCAR**	NA	409.21	Stock	NA
CA07990	NCAR**	NA	349.93	Stock	NA
CA07917	NCAR**	NA	378.70	Stock	NA
CA07941	NCAR**	NA	472.89	Stock	NA
JJ23428	NCAR**	NA	383.65	Stock	NA

* Value assigned in 2010 by WCC-Empa

** Value assigned in 2009 by NCAR, CA cylinders likely with $d^{13}C$ of approx. -30 ‰

Operation and Maintenance

Since the instrument was not yet running at the station, no maintenance has been done. It is recommended that the instrument is checked for general operation during station visits. The pressure of all standard gases needs to be logged in a check list. Exchange of the inlet filter is recommended every 2-6 months, depending on pollution at the site.

Comparison with WCC-Empa travelling standards

The comparison involved repeated challenges of the MKN instruments with randomised CH_4 and CO_2 levels from laboratory and working standards at Empa. The instrument was initially calibrated using one WCC-Empa calibrated tank on actual NOAA scales and zero air. 72 hours after this initial calibration a set of standards was measured, and no further corrections was applied to the data.

Setup and Connections

Table 10 shows details of the experimental setup during the comparison of the transfer standards and the station analyser. The data used for the evaluation was recorded by the station data acquisition system.

Table 10. Experimental details of the comparison.

Travelling standard (TS)	
WCC-Empa laboratory and working standards (30 l aluminium cylinder containing a mixture of natural and synthetic air).	
Station Analysers (OA)	
Model, S/N	PICARRO G1301 #334-CFADS080
Principle	CRDS
Drying system	Nafion dryer, PD-50T-24SS
Comparison procedures	
Connection	Connected to WCC-Empa valve box at Empa

Results

The results of the assessment are shown in the Executive Summary (Figures and Equations), and the individual measurements of the TS are presented in the following Tables.

Table 11. CH_4 aggregates computed from single analysis (1-min mean and standard deviation) for each level during the comparison of the Picarro G1301 #334-CFADS080 (OA) with the WCC-Empa TS.

Date / Time	TS Cylinder	TS (ppb)	sdTS (ppb)	OA (ppb)	sd OA (ppb)	N	OA-TS (ppb)	OA-TS (%)
(15-09-07 09:55:00)	zero	0.00	0.10	0.14	0.07	3	0.14	NA
(15-09-07 10:05:00)	CB09915	1986.67	0.22	1986.33	0.19	3	-0.34	-0.02
(15-09-07 10:15:00)	150413_CB11139	2623.63	0.18	2623.55	0.26	3	-0.08	0.00
(15-09-07 10:25:00)	150821_CB08835	1969.81	0.19	1970.12	0.08	3	0.31	0.02
(15-09-07 10:35:00)	120307_CB08963	2470.83	0.49	2470.87	0.08	3	0.04	0.00
(15-09-07 10:45:00)	150219_CB11167	2160.87	0.47	2161.09	0.11	3	0.22	0.01
(15-09-07 10:55:00)	120614_CB09197	1778.02	0.09	1778.52	0.18	3	0.50	0.03
(15-09-07 11:05:00)	CC311846	1804.62	0.15	1805.12	0.05	3	0.50	0.03
(15-09-07 11:15:00)	150311_CB11202	1687.73	0.08	1688.02	0.15	3	0.29	0.02
(15-09-07 11:25:00)	130822_CB10205	2397.69	0.15	2398.20	0.15	3	0.51	0.02
(15-09-07 11:35:00)	CC311856	1483.72	0.18	1484.47	0.27	3	0.75	0.05
(15-09-07 11:45:00)	zero	0.00	0.10	0.15	0.08	3	0.15	NA
(15-09-07 11:55:00)	CB09915	1986.67	0.22	1987.24	0.22	3	0.57	0.03
(15-09-07 12:05:00)	150413_CB11139	2623.63	0.18	2624.01	0.05	3	0.38	0.01
(15-09-07 12:15:00)	150821_CB08835	1969.81	0.19	1970.18	0.11	3	0.37	0.02
(15-09-07 12:25:00)	120307_CB08963	2470.83	0.49	2471.18	0.16	3	0.35	0.01
(15-09-07 12:35:00)	150219_CB11167	2160.87	0.47	2161.20	0.21	3	0.33	0.02
(15-09-07 12:45:00)	120614_CB09197	1778.02	0.09	1778.80	0.20	3	0.78	0.04
(15-09-07 12:55:00)	CC311846	1804.62	0.15	1805.40	0.21	3	0.78	0.04
(15-09-07 13:05:00)	150311_CB11202	1687.73	0.08	1688.46	0.15	3	0.73	0.04
(15-09-07 13:15:00)	130822_CB10205	2397.69	0.15	2398.27	0.16	3	0.58	0.02
(15-09-07 13:25:00)	CC311856	1483.72	0.18	1484.67	0.17	3	0.95	0.06

Table 12. CO_2 aggregates computed from single analysis (1-min mean and standard deviation) for each level during the comparison of the Picarro G1301 #334-CFADS080 (OA) with the WCC-Empa TS.

Date / Time	TS Cylinder	TS (ppm)	sdTS (ppm)	OA (ppm)	sd OA (ppm)	N	OA-TS (ppm)	OA-TS (%)
(15-09-07 09:55:00)	zero	0.00	0.05	0.05	0.00	3	0.05	NA
(15-09-07 10:05:00)	CB09915	448.44	0.01	448.42	0.01	3	-0.02	0.00
(15-09-07 10:15:00)	150413_CB11139	413.35	0.01	413.34	0.01	3	-0.01	0.00
(15-09-07 10:25:00)	150821_CB08835	392.93	0.01	392.95	0.02	3	0.02	0.01
(15-09-07 10:35:00)	120307_CB08963	363.65	0.04	363.69	0.01	3	0.04	0.01
(15-09-07 10:45:00)	150219_CB11167	440.95	0.00	440.96	0.01	3	0.01	0.00
(15-09-07 10:55:00)	120614_CB09197	329.52	0.01	329.56	0.02	3	0.04	0.01
(15-09-07 11:05:00)	CC311846	377.85	0.03	377.87	0.02	3	0.02	0.01
(15-09-07 11:15:00)	150311_CB11202	353.77	0.03	353.81	0.01	3	0.04	0.01
(15-09-07 11:25:00)	130822_CB10205	427.19	0.01	427.21	0.02	3	0.02	0.00
(15-09-07 11:35:00)	CC311856	252.12	0.02	252.20	0.01	3	0.08	0.03
(15-09-07 11:45:00)	zero	0.00	0.05	0.06	0.01	3	0.06	NA
(15-09-07 11:55:00)	CB09915	448.44	0.01	448.43	0.04	3	-0.01	0.00
(15-09-07 12:05:00)	150413_CB11139	413.35	0.01	413.39	0.02	3	0.04	0.01
(15-09-07 12:15:00)	150821_CB08835	392.93	0.01	392.99	0.02	3	0.06	0.02
(15-09-07 12:25:00)	120307_CB08963	363.65	0.04	363.70	0.01	3	0.05	0.01
(15-09-07 12:35:00)	150219_CB11167	440.95	0.00	440.98	0.01	3	0.03	0.01
(15-09-07 12:45:00)	120614_CB09197	329.52	0.01	329.58	0.00	3	0.06	0.02
(15-09-07 12:55:00)	CC311846	377.85	0.03	377.85	0.02	3	0.00	0.00
(15-09-07 13:05:00)	150311_CB11202	353.77	0.03	353.82	0.01	3	0.05	0.01
(15-09-07 13:15:00)	130822_CB10205	427.19	0.01	427.23	0.03	3	0.04	0.01
(15-09-07 13:25:00)	CC311856	252.12	0.02	252.22	0.01	3	0.10	0.04

WCC-Empa Traveling Standards

Ozone

The WCC-Empa travelling standard (TS) was compared with the Standard Reference Photometer before and after the audit. The following instruments were used:

WCC-Empa ozone reference: NIST Standard Reference Photometer SRP #15 (Master)

WCC-Empa TS: TEI 49C-PS #56891-310, BKG -0.3, COEF 1.008

Zero air source: Pressurized air – Breitfuss zero air generator – Purafil – charcoal – outlet filter

The results of the TS calibration before the audit and the verification of the TS after the audit are given in Table 13. The TS passed the assessment criteria defined for maximum acceptable bias before and after the audit (Klausen et al., 2003) (cf. Figure 9). The data were pooled and evaluated by linear regression analysis, considering uncertainties in both instruments. From this, the unbiased ozone mixing ratio produced (and measured) by the TS can be computed (Equation 6a). The uncertainty of the TS (Equation 6b) was estimated previously (cf. equation 19 in (Klausen et al., 2003)).

$$X_{TS}\text{ (ppb)} = ([TS] + 0.13\text{ ppb}) / 1.0007 \quad (6a)$$

$$u_{TS}\text{ (ppb)} = \text{sqrt}((0.43\text{ ppb})^2 + (0.0034 * X)^2) \quad (6b)$$

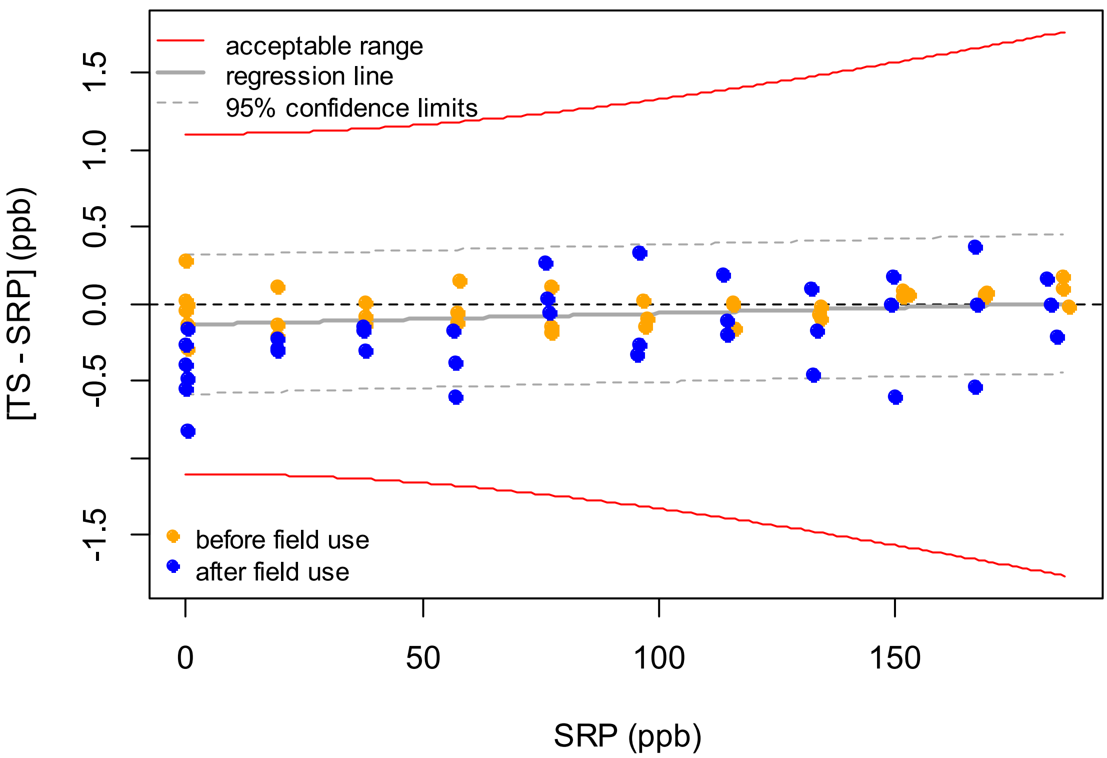

Figure 9. *Deviations between traveling standard (TS) and Standard Reference Photometer (SRP) before and after use of the TS at the field site.*

Table 13. Five-minute aggregates computed from 10 valid 30-second values for the comparison of the Standard Reference Photometer (SRP) with the WCC-Empa traveling standard (TS).

Date	Run	Level#	SRP (ppb)	sdSRP (ppb)	TS (ppb)	sdTS (ppb)
2014-07-30	1	0	-0.02	0.33	-0.06	0.20
2014-07-30	1	95	97.37	0.26	97.27	0.05
2014-07-30	1	60	57.52	0.17	57.39	0.11
2014-07-30	1	150	151.78	0.32	151.83	0.09
2014-07-30	1	170	169.24	0.22	169.29	0.10
2014-07-30	1	75	77.36	0.20	77.22	0.12
2014-07-30	1	185	185.59	0.23	185.69	0.19
2014-07-30	1	20	19.34	0.28	19.21	0.13
2014-07-30	1	40	37.86	0.18	37.74	0.12
2014-07-30	1	135	134.18	0.17	134.12	0.17
2014-07-30	1	115	115.84	0.22	115.83	0.09
2014-07-30	1	0	-0.07	0.21	-0.05	0.18
2014-07-30	2	0	0.17	0.20	-0.11	0.12
2014-07-30	2	155	152.87	0.21	152.93	0.14
2014-07-30	2	170	169.37	0.18	169.44	0.35
2014-07-30	2	75	77.46	0.22	77.27	0.10
2014-07-30	2	55	57.49	0.20	57.43	0.14
2014-07-30	2	40	37.76	0.18	37.69	0.07
2014-07-30	2	185	185.42	0.29	185.60	0.08
2014-07-30	2	115	115.87	0.09	115.88	0.10
2014-07-30	2	95	96.82	0.23	96.83	0.07
2014-07-30	2	135	134.37	0.32	134.35	0.11
2014-07-30	2	20	19.37	0.32	19.16	0.09
2014-07-30	2	0	0.07	0.28	0.08	0.05
2014-07-30	3	0	-0.24	0.13	0.04	0.06
2014-07-30	3	60	57.61	0.25	57.76	0.06
2014-07-30	3	185	186.77	0.34	186.76	0.23
2014-07-30	3	115	116.04	0.35	115.87	0.09
2014-07-30	3	135	134.31	0.31	134.21	0.09
2014-07-30	3	40	37.76	0.14	37.77	0.07
2014-07-30	3	75	77.31	0.26	77.42	0.07
2014-07-30	3	20	19.10	0.19	19.21	0.13
2014-07-30	3	170	169.29	0.26	169.36	0.27
2014-07-30	3	150	151.74	0.21	151.83	0.07
2014-07-30	3	95	97.09	0.17	96.95	0.09
2014-07-30	3	0	0.14	0.23	0.01	0.07
2015-02-03	4	0	0.22	0.29	-0.60	0.18
2015-02-03	4	55	57.15	0.22	56.78	0.10
2015-02-03	4	185	184.49	0.34	184.28	0.18
2015-02-03	4	115	114.70	0.39	114.50	0.17
2015-02-03	4	135	132.90	0.25	132.45	0.16
2015-02-03	4	40	37.56	0.19	37.39	0.16
2015-02-03	4	75	76.36	0.22	76.40	0.13
2015-02-03	4	20	19.31	0.32	19.02	0.26
2015-02-03	4	165	167.30	0.26	167.30	0.31
2015-02-03	4	150	149.76	0.56	149.94	0.26
2015-02-03	4	95	95.87	0.25	95.61	0.13
2015-02-03	4	0	-0.06	0.37	-0.45	0.19
2015-02-03	5	0	-0.19	0.14	-0.46	0.17
2015-02-03	5	135	133.73	0.35	133.55	0.09

Date	Run	Level[#]	SRP (ppb)	sdSRP (ppb)	TS (ppb)	sdTS (ppb)
2015-02-03	5	75	76.73	0.14	76.68	0.26
2015-02-03	5	20	19.17	0.18	18.87	0.17
2015-02-03	5	185	183.15	0.43	183.16	0.33
2015-02-03	5	55	57.11	0.25	56.51	0.24
2015-02-03	5	115	114.32	0.26	114.21	0.17
2015-02-03	5	40	37.78	0.26	37.48	0.17
2015-02-03	5	165	167.13	0.23	166.60	0.22
2015-02-03	5	150	149.95	0.12	149.36	0.26
2015-02-03	5	95	95.62	0.25	95.30	0.17
2015-02-03	5	0	-0.02	0.16	-0.57	0.28
2015-02-03	6	0	0.06	0.33	-0.43	0.20
2015-02-03	6	35	37.43	0.21	37.28	0.20
2015-02-03	6	95	95.77	0.38	96.11	0.16
2015-02-03	6	165	166.98	0.25	167.35	0.14
2015-02-03	6	20	19.29	0.13	19.06	0.12
2015-02-03	6	55	56.73	0.21	56.57	0.15
2015-02-03	6	75	75.97	0.25	76.24	0.19
2015-02-03	6	115	113.86	0.22	114.05	0.08
2015-02-03	6	130	132.17	0.50	132.27	0.19
2015-02-03	6	150	149.43	0.29	149.43	0.14
2015-02-03	6	180	182.38	0.31	182.55	0.14
2015-02-03	6	0	0.03	0.09	-0.13	0.22

[#]the level is only indicative.

Carbon Monoxide

A CO in air standard (080304_CA06112, 51.02 ppm CO, 1300 psi) prepared by WCC-Empa and calibrated against the WMO-X2000 / X2014 carbon monoxide scale (Novelli et al., 2003) at WCC-Empa has been used in combination with a dilution system. Levels of 0, 50, 100, 150, 200, 300, ..., 1000 ppb were generated with this system. The MFCs (MFC1: Red-y GSC-A3SA-BB21, MFC2: Red-y GSC-B5SA-BB23) of the dilution were calibrated against the MOLBLOC flow reference at Empa, and the results are shown in Figure 10.

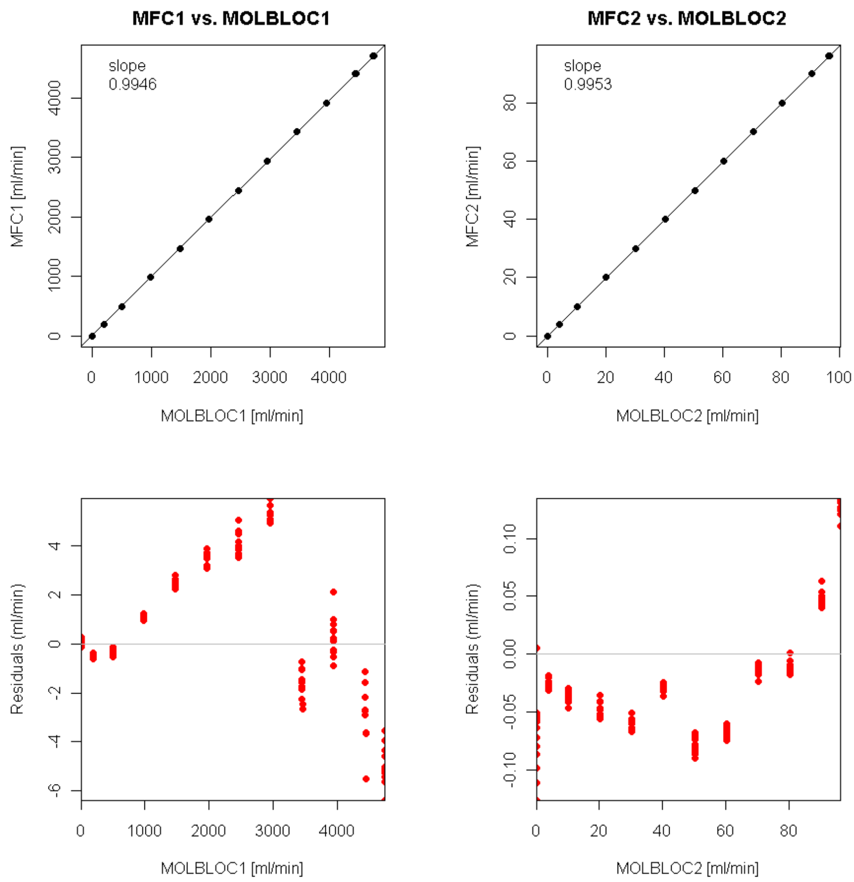

Figure 10. *Calibration of the MFCs against the MOLBLOC flow reference.*

GAW World Calibration Centre WCC-Empa
GAW QA/SAC Switzerland
Empa / Laboratory Air Pollution - Environmental Technology
CH-8600 Dübendorf, Switzerland
mailto:gaw@empa.ch

Ozone Audit Executive Summary

0.1	Station Name:	Mt. Kenya
0.2	GAW ID:	MKN
0.3	Coordinates/Elevation:	0.06220°S 37.29720°E (3678m a.s.l.)
Parameter:		Surface Ozone

1.1	Date of Audit:	2015-01-17
1.2	Auditor:	Christoph Zellweger and Peter Graf
1.3	Station staff involved in audit:	Constance C. Okuku and Charles Kioko
1.4	Ozone Reference [SRP]:	NIST SRP#15
1.5	Ozone Transfer Standard [TS]	
1.5.1	Model and serial number:	TEI 49C-PS #56891-310, BKG -0.3, COEF 1.008
1.5.2	Range of calibration:	0 – 200 ppb
1.5.3	Mean calibration (ppb):	[TS] = (1.0007±0.0006) • [SRP] - (0.13±0.05)
1.6	Ozone Analyser [OA]	
1.6.1	Model:	TEI 49C #0330102716
1.6.2	Range of calibration:	0 – 100 ppb
1.6.3	Coefficients at start of audit	BKG = +0.0; COEF = 1.015
1.6.4	Calibration at start of audit (ppb):	[OA] = (0.9986±0.0002) • [SRP] - (0.86±0.02)
1.6.5	Unbiased ozone mixing ratio (ppb) at start of audit:	X_{O3} (ppb) = ([OA] + 0.18 ppb) / 0.9941
1.6.6	Standard uncertainty remaining after compensation of calibration bias (ppb):	u_{O3} (ppb) = sqrt (0.30 ppb^2 + 2.61e-05 * X_{O3}^2)
1.6.7	Coefficients after audit	NA
1.6.8	Calibration after audit (ppb):	NA
1.6.9	Unbiased ozone mixing ratio (ppb) after audit:	NA
1.6.10	Standard uncertainty remaining after compensation of calibration bias (ppb):	NA
1.7	Comments:	NA
1.8	Reference:	WCC-Empa Report 15/1b

[OA]: Instrument readings; [SRP]: SRP readings; X_{O3}: mixing ratios on SRP scale

GAW World Calibration Centre WCC-Empa
GAW QA/SAC Switzerland
Empa / Laboratory Air Pollution - Environmental Technology
CH-8600 Dübendorf, Switzerland
mailto:gaw@empa.ch

Ozone Audit Executive Summary

0.1	Station Name:	KMD Nairobi
0.2	GAW ID:	
0.3	Coordinates/Elevation:	1.30158°S 36.75973°E (1795 m a.s.l.)
Parameter:		Surface Ozone

1.1	Date of Audit:	2015-01-17
1.2	Auditor:	Christoph Zellweger and Peter Graf
1.3	Station staff involved in audit:	Zablon W. Shilenje
1.4	Ozone Reference [SRP]:	NIST SRP#15
1.5	Ozone Transfer Standard [TS]	
1.5.1	Model and serial number:	TEI 49C-PS #56891-310, BKG -0.3, COEF 1.008
1.5.2	Range of calibration:	0 – 200 ppb
1.5.3	Mean calibration (ppb):	[TS] = (1.0007±0.0006) • [SRP] - (0.13±0.05)
1.6	Ozone Calibrator [OC]	
1.6.1	Model:	TEI 49i-PS #1127049769
1.6.2	Range of calibration:	0 – 100 ppb
1.6.3	Coefficients at start of audit	BKG = +0.0; COEF = 1.014
1.6.4	Calibration at start of audit (ppb):	[OC] = (0. 9923±0.0003) • [SRP] - (0.03±0.04)
1.6.5	Unbiased ozone mixing ratio (ppb) at start of audit:	X_{O3} (ppb) = ([OC] + 0.03 ppb) / 0.9923
1.6.6	Standard uncertainty remaining after compensation of calibration bias (ppb):	u_{O3} (ppb) = sqrt (0.29 ppb^2 + 2.58e-05 * X_{O3}^2)
1.6.7	Coefficients after audit	NA
1.6.8	Calibration after audit (ppb):	NA
1.6.9	Unbiased ozone mixing ratio (ppb) after audit:	NA
1.6.10	Standard uncertainty remaining after compensation of calibration bias (ppb):	NA
1.7	Comments:	NA
1.8	Reference:	WCC-Empa Report 15/1b

[OC]: Instrument readings; [SRP]: SRP readings; X_{O3}: mixing ratios on SRP scale

GAW World Calibration Centre WCC-Empa
GAW QA/SAC Switzerland
Empa / Laboratory Air Pollution - Environmental Technology
CH-8600 Dübendorf, Switzerland
mailto:gaw@empa.ch

Ozone Audit Executive Summary

0.1	Station Name:	KMD Nairobi
0.2	GAW ID:	
0.3	Coordinates/Elevation:	1.30158°S 36.75973°E (1795 m a.s.l.)
Parameter:		Surface Ozone

1.1	Date of Audit:	2015-01-17
1.2	Auditor:	Christoph Zellweger and Peter Graf
1.3	Station staff involved in audit:	Zablon W. Shilenje
1.4	Ozone Reference [SRP]:	NIST SRP#15
1.5	Ozone Transfer Standard [TS]	
1.5.1	Model and serial number:	TEI 49C-PS #56891-310, BKG -0.3, COEF 1.008
1.5.2	Range of calibration:	0 – 200 ppb
1.5.3	Mean calibration (ppb):	[TS] = (1.0007±0.0006) • [SRP] - (0.13±0.05)
1.6	Ozone Calibrator [OA]	
1.6.1	Model:	TEI 49i #1122849256
1.6.2	Range of calibration:	0 – 100 ppb
1.6.3	Coefficients at start of audit	BKG = -0.1; COEF = 1.016
1.6.4	Calibration at start of audit (ppb):	[OA] = (0. 9861±0.0014) • [SRP] - (0.21±0.06)
1.6.5	Unbiased ozone mixing ratio (ppb) at start of audit:	X_{O3} (ppb) = ([OA] + 0.21 ppb) / 0.9861
1.6.6	Standard uncertainty remaining after compensation of calibration bias (ppb):	u_{O3} (ppb) = sqrt (0.29 ppb^2 + 2.58e-05 * X_{O3}^2)
1.6.7	Coefficients after audit	NA
1.6.8	Calibration after audit (ppb):	NA
1.6.9	Unbiased ozone mixing ratio (ppb) after audit:	NA
1.6.10	Standard uncertainty remaining after compensation of calibration bias (ppb):	NA
1.7	Comments:	NA
1.8	Reference:	WCC-Empa Report 15/1b

[OA]: Instrument readings; [SRP]: SRP readings; X_{O3}: mixing ratios on SRP scale

GAW World Calibration Centre WCC-Empa
GAW QA/SAC Switzerland
Empa / Laboratory Air Pollution - Environmental Technology
CH-8600 Dübendorf, Switzerland
mailto:gaw@empa.ch

Carbon Monoxide Audit Executive Summary

0.1	Station Name:	Mt. Kenya
0.2	GAW ID:	MKN
0.3	Coordinates/Elevation:	0.06220°S 37.29720°E (3678 m a.s.l.)
Parameter:		Carbon Monoxide

1.1	Date of Audit:	2015-01-19/20
1.2	Auditor:	Christoph Zellweger and Peter Graf
1.3	Station staff involved in audit:	Constance C. Okuku and Charles Kioko
1.4	WCC-Empa CO Reference:	NOAA laboratory standards (WMO-X2014 scale)
1.5	CO Transfer Standard [TS]	080304_CA06112, 51.02 ppm CO, 1300 psi calibrated against the WCC-Empa laboratory standards, WMO-X2014 scale, dilution unit.
1.6	Station Analyser:	
1.6.1	Analyser Model:	Horiba APMA360 #890617035
1.6.2	Range of calibration:	0 – 1000 ppb
1.6.3	Coefficients at start of audit	Zero -8, SPAN 1. 0300
1.6.4	Calibration at start of audit (ppb):	CO = (0.9382±0.0135) • X_{CO} - (2.8±7.3)
1.6.5	Unbiased CO mixing ratio (ppb) at start of audit:	X_{CO} (ppb) = (CO + 2.8 / 0.9382
1.6.6	Standard uncertainty after compensation of calibration bias at start of audit (ppb):	u_{CO} (ppb) = sqrt (335.0 ppb^2 + 1.01e-04 * X_{CO}^2)
1.6.7	Coefficients after audit	Zero -16, SPAN 1. 0900
1.6.8	Calibration after audit (ppb):	CO = (0.9838±0.0147) • X_{CO} - (36.2±8.0)
1.6.9	Unbiased CO mixing ratio (ppb) after audit:	X_{CO} (ppb) = (CO + 36.28 / 0.9838
1.6.10	Standard uncertainty after compensation of calibration bias after audit(ppb):	u_{CO} (ppb) = sqrt (375.3 ppb^2 + 1.01e-04 * X_{CO}^2)
1.7	Comments:	NA
1.8	Reference:	WCC-Empa Report 15/1b

[CO]: Instrument readings; X: mixing ratios on the WMO-X2014 CO scale.

GAW World Calibration Centre WCC-Empa
GAW QA/SAC Switzerland
Empa / Laboratory Air Pollution - Environmental Technology
CH-8600 Dübendorf, Switzerland
mailto:gaw@empa.ch

Methane Audit Executive Summary (MKN)

0.1	Station Name:	Mt. Kenya
0.2	GAW ID:	MKN
0.3	Coordinates/Elevation:	0.06220°S 37.29720°E (3678 m a.s.l.)
Parameter:		Methane

1.1	Date of Audit:	2015-09-07
1.2	Auditor:	Christoph Zellweger
1.3	Staff involved in audit:	None (see 1.7)
1.4	WCC-Empa CH_4 Reference:	NOAA laboratory standards (WMO-X2004A scale)
1.5	CH_4 Transfer Standard [TS]	TS calibrated against the WCC-Empa laboratory standards
1.6	Station Analyser:	
1.6.1	Analyser Model:	PICARRO G1301 #334-CFADS080
1.6.2	Range of calibration:	0 – 2624 ppb
1.6.3	Coefficients at start of audit	NA
1.6.4	Calibration at start of audit (ppb):	CH_4 = (0. 99999±0.00010) • X_{CH4} + (0.42±0.20) ppb
1.6.5	Unbiased CH_4 mixing ratio (ppb) at start of audit:	X_{CH4} (ppb) = (CH_4 -0.42 ppb) / 0.99999
1.6.6	Standard uncertainty after compensation of calibration bias at start of audit (ppb):	u_{CH4} (ppb) = sqrt (0.3 ppb^2 + 1.30e-07 * X_{CH4}^2)
1.6.7	Coefficients after audit	NA
1.6.8	Calibration after audit (ppb):	NA
1.6.9	Unbiased CH_4 mixing ratio (ppb) after audit:	NA
1.6.10	Standard uncertainty after compensation of calibration bias after audit(ppb):	NA
1.7	Comments:	NA
1.8	Reference:	WCC-Empa Report 15/1b

[CH_4]: Instrument readings; X: mixing ratios on the WMO-X2004A CH_4 scale.

GAW World Calibration Centre WCC-Empa
GAW QA/SAC Switzerland
Empa / Laboratory Air Pollution - Environmental Technology
CH-8600 Dübendorf, Switzerland
mailto:gaw@empa.ch

Carbon Dioxide Audit Executive Summary (MKN)

0.1	Station Name:	Mt. Kenya
0.2	GAW ID:	MKN
0.3	Coordinates/Elevation:	0.06220°S 37.29720°E (3678m a.s.l.)
Parameter:		Carbon Dioxide

1.1	Date of Audit:	2015-09-07
1.2	Auditor:	Christoph Zellweger
1.3	Staff involved in audit:	None (see 1.7)
1.4	WCC-Empa CO_2 Reference:	NOAA laboratory standards (WMO-X2007 scale)
1.5	CO_2 Transfer Standard [TS]	TS calibrated against the WCC-Empa laboratory standards
1.6	Station Analyser:	
1.6.1	Analyser Model:	PICARRO G1301 #334-CFADS080
1.6.2	Range of calibration:	0 – 449 ppm
1.6.3	Coefficients at start of audit	NA
1.6.4	Calibration at start of audit (ppm):	CO_2 = (0. 99987±0.00004) • X_{CO2} +(0.08±0.02) ppm
1.6.5	Unbiased CO_2 mixing ratio (ppm) at start of audit:	X_{CO2} (ppm) = (CO_2 - 0.08 ppm) / 0.99987
1.6.6	Standard uncertainty after compensation of calibration bias at start of audit (ppm):	u_{CO2} (ppm) = sqrt (0.002 ppm^2 + 3.28e-08 * X_{CO2}^2)
1.6.7	Coefficients after audit	NA
1.6.8	Calibration after audit (ppm):	NA
1.6.9	Unbiased CO_2 mixing ratio (ppm) after audit:	NA
1.6.10	Standard uncertainty after compensation of calibration bias after audit(ppm):	NA
1.7	Comments:	NA
1.8	Reference:	WCC-Empa Report 15/1b

[CO_2]: Instrument readings; X: mixing ratios on the WMO-X2007 CO_2 scale.

REFERENCES

Herzog, A., Buchmann, B., and Hofer, P.: System Audit of Surface Ozone Measurements GAW Global Station Mt. Kenya including Ozone Sounding, Nairobi, Kenya, WCC-Empa Report 00/1, Empa, Dübendorf, Switzerland, 25 pp., 2000.

Klausen, J., Henne, S., Zellweger, C., and Buchmann, B.: System and Performance Audit of Surface Ozone and Carbon Monoxide at the Global GAW Station Mt. Kenya, January 2006, Empa-WCC Report 06/1, Dübendorf, Switzerland, 39 pp., 2006.

Klausen, J., Zellweger, C., Buchmann, B., and Hofer, P.: Uncertainty and bias of surface ozone measurements at selected Global Atmosphere Watch sites, Journal of Geophysical Research-Atmospheres, 108, 4622, doi:4610.1029/2003JD003710, 2003.

Rella, C. W., Chen, H., Andrews, A. E., Filges, A., Gerbig, C., Hatakka, J., Karion, A., Miles, N. L., Richardson, S. J., Steinbacher, M., Sweeney, C., Wastine, B., and Zellweger, C.: High accuracy measurements of dry mole fractions of carbon dioxide and methane in humid air, Atmos. Meas. Tech., 6, 837-860, 2013.

WMO: 17th WMO/IAEA Meeting on Carbon Dioxide, Other Greenhouse Gases and Related Tracers Measurement Techniques (GGMT-2013), Beijing, China, 10-13 June 2013, GAW Report No. 213, World Meteorological Organization, Geneva, Switzerland, 2014.

WMO: Guidelines for Continuous Measurements of Ozone in the Troposphere, WMO TD No. 1110, GAW Report No. 209, World Meteorological Organization, Geneva, Switzerland, 2013.

WMO: Standard Operating Procedure (SOP) for System and Performance Audits of Trace Gas Measurements at WMO/GAW Sites, Version 1.5-20071212, World Meteorological Organization, Scientific Advisory Group Reactive Gases, Geneva, Switzerland, 2007a.

WMO: WMO Global Atmosphere Watch (GAW) Strategic Plan: 2008 – 2015, GAW Report #172, World Meteorological Organization, Geneva, Switzerland, 2007b.

Zellweger, C., Buchmann, B., Klausen, J., and Hofer, P.: System and Performance Audit of Surface Ozone, Global GAW Station Mt. Kenya, February 2000, Empa-WCC Report 02/1, Dübendorf, Switzerland, 39 pp., 2002.

Zellweger, C., Klausen, J., and Buchmann, B.: System and Performance Audit of Surface Ozone and Carbon Monoxide at the Global GAW Station Mt. Kenya, February 2005, WCC-Empa Report 05/1, Dübendorf, Switzerland, 39 pp., 2005.

Zellweger, C., Klausen, J., and Buchmann, B.: System and Performance Audit of Surface Ozone and Carbon Monoxide at the Global GAW Station Mt. Kenya, Kenya, November 2008, WCC-Empa Report 08/5, Dübendorf, Switzerland, 35 pp., 2008.

Zellweger, C., Klausen, J., Steinbacher, M., and Buchmann, B.: System and Performance Audit of Surface Ozone and Carbon Monoxide at the Global GAW Station Mt. Kenya, Kenya, June 2010, WCC-Empa Report 10/4, Dübendorf, Switzerland, 41 pp., 2010.

LIST OF ABBREVIATIONS

AIRCOA	Autonomous Inexpensive, Robust, CO_2 Analyzer)
BKG	Background
COEF	Coefficient
CRDS	Cavity Ring-Down Spectroscopy
DQO	Data Quality Objective
ESRL	Earth System and Research Laboratory
GAW	Global Atmosphere Watch
GAWSIS	GAW Station Information System
GAWTEC	GAW Training and Education Centre
GHG	Greenhouse Gases
KMD	Kenya Meteorological Department
LS	Laboratory Standard
MKN	Mt. Kenya GAW Station
NA	Not Applicable
NCAR	National Center for Atmospheric Research
NOAA	National Oceanic and Atmospheric Administration
NDIR	Non-Dispersive Infrared
SOP	Standard Operating Procedure
TI	Travelling Instrument
TS	Traveling Standard
WCC-Empa	World Calibration Centre Empa
WDCGG	World Data Centre for Greenhouse Gases
WMO	World Meteorological Organization