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SYSTEM AND PERFORMANCE AUDIT OF SURFACE OZONE, METHANE, CARBON DIOXIDE AND CARBON MONOXIDE AT THE GLOBAL GAW STATION BUKIT KOTOTABANG INDONESIA, NOVEMBER 2011

Submitted by

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EXECUTIVE SUMMARY AND RECOMMENDATIONS

The sixth system and performance audit at the Global GAW station Bukit Kototabang was conducted by WCC-Empa[1] from 1 thru 8 November 2011 in agreement with the WMO/GAW quality assurance system [*WMO*, 2007a]. The Bukit Kototabang (BKT) GAW station is coordinated by the Meteorological, Climatological and Geophysical Agency (BMKG).

Previous audits at the Bukit Kototabang GAW observatory were conducted in July 1999 [Herzog, et al., 1999], in July 2001 [Zellweger, et al., 2001], in March 2004 [Zellweger, et al., 2004], in February 2007 [Zellweger, et al., 2007], and in July 2008 [*Zellweger et al.*, 2008].

The following people contributed to the audit:

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This report summarises the assessment of the Bukit Kototabang GAW station in general, as well as the surface ozone, methane, carbon dioxide and carbon monoxide measurements in particular. The assessment criteria for the ozone comparison were developed by WCC-Empa and QA/SAC Switzerland [*Hofer et al.*, 2000; *Klausen et al.*, 2003].

The report is distributed to the BMKG Jakarta, BMKG Bukit Kototabang, the World Calibration Centre for Methane at the Japanese Meteorological Agency (JMA) 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, serious and critical and are complemented with a priority (*** indicating highest priority) and a suggested completion date.

Station Location and Access

The Bukit Kototabang GAW Station is located on Sumatra, Indonesia, and is roughly 17 km north of the town Bukittinggi. The station is situated in the equatorial zone on the ridge of a high plateau at an altitude of 864.5 m a.s.l., and 40 km off the western coastline. The station is reached over a small paved access road which is closed to the public. However, this small access road to the station enabled farmers to develop the area, and agricultural activities (mainly banana and cassava plantations) increased since the last audit by WCC-Empa. Access to the site is possible by road throughout the year. The station location is adequate for the intended purpose. Research facilities and offices of the National Institute of Aeronautics and Space (LAPAN) are located about 200m southeast of the GAW station. The GAW Station and LAPAN share the same access road.

[1]WMO/GAW World Calibration Centre for Surface Ozone, Carbon Monoxide and Methane. 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.

Station Facilities

The facilities at the site consist of a large one-story building, which provides sufficient space for offices, meeting room and laboratories. The building was renovated since the last audit. Following a recommendation of the last WCC-Empa audit report, an internet connection independent from LAPAN was established; however, this connection was unreliable throughout the audit period, and the bandwidth was low. The power supply to the station is relatively unreliable; in case of a power outage, the UPS unit is able to bridge power for a few minutes, and normally, the large diesel generator located at the junction to the main road (approx. 2 km from the station) starts within this time. However, it was noticed that power outages occurred approx. 10 times per months in 2011.

Recommendation 1 (*, serious, 2012)**
The number of power outages should be reduced; in principle, the system with the UPS unit bridging the period to the start of the generator is suitable, but it needs to be ensured that the diesel generator is working properly (maintenance, re-fuelling) and that the UPS has enough capacity.

Station Management and Operation

Bukit Kototabang is visited during weekdays by approximately 8-10 scientists, technical and administrational staff. During weekends, one to three operators are present during working hours. The operation of the station and the measurements improved significantly since the last audit; however, it is important that staff with a scientific background is directly involved with the daily operation of the BKT station. In addition, funding issues as well as complicated bureaucracy (import/export of goods) jeopardize the very valuable time series of BKT.

Recommendation 2 (*, minor, ongoing)**
BMKG should continue to explore all possibilities for operator training. Participation in GAWTEC courses and other means of continuing education is important and strongly encouraged, and the knowledge needs to be shared between all station staff.

Recommendation 3 (*, serious, ongoing)**
Funding is needed to sustain the valuable time series of BKT. For each instrument, funds must be available for maintenance, repair, consumables as well as calibration gases. Funding should be planned ahead, and should include amortization of the equipment considering a typical instrument lifetime of ten years. Part of the ongoing funding should be flexible, since it is very difficult to predict the actual need for replacement parts and instrument repair.

Air Inlet Systems

In 2010, a common air inlet system for surface O_3, CO, NO_x and SO_2 was installed. The design of this air inlet system is fully adequate and should minimise potential condensation of water vapour in the lines leading to the instruments, since the common sampling manifold is located below the analysers and is equipped with a water collection container. It was recognised during previous WCC-Empa audits that approx. 1-% ozone is lost in the additional drying system. The current measurements confirmed a loss in the inlet system, and it was found to be larger (approx. 2%) compared to previous audits. This can be explained by the fact that currently only one instrument is connected, which doubles the residence time in the water trap. It should be considered to remove the water trap because condensation should no longer be an issue with the current air inlet set-up. The sample air passes a drying cartridge filled with Silicagel prior to SO_2 analysis. A heatless dryer with two cylinders filled with Silicagel that are self-regenerated in a cyclic mode is installed upstream of the NO-NO_x analyser. The use of Silicagel was considered to be suboptimal due to potential losses on the desiccant. Tests at Empa with a similar setup following the audit showed significant losses, particularly for SO_2 and NO_2. Action was taken after the audit by BMKG staff to improve the situation.

The Picarro CH_4/CO_2 system is using direct Eaton Synflex 1300 sampling lines to three different levels of the tower (10m, 20m and 32m). The lines have all the same tubing length and are continuously flushed to avoid a potential time shift of the sampling. This inlet is fully adequate for the CH_4/CO_2 measurements.

Surface Ozone Measurements

The surface ozone measurements at Bukit Kototabang were established in 1996, and continuous time series are available since then except for the period between August 1999 and July 2001 are available since then.

Instrumentation. Currently the station is equipped with a TEI 49C ozone analyser. The instrumentation is fully adequate for its intended purpose.

Standards. The station is equipped with an ozone standard (TEI49i-PS) which was purchased in 2009 and replaced the TEI 49-PS calibrator following a recommendation of the last WCC-Empa audit report. With this instrumentation, adequate ozone calibrations are possible. Calibrations are performed every 3 months. However, settings of the ozone analyser are not changed according to the calibrations.

Intercomparison (Performance Audit). The ozone analyser as well as the ozone calibrator of Bukit Kototabang were compared against the WCC-Empa travelling standard with traceability to a Standard Reference Photometer (SRP). The results of the comparisons are summarised below. The data acquired by the WCC-Empa data acquisition system was used for data evaluation, and no further corrections were applied. The following equations characterise the bias of the different instruments in their current states:

TEI 49C #58547-318 (BKG 0.1 ppb, SPAN 1.014) – main analyser:

Unbiased O_3 mixing ratio (ppb): X_{O3} (ppb) = ([OA] + 0.0 ppb) / 1.0022 (1a)

Standard uncertainty (ppb): u_{O3} (ppb) = sqrt (0.3 ppb^2 + 2.65e-05 * X_{O3}^2) (1b)

TEI 49i-PS #0917736398 (BKG 0.0 ppb, SPAN 1.012) – station calibrator:

Unbiased O_3 mixing ratio (ppb): X_{O3} (ppb) = ([OC] + 0.6 ppb) / 0.9825 (1c)

Standard uncertainty (ppb): u_{O3} (ppb) = sqrt (0.3 ppb^2 + 2.71e-05 * X_{O3}^2) (1d)

The results of the comparisons are further presented in the following Figures.

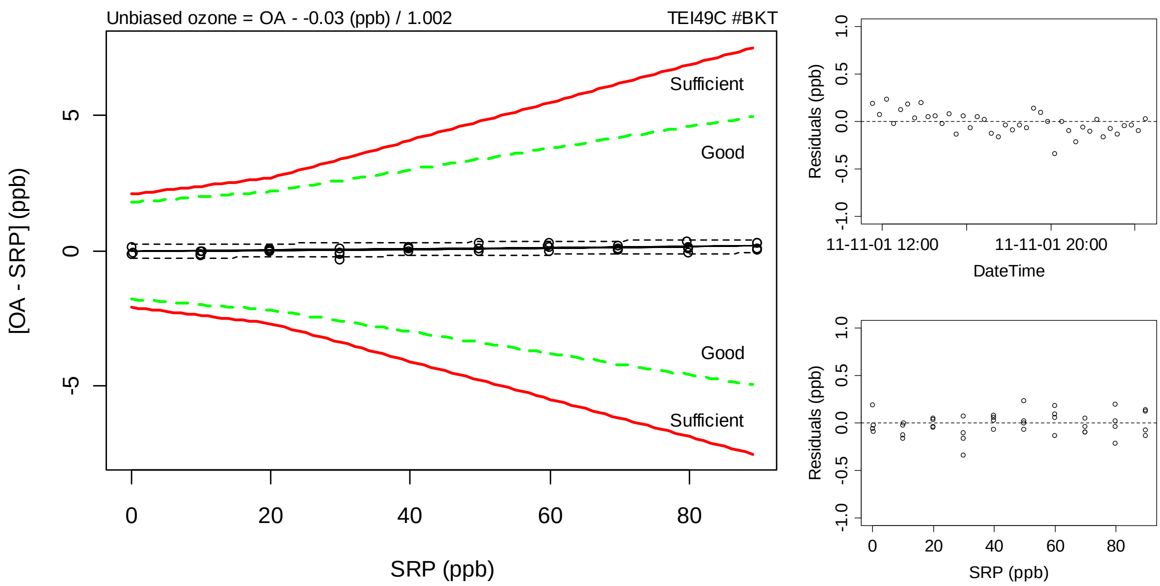

Figure 1. Left: Bias of the BKT ozone analyser (TEI 49C #58547-318) with respect to the SRP as a function of mole fraction. Each point represents the average of the last 10 one-minute values at a given level. Areas defining 'good' and 'sufficient' agreement according to GAW assessment criteria are delimited by green and red lines. 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).

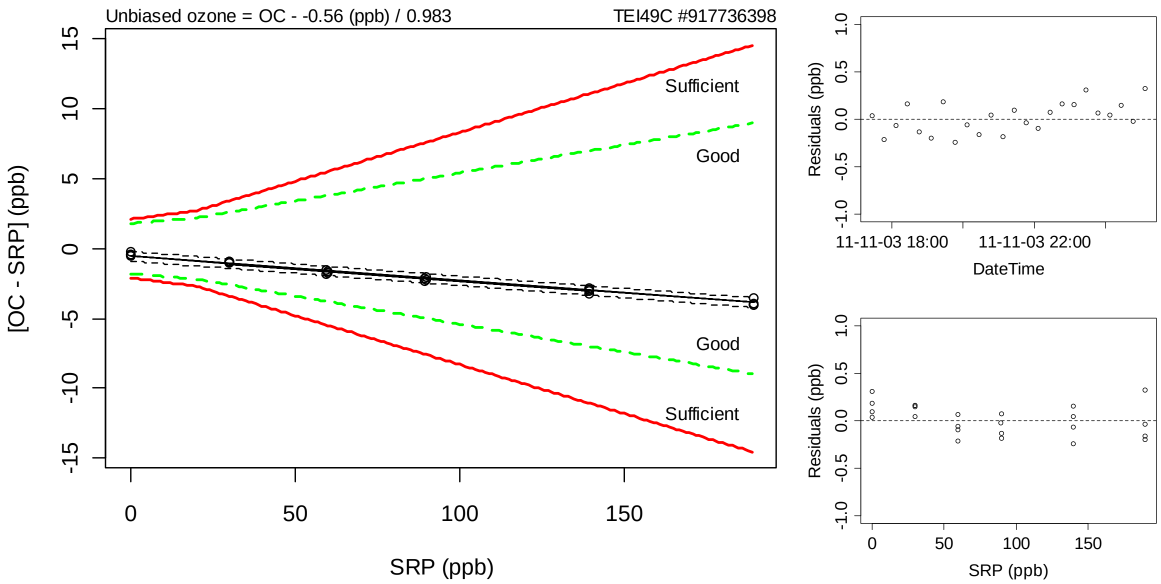

Figure 2. Same as Figure 1, for TEI 49i-PS #0917736398 station calibrator.

Carbon Monoxide Measurements

Continuous measurements of CO at BKT started in July 2001, and data is available since then. No changes were made concerning the measurement setup since the last audit by WCC-Empa in 2008.

Instrumentation. A refurbished Horiba APMA 360 was installed at BKT in 2007. The original TEI 48C-TL was decommissioned after the audit in 2008. The instrumentation is adequate for the intended purpose; however, the analyser is reaching the end of its expected lifetime, and replacement should be initiated early enough to ensure overlapping measurement time between instruments.

> **Recommendation 4 (**, serious, 2012-13)**
> *Due to the age of the CO analyser, replacement is needed within the next few years.*

Standards. Initially when CO measurements were established, the station was equipped with two carbon monoxide standards. One standard had a mole fraction of approx. 1 ppm CO in air and was used for direct calibrations of the instrument. The other standard had a mole fraction of approx. 50 ppm CO in air and was used for automatic span checks after dilution with zero air. During the audit, only the high CO standard was available since the 1 ppm standard was used up in 2009. WCC-Empa provided a replacement of the high standard, as well as three tanks with CO mole fractions between 477 and 1175 ppb CO in air for direct instrument calibrations/checks. However, these three standards are mainly for the use of automatic span checks of the Picarro CO_2/CH_4 system and should only periodically used for manual checks of the Horiba instrument due to the large gas consumption (e.g. every 3 months). With this equipment, adequate calibration of the carbon monoxide measurements is possible. However, all standards have been delivered to the station by WCC-Empa, and no local calibration gas supplier is available. Regular zero and span (at approx. 425 ppb) checks are performed every 4 hours.

> **Recommendation 5 (***, critical, 2012)**
> *As recommended after previous WCC-Empa audits, funds are needed for the purchase of calibration gases and working standards to ensure the long term operation of the BKT station. BMKG must not rely on delivery of calibration gases by WCC-Empa. This recommendation is valid for all measurement parameters.*
>
> **Recommendation 6 (***, serious, 2012)**
> *Alternatives to the use of expensive calibration gases for regular checks should be explored. It is recommended to purchase e.g. pressurised air from a local supplier, and perform tests concerning the suitability of such a gas for automatic or manual checks (also for the Picarro system). It could also be explored if empty tanks could be re-filled with air (e.g. by a dive shop).*
>
> **Recommendation 7 (***, minor, ongoing)**
> *If re-filling of empty Scott Marrin tanks (with a valid DOT) is not possible, these cylinders should be returned to Empa for re-filling.*

Intercomparison (Performance Audit).

In addition the present audit, a comparison was performed during a visit of QA/SAC Switzerland (Jörg Klausen) in October 2009; this data has not yet been published and is therefore presented here. The comparison involved repeated challenges of the BKT instrument with randomised carbon monoxide levels generated by dilution of a standard with high CO mole fraction (090325_CA06494 44.86 ppm CO in air) with zero air. The average zero reading during the comparisons were used for the zero correction of the comparison data. After the first comparison, the instrument calibration settings were adjusted, and the comparison was repeated. The following equations characterise the instrument bias, and the results are further illustrated in Figure 3 and Figure 4 with respect to the WMO GAW Data Quality Objectives (DQOs) [WMO, 2010; 2011]:

Horiba APMA360 #890617034 (Before adjustment: Zero -1, SPAN 1.0338):

Unbiased CO mixing ratio: X_{CO} (ppb) = (CO – 0.2) / 0.8982 (2a)

Remaining standard uncertainty: u_{CO} (ppb) = sqrt (3.4 ppb^2 + 1.01e-04 * X_{CO}^2) (2b)

Horiba APMA360 #890617034 (After adjustment: Zero -1, SPAN 1. 1035):

Unbiased CO mixing ratio: X_{CO} (ppb) = (CO + 0.2) / 0.9891 (2c)

Remaining standard uncertainty: u_{CO} (ppb) = sqrt (5.8 ppb^2 + 1.01e-04 * X_{CO}^2) (2d)

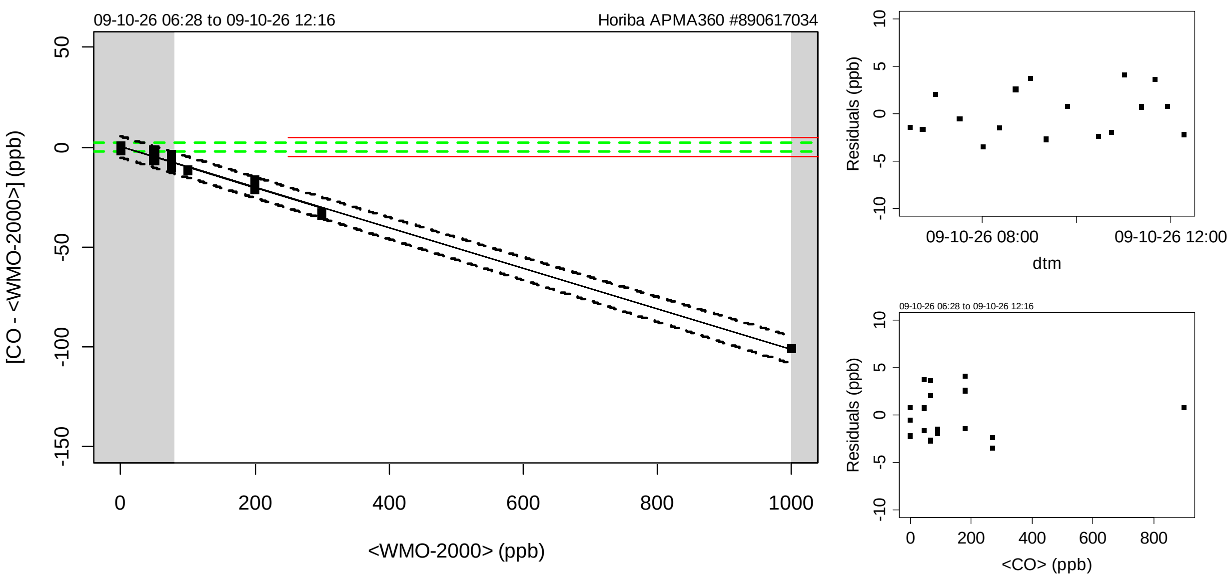

Figure 3. CO comparison performed by QA/SAC Switzerland in 2009, before adjustments of the instrument calibration settings. Left: Bias of Bukit Kototabang Horiba APMA360 carbon monoxide instrument with respect to the WMO2000 reference scale as a function of mole fraction using 090325_CA06494 as the reference gas. The white area represents the mole fraction range relevant for BKT, whereas the green lines correspond to the DQOs. Each point represents the average of data at a given level from a specific run. The dashed lines around the regression lines are the Working-Hotelling 95% confidence bands. Right: Regression residuals (time dependence and mole fraction dependence).

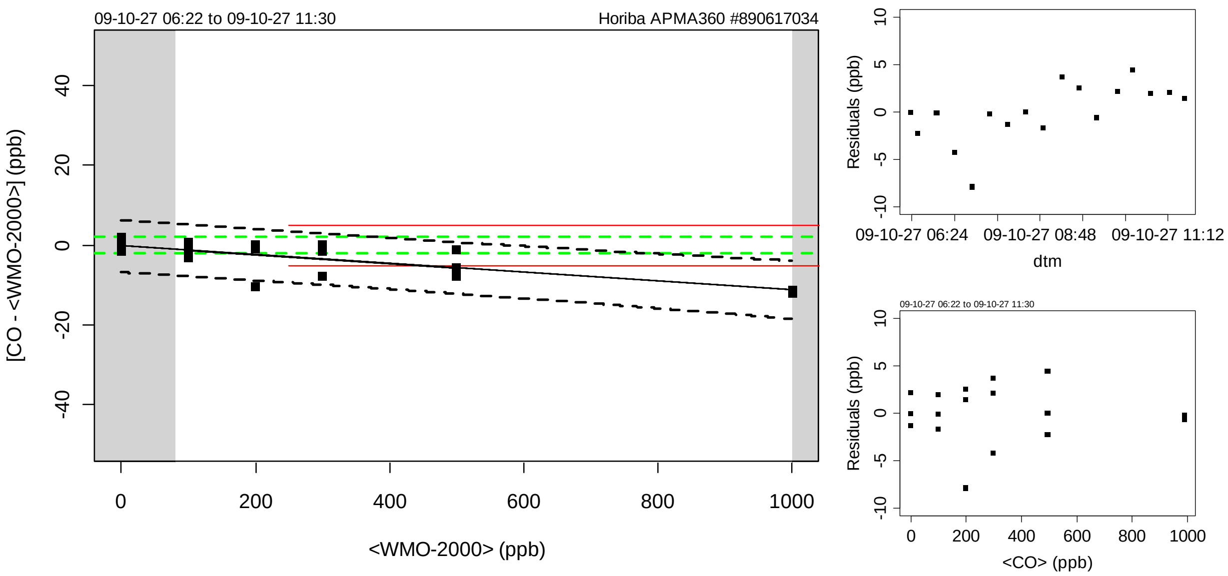

Figure 4. Same as above after adjustments of the calibration settings.

During the current audit, three different comparisons were made with the Horiba APMA360 analyser of BKT. The first comparison was made using a dilution system with the existing CO standard that was used for automatic checks since 2009 (090325_CA06494 44.86 ppm CO in air), the second using a new CO standard provided by WCC-Empa (110818_CB08874 29.70 ppm CO in air), and the third using travelling standards provided by WCC-Empa. The comparison involved repeated challenges of the BKT instrument with randomised carbon monoxide levels from these traveling standards. The following equations characterise the instrument bias, and the results are further illustrated in Figure 5 to Figure 7 with respect to the WMO GAW Data Quality Objectives (DQOs) [WMO, 2010; 2011]:

Horiba APMA360 #890617034 (Zero -1, SPAN 1.1035):

1st comparison using dilution system and 090325_CA06494 44.86 ppm CO in air

Unbiased CO mixing ratio: X_{CO} (ppb) = (CO – 4.5) / 0.9092 (2e)

Remaining standard uncertainty: u_{CO} (ppb) = sqrt (4.2 ppb^2 + 1.01e-04 * $X_{CO}{}^2$) (2f)

2nd comparison using dilution system and 110818_CB08874 29.70 ppm CO in air

Unbiased CO mixing ratio: X_{CO} (ppb) = (CO – 4.0) / 0.9019 (2g)

Remaining standard uncertainty: u_{CO} (ppb) = sqrt 6.2 ppb^2 + 1.01e-04 * $X_{CO}{}^2$) (2h)

3rd comparison using WCC-Empa travelling standards

Unbiased CO mixing ratio: X_{CO} (ppb) = (CO + 1.2) / 0.9093 (2i)

Remaining standard uncertainty: u_{CO} (ppb) = sqrt (9.3 ppb^2 + 1.01e-04 * $X_{CO}{}^2$) (2k)

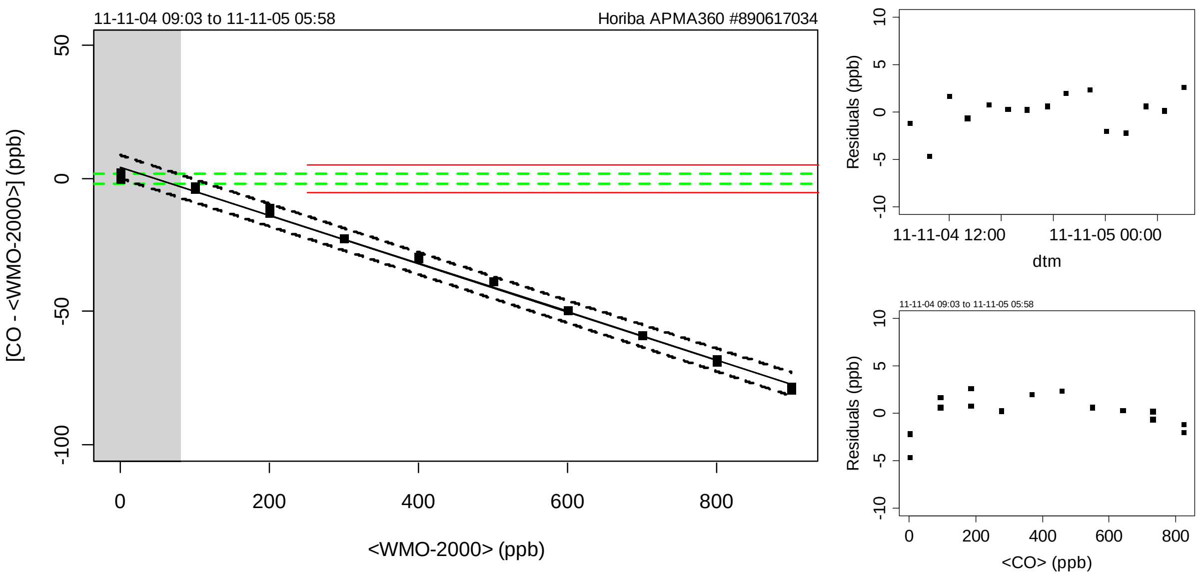

Figure 5. CO comparison performed by WCC-Empa in 2011. Left: Bias of Bukit Kototabang Horiba APMA360 carbon monoxide instrument with respect to the WMO2000 reference scale as a function of mole fraction by dilution with zero air using 090325_CA06494 as the reference gas. The white area represents the mole fraction range relevant for BKT, whereas the green lines correspond to the DQOs. Each point represents the average of data at a given level from a specific run. The dashed lines around the regression lines are the Working-Hotelling 95% confidence bands. Right: Regression residuals (time dependence and mole fraction dependence).

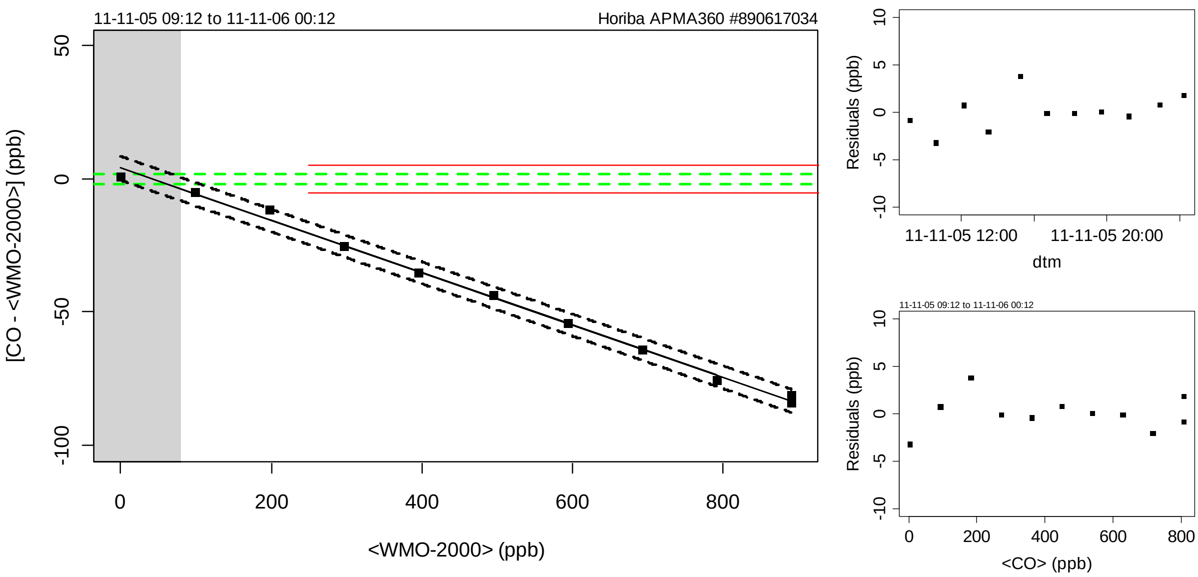

Figure 6. Same as above with 110818_CB08874 as the reference gas.

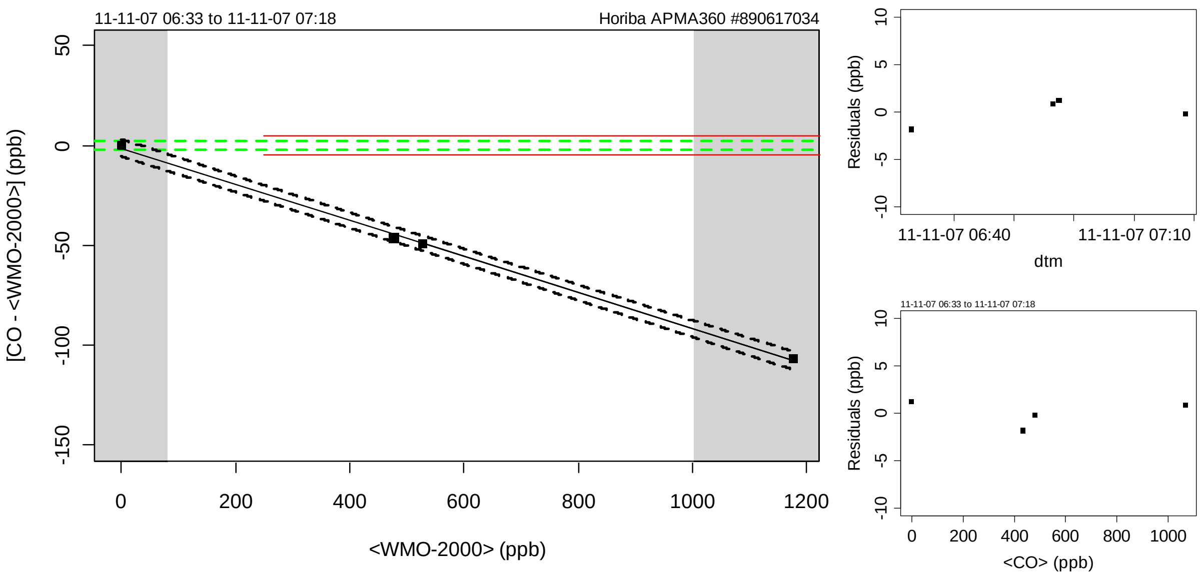

Figure 7. Same as above with using WCC-Empa travelling standards as reference.

The results of the comparisons made in 2011 showed a very consistent bias of the BKT Horiba APMA360 of 8.2 – 9.3%. However, this indicates a drift since the comparison made by QA/SAC Switzerland in 2009 with the same instrument settings, where a bias of 1.1% was found. Before this, the instrument calibration settings were unchanged since the installation in 2007, and a drift was also observed based on the audits by WCC-Empa in 2008 (bias 6.6%) and by QA/SAC Switzerland (bias 10.3%). Based on these results, a loss of sensitivity of 0.008% per day was observed between 2008 and 2009, and 0.010% per day between 2009 and 2011. This indicates that the instrument is drifting over time, and that the drift is becoming larger over time. In principle, the drift should also be visible in the automatic span checks; however, these results indicate only a very small drift over time. The reason for this has to be explored, and these results should be considered for the final data validation of the BKT CO series measured with the Horiba APMA360 instrument. It is therefore important that both automatic and manual span checks are regularly performed. In addition, direct measurements of span gases should be made at least every three months.

Methane and Carbon Dioxide Measurements

Continuous measurements of CH_4 and CO_2 at BKT started in 2009 using a Picarro G1301 CRDS analyser. The instrument was purchased by BMKG, and the peripherals (NOAA standards, valve box, inlet lines) were provided by QA/SAC Switzerland with financial support of MeteoSwiss.

Instrumentation. A Picarro G1301 CO_2, CH_4 and H_2O analyser is available at BKT. Ambient air is sampled from the tower at three different levels (10, 20, 32 m) and dried by a Nafion dryer prior to analysis.

Standards. At the time of the audit, three NOAA/ESRL laboratory standards were available for calibrations. These standards have been used for regular calibrations, and consequently, a large amount of the gas was already consumed at the time of the audit. The pressure in the remaining three standards was between 200 and 790 psi (initial filling pressure is approx. 1900 psi), and one standard was already empty. WCC-Empa recommends the purchase of one NOAA standard (CO, CO2, CH4) per year to ensuring continuity of the measurements. During the present audit, WCC-Empa provided three additional working standards which should be used for regular checks/calibrations of the instrument. Calibrations with three NOAA tanks are performed every 47 hours. One of the NOAA tanks is measured every 11 hours. During the audit, the calibration frequency was reduced to the following sequence:

14 h Air – 20 min S1 – 20 min S2 – 20 min S3 – 30h Air – 20 min S1 – 30h Air – 20 min S2 – 30h Air – 20 min S3 – 14 h Air

Air = (20 min 10m Inlet - 20min 20m Inlet - 80min 32m Inlet); S1-S3 = Standards 1-3

In addition, the sampling sequence was modified that sampling is predominantly (80 min of 120 min) made from the 32 m level while the lower levels are sampled for 20 min each.

Intercomparison (Performance Audit). The comparison involved repeated challenges of the BKT instrument with randomised carbon dioxide and methane levels from traveling standards. The results of the comparison measurements for the individual measurement parameters are summarised and illustrated below.

The following equations (3a-b for CH_4 and 4a-b for CO_2) characterise the instrument bias. The results are further illustrated in for CH_4 in Figure 8 and for CO_2 in Figure 9 with respect to the relevant mole fraction range (white area) and the WMO/GAW DQOs (red and green lines) [*WMO*, 2009; 2011].

Picarro G1301 #CFADS-027:

Unbiased CH_4 mixing ratio:	X_{CH4} (ppb) = (CH_4 + 0.63) / 1.00003	(3a)
Remaining standard uncertainty:	u_{CH4} (ppb) = sqrt (0.11 ppb^2 + 1.30e-07 * X_{CH4}^2)	(3b)
Unbiased CO_2 mixing ratio:	X_{CO2} (ppm) = (CO_2 – 2.82) / 0.99285	(4a)
Remaining standard uncertainty:	u_{CO2} (ppm) = sqrt (0.00 ppm^2 + 3.28e-08 * X_{CO2}^2)	(4b)

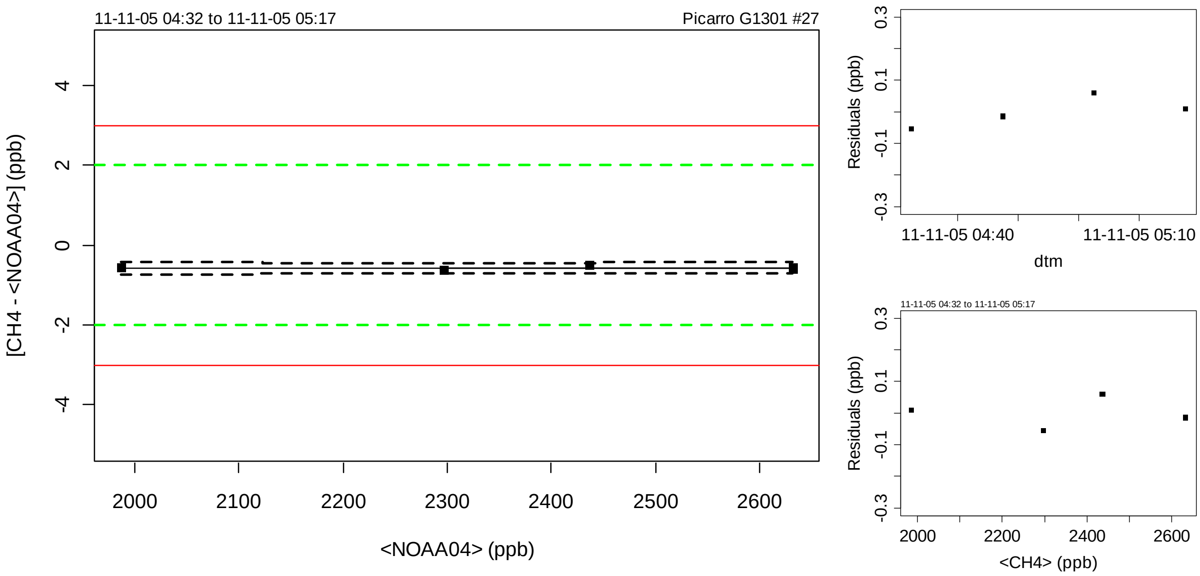

Figure 8. Left: Bias of Bukit Kototabang Picarro G1301 methane instrument with respect to the NOAA04 reference scale as a function of mole fraction. The white area represents the mole fraction range relevant for BKT, whereas the red and green lines correspond to the DQOs. Each point represents the average of data at a given level from a specific run. The dashed lines around the regression lines are the Working-Hotelling 95% confidence bands. Right: Regression residuals (time dependence and mole fraction dependence).

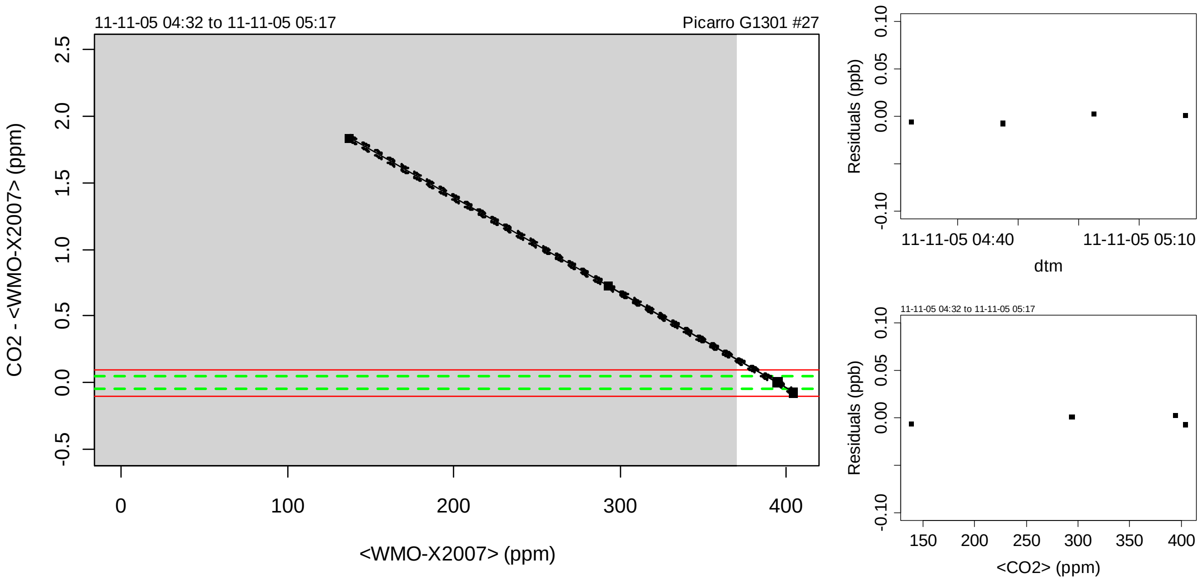

Figure 9. Left: Bias of Bukit Kototabang Picarro G1301 carbon dioxide instrument with respect to the WMO-X2007 reference scale as a function of mole fraction. The white area represents the mole fraction range relevant for BKT, whereas the red and green lines correspond to the DQOs. Each point represents the average of data at a given level from a specific run. The dashed lines around the regression lines are the Working-Hotelling 95% confidence bands. Right: Regression residuals (time dependence and mole fraction dependence).

The mole fractions of WCC-Empa travelling standards were significantly outside the range of the BKT NOAA laboratory standards, which enables an assessment of the overall consistency of the instrument calibration using the NOAA standards. For CH_4, the agreement was well within the DQOs of 2 ppb, which means that the calibration based on the BKT NOAA standards is consistent with the WCC-Empa assigned values of the travelling standards. However, larger deviations were observed for CO_2, which was expected due to the very small mole fraction range of the BKT NOAA standards (377.77 - 389.14 ppm). Only very small changes of the NOAA assigned values (within the uncertainties of the NOAA values) would lead to a perfect agreement between WCC-Empa and BKT. Table 1 summarises the WCC-Empa assigned values based on the comparison with the travelling standards. A further indication that the NOAA assigned values should be corrected is the extremely small regression residuals (cf. Figure 9), which were below 0.01 ppm. For future on-site diagnostics, the internal consistency of a suite of laboratory standards can be better assessed if zero air is available. It is recommended that a zero air source is available at BKT (CO2 and CH4 free air). For CO2, an appropriate scrubber (Ascarite in combination with magnesium perchlorate) could be used. Alternatively, the zero readings of the instrument could be checked using CO2 and CH4 free synthetic air or pure nitrogen.

Table 1. Measurement Programme at the BKT Station (In-situ gas measurements only)

Cylinder #	*NOAA value (ppm)*	*WCC-Empa value (ppm)*	*WCC-NOAA (ppm)*
CB08900	389.08	389.04	-0.04
CB08853	379.11	379.00	-0.11
CB08819	377.78	377.66	-0.12

Based on the above results, the following recommendations are made:

Recommendation 8 (, minor, when new NOAA standards are purchased)**

The NOAA/ESRL laboratory standards used for calibrations of the Picarro instrument and assignments of CO_2 and CH_4 numbers to working standards should span a mole fraction range that covers or better exceeds the range of observed values. A range of 360 – 500 ppm CO_2 and 1750 – 2100 ppb CH_4 would be appropriate for the BKT station.

Recommendation 9 (, minor, ongoing until further confirmation/contradiction)**

The WCC-Empa assigned CO_2 values (Table 1) should be used until further evidence for confirmation or contradiction is obtained (e.g. by the purchase of additional NOAA standards).

Data Acquisition and Management

BKT is equipped with a centralised data acquisition system (GAWDAQ) for surface ozone, the reactive gases as well as the aerosol parameters. The system was programmed by QA/SAC-Switzerland and is based on LabView. Data is automatically transferred to an FTP server (currently located at Empa) in near-real time for further data processing. Data of the Picarro instrument are acquired using the internal software of the Picarro system. These data is manually transferred to the GAWDAQ computer and is also automatically transferred to Empa.

Data Submission

Data have been submitted to the World Data Centre for Greenhouse Gases (WDCGG). In-situ data for surface ozone (1996-2007), carbon monoxide (2001-2007), NO_2 and SO_2 passive samplers (1996-2005) is available from WDCGG. It was recognized during the WCC-Empa audit in 2008 that some of the available SO2 and NO2 data is not plausible and needs to be withdrawn from WDCGG until it has been reviewed and quality controlled. Methane and carbon dioxide data has not yet been submitted due to the recent start of the measurements. Submission delays should be no longer than 1-2 years.

Recommendation 10 (*, minor, ongoing)**
It was noticed that the GAWSIS entries were outdated at the time of the audit (e.g. CH_4 and CO_2 time series were not yet registered). The information needs to be regularly reviewed, corrected and complemented.

Conclusions

The Bukit Kototabang GAW station considerably improved over the last ten years in many aspects:

The measurement programme was significantly extended with the addition of continuous CO_2, CH_4, NO_x and SO_2 measurements. The purchase of new (modern) instrumentation by BMKG in the last few years was a big step forward. Funding is now needed to sustain these measurements in future; however, complicated bureaucracy (import/export of goods) jeopardizes the very valuable time series of BKT. Part of the ongoing funding should be flexible, since it is very difficult to predict the actual need for replacement parts and instrument repair.

The situation concerning documentation, QA/QC procedures, and competence of staff also improved. However, more scientific knowledge both at the station and at BMKG and active use of the data is highly encouraged. Therefore, ongoing training of operators and international collaborations are highly important and should be continued.

Existing measurements were running stable since the last audit by WCC-Empa, and the results of the previous audit were confirmed. However, the CO instrument is reaching the end of its useful lifetime and needs replacement before it fails to avoid data gaps.

The existing time series need now be quality controlled and submitted to WDCGG.

Summary Ranking of the Bukit Kototabang GAW Station

System Audit Aspect	Adequacy#	Comment
Access	(5)	Year-round access by road
Facilities		
Laboratory and office space	(5)	Large research facilities
Internet access	(4)	Available, low bandwidth
Air Conditioning	(5)	Now fully operational
Power supply	(4)	Approx. 10 power outages per month
General Management and Operation		
Organisation	(4)	Well organised, but bureaucracy and funding issues
Competence of staff	(3)	Technical and scientific training of staff needed
Air Inlet System (except CH_4, CO_2)	(4)	Drying units problematic
Air Inlet System (CH_4, CO_2)	(5)	Adequate system
Instrumentation		
Ozone	(5)	Up-to-date instrumentation
Carbon monoxide	(3)	Replacement needed
NO_x, SO_2	(4)	Drying units problematic
Carbon dioxide and Methane	(5)	Picarro G1301
Standards		
Ozone	(4)	TEI 49i-PS, no comparisons to other references
CO, CH_4 and CO_2	(3)	Still dependent on twinning partner, NOAA and working standards from WCC-Empa
Data Management		
Data acquisition	(4)	LabView based central DAQ
Data processing	(3)	Still reliant on Empa
Data submission	(3)	Relatively long submissions delays (>3yrs)

#0: inadequate thru 5: adequate.

Dübendorf, March 2012

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

APPENDIX

Global GAW Station Bukit Kototabang

Site description

Bukit Koto Tabang is located roughly 17 km north of the town Bukittinggi (population: 85'000). It is situated in the equatorial zone on the ridge of a high plateau at an altitude of 864.5 m a.s.l., and 40 km off the western coastline. The facilities at the site consist of a large one-story building, which was renovated since the last audit in 2008 and provides excellent space for offices, meeting room and laboratories. The station can be reached over a small access road and is located two kilometres off the westerly main road (moderate traffic) between Padang and Medan. The small access road to the station enabled farmers to develop the area. More information about the Bukit Kototabang GAW station can be found in the GAW Station Information System (GAWSIS) (http://gaw.empa.ch/gawsis) and in Nurhayati and Nakajima [2012].

Measurement Programme

The measurement programme of Bukit Kototabang significantly enlarged over the past few year except for the NOAA flask sampling which recently stopped due to funding constraints. An overview of the measurement programme and its status as of November 2011 is shown in Table 2. Refer to GAWSIS for more details and a complete overview of the measurement programme.

Table 2. Measurement Programme at the BKT Station

Parameter	*Current Instrument*
Aerosol	
Light absorption coefficient#	Aethalometer
Light scattering coefficient	Nephelometer (Ecotech M9003)
Mass concentration (PM10)	Betameter
Mass concentration (TSP)	Hivol sampler
Ozone	
Surface ozone	UV absorption (TEI 49C)
Greenhouse Gas	
CO_2, CH_4	Picarro G1301
NOAA Flask Sampling	Discontinued since 2011
Reactive Gas	
CO	NDIR (HORIBA APMA360)
NO_2, SO_2	TEI i-Series, Trace Level
Solar radiation	
Global irradiance	Pyranometer (Eppley QPSP)
Diffuse irradiance	Pyrheliometer (direct broadband)
Direct irradiance	Pyrheliometer (global broadband)
UV Broadband	Pyrheliometer (global broadband)
Precipitation Chemistry	
Electric conductivity and pH	
Inorganic ions	IC (Dionex)
POP	
POPs	Passive samplers
Ancillary Measurements	
Meteo	

Trace Gas Distributions at Bukit Kototabang

The monthly and yearly distribution for surface ozone, carbon monoxide (both data from station analysers for 2006), methane and carbon dioxide (NOAA flask data for 2009-10) at Bukit Kototabang is shown in Figure 10.

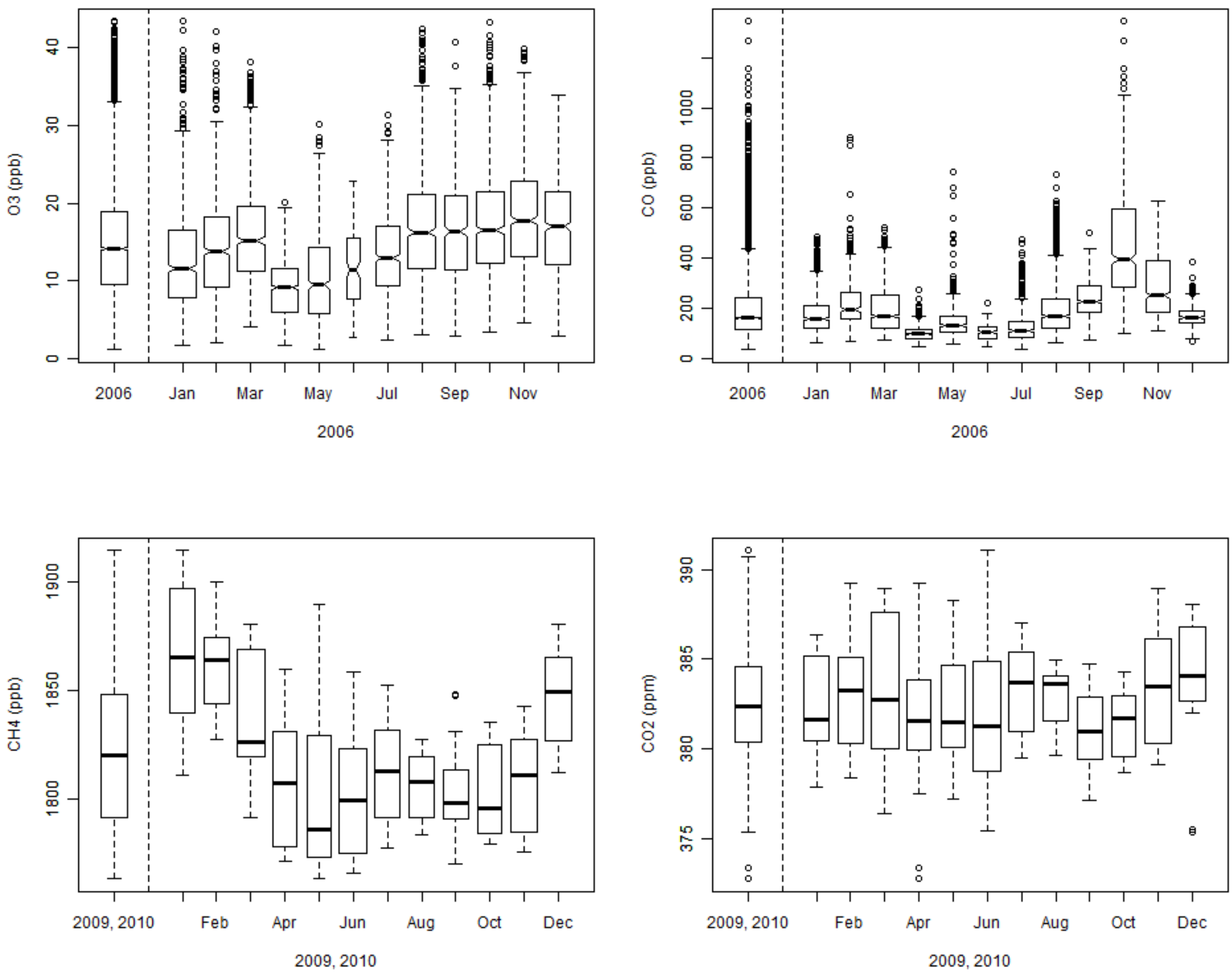

Figure 10. Yearly and monthly box plots for surface ozone surface ozone, carbon monoxide (both 2006, BKT data), methane and carbon dioxide (both NOAA flask data). The boxes indicate the 25, 50, and 75 percentile, respectively. Whiskers mark data within 1.5 times the inter-quartile range, and open circles denote data outside this range. The width of the boxes is proportional to the number of data points available for each month.

Organisation and Contact Persons

The Bukit Kototabang GAW station is run and coordinated by the Indonesian Meteorological, Climatological and Geophysical Agency (BMKG). The station is under the direct responsibility of the Director-General, but operation and administration have been delegated to the Center for Climate Change and Air Quality (Climatology Department). An organisational chart for the relevant parts of BMKG for Bukit Kototabang as of November 2011 is shown in Figure 11. Refer to GAWSIS for more detailed contact information.

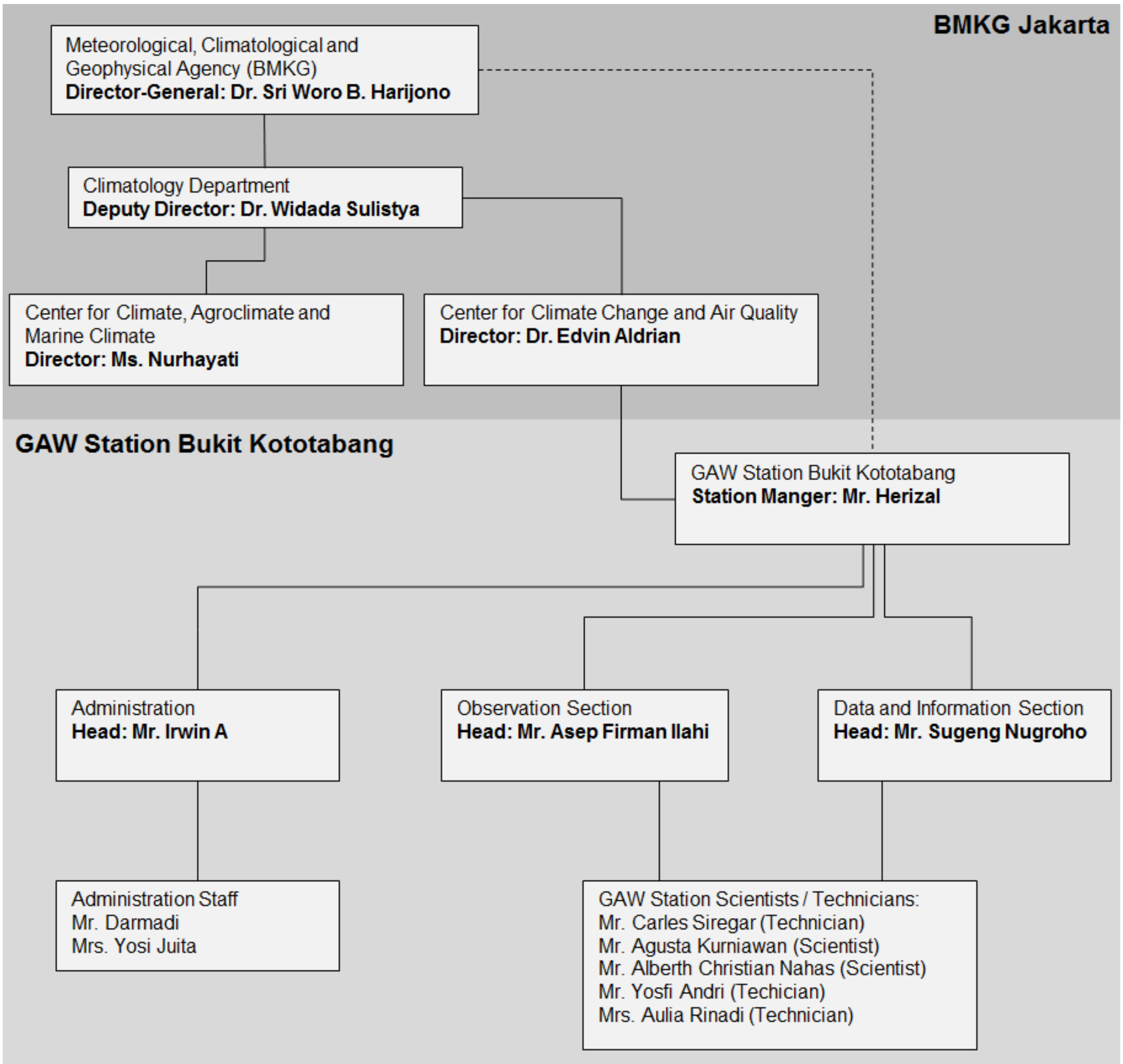

Figure 11. Organisational chart of the BKT GAW activities as of November 2011**.**

Surface Ozone Measurements

Monitoring Set-up and Procedures

Air Conditioning

The laboratory where the instruments are installed is air-conditioned using two wall mounted air conditioning units, and the instruments are protected from direct sunlight. The temperature of the laboratory is approx. 27°C which is slightly below the maximum ambient temperature. No modifications are necessary.

Air Inlet System

Location of air intake:	The air intake is mounted on the terrace approx. 4 m above the roof, 7.5 m above ground. The same common inlet line is used for CO, O_3, SO_2 and NO_x measurements.
Inlet protection:	Protection against rain water / snow / insects.
Tubing / Material:	The inlet is made of ca. 12 m ½" PFA tubing, and connections to individual instruments are made by PFA tees. The flow in the inlet line is approx. 20 l min^{-1}, controlled by a Thomas 807 pump. From the tee connection to the instrument by ca. 2.5 m ¼" PFA tubing, flow rate 1 l min^{-1}. A water trap (1 l glass bottle with PTFE fitting, cooled to 4°C by an Engel Portable Refrigerator) is used.
Inlet filter:	PTFE filter holder, Whatman TE38 PTFE inlet filter, 5µm pore size.
Residence time:	approx. 65 s

Instrumentation

Currently, one instrument using UV absorption technique (TEI 49C) is used the station for continuous surface ozone measurements. Instrumental details are summarised in Table 3.

Standards

A TEI 49i-PS ozone standard is available, for details refer to Table 3.

Operation and Maintenance

Check for general operation:	Daily (Mon – Sun).
Zero / Span check:	None.
Calibration/checks with standard:	Every 3 months (levels 10, 20, 30, 50, 80, 100, 200 ppb).
Inlet filter exchange:	Usually every 2 weeks, sometimes longer, more often in case of pollution episodes.
Other (cleaning, leak check etc.):	As required.

Data Acquisition and Data Transfer

The BKT station is equipped with a custom made data acquisition system (GAWDAQ) based on LabView. The GAWDAQ acquires all metadata that are available from the instrument. 1-minute values are automatically stored in an Access data base, which is incrementally transferred every three hours to Empa servers.

Data Treatment

Data is evaluated by the station staff using Excel, and monthly summary reports are prepared. This data evaluation method is not recommended, since QA/SAC-Switzerland developed a software tool (GAW Data Analysis and Data Integration - DANDI) that allows station data managers to concisely organise their monitored data and report it to the world data centres (WDC). The package uses rationale databases to store data in an individual database. The package incorporates the concepts of raw data import, data flagging/reviewing, data corrections, data aggregation, and uncertainty reporting. DANDI was programmed using the freely available R environment [*R Development Core Team*, 2009]. Until now, data validation and flagging is still dependent on collaboration with QA/SAC-Switzerland. Responsibility for data validation should however be transferred to the station staff.

Data Submission

Data have been submitted to the World Data Centre for Greenhouse Gases (WDCGG). Currently in-situ data for surface ozone from 1996 to 2007 is available from WDCGG.

Documentation

All information is entered in electronic log books and checklists. The information was sufficiently 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 travelling standard was used for the 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 including its inlet filter using approx. 1.5 m of PFA tubing. Table 3 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 DAQ was used.

Table 3. Experimental details of the ozone comparison.

Travelling standard (TS)	
Model, S/N	TEI 49i-PS #0810-153 (WCC-Empa)
Settings	BKG = -0.2; COEFF = 1.009
Station Analyser (OA) – main instrument	
Model, S/N	TEI 49C #58547-318
Principle	UV absorption
Range	0-1 ppm
Settings	BKG = +0.1; COEFF = 1.012
Pressure readings (torr)	Ambient 686.5, OA 685.0, no adjustments were made
Station Calibrator (OC)	
Model, S/N	TEI 49i-PS #0917736398
Principle	UV absorption
Range	0-1 ppm
Settings	BKG = 0.0; COEFF = 1.012
Pressure readings (torr)	Ambient 685.8, OC 686.1, no adjustments were made

Results

Each ozone level was applied for 15 minutes, and the last 10 one-minute averages were aggregated. These aggregates were used in the assessment of the comparison as described elsewhere *[Klausen et al., 2003]*. All results are valid for the calibration factors as given in Table 3 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) values.

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

Table 4. Ten-minute aggregates computed from the last 10 of a total of 15 one-minute values for the comparison of the main BKT ozone analyser (OA) TEI 49C #58547-318 with the WCC-Empa travelling standard (TS).

Date - Time (LST)	Run #	Level (ppb)	TS (ppb)	OA (ppb)	sdTS (ppb)	sdOA (ppb)	OA-TS (ppb)	OA-TS (%)
2011-11-01 11:30	1	0	0.07	0.08	0.22	0.03	0.01	NA
2011-11-01 11:50	1	30	30.00	29.91	0.12	0.09	-0.09	-0.30
2011-11-01 12:10	1	50	50.02	50.09	0.08	0.04	0.07	0.10
2011-11-01 12:30	1	10	10.10	9.90	0.28	0.12	-0.20	-2.00
2011-11-01 12:50	1	90	89.98	89.95	0.15	0.16	-0.03	0.00
2011-11-01 13:10	1	60	60.03	60.05	0.12	0.09	0.02	0.00
2011-11-01 13:30	1	20	19.99	19.86	0.15	0.10	-0.13	-0.70
2011-11-01 13:50	1	80	79.98	80.01	0.08	0.11	0.03	0.00
2011-11-01 14:10	1	70	70.00	69.90	0.08	0.08	-0.10	-0.10
2011-11-01 14:30	1	40	39.99	39.89	0.10	0.05	-0.10	-0.30
2011-11-01 14:50	2	0	0.30	0.11	0.12	0.04	-0.19	NA
2011-11-01 15:10	2	40	40.02	39.93	0.12	0.08	-0.09	-0.20
2011-11-01 15:30	2	90	90.02	89.73	0.07	0.09	-0.29	-0.30
2011-11-01 15:50	2	60	60.03	59.93	0.11	0.08	-0.10	-0.20
2011-11-01 16:10	2	50	49.99	49.76	0.08	0.10	-0.23	-0.50
2011-11-01 16:30	2	20	20.01	19.89	0.09	0.04	-0.12	-0.60
2011-11-01 16:50	2	80	80.01	79.87	0.06	0.06	-0.14	-0.20
2011-11-01 17:10	2	10	10.05	9.75	0.19	0.06	-0.30	-3.00
2011-11-01 17:30	2	30	30.01	29.68	0.13	0.06	-0.33	-1.10
2011-11-01 17:50	2	70	70.00	69.81	0.09	0.05	-0.19	-0.30
2011-11-01 18:10	3	0	0.24	-0.02	0.15	0.06	-0.26	NA
2011-11-01 18:30	3	20	20.00	19.79	0.16	0.05	-0.21	-1.00
2011-11-01 18:50	3	40	40.01	39.78	0.11	0.10	-0.23	-0.60
2011-11-01 19:10	3	90	89.98	89.96	0.10	0.07	-0.02	0.00
2011-11-01 19:30	3	60	60.00	59.94	0.08	0.06	-0.06	-0.10
2011-11-01 19:50	3	10	10.23	10.06	0.38	0.13	-0.17	-1.70
2011-11-01 20:10	3	30	29.99	29.49	0.20	0.10	-0.50	-1.70
2011-11-01 20:30	3	50	50.02	49.86	0.11	0.07	-0.16	-0.30
2011-11-01 20:50	3	70	70.01	69.75	0.11	0.08	-0.26	-0.40
2011-11-01 21:10	3	80	80.01	79.63	0.10	0.08	-0.38	-0.50
2011-11-01 21:30	4	0	0.23	0.00	0.19	0.03	-0.23	NA
2011-11-01 21:50	4	30	30.00	29.74	0.13	0.06	-0.26	-0.90
2011-11-01 22:10	4	50	49.98	49.84	0.11	0.08	-0.14	-0.30
2011-11-01 22:30	4	10	10.06	9.72	0.24	0.07	-0.34	-3.40
2011-11-01 22:50	4	90	90.03	89.79	0.07	0.09	-0.24	-0.30
2011-11-01 23:10	4	60	60.01	59.72	0.09	0.08	-0.29	-0.50
2011-11-01 23:30	4	20	20.00	19.78	0.18	0.09	-0.22	-1.10
2011-11-01 23:50	4	80	79.99	79.80	0.05	0.06	-0.19	-0.20
2011-11-02 00:10	4	70	69.97	69.72	0.08	0.10	-0.25	-0.40
2011-11-02 00:30	4	40	39.99	39.85	0.14	0.08	-0.14	-0.40

Table 5. Ten-minute aggregates computed from the last 10 of a total of 15 one-minute values for the comparison of the BKT ozone calibrator (OC) TEI 49i-PS #0917736398 with the WCC-Empa travelling standard (TS).

Date - Time (LST)	Run #	Level (ppb)	TS (ppb)	OC (ppb)	sdTS (ppb)	sdOC (ppb)	OC-TS (ppb)	OC-TS (%)
2011-11-03 17:26	1	0	0.28	-0.39	0.21	0.03	-0.67	NA
2011-11-03 17:46	1	60	59.97	57.89	0.11	0.06	-2.08	-3.50
2011-11-03 18:06	1	140	140.02	136.53	0.11	0.11	-3.49	-2.50
2011-11-03 18:26	1	30	29.98	28.86	0.21	0.08	-1.12	-3.70
2011-11-03 18:46	1	90	89.99	87.41	0.08	0.12	-2.58	-2.90
2011-11-03 19:06	1	190	190.01	185.41	0.08	0.09	-4.60	-2.40
2011-11-03 19:26	2	0	0.28	-0.25	0.21	0.02	-0.53	NA
2011-11-03 19:46	2	140	140.01	136.34	0.12	0.08	-3.67	-2.60
2011-11-03 20:06	2	60	60.01	58.08	0.14	0.11	-1.93	-3.20
2011-11-03 20:26	2	190	190.02	185.46	0.09	0.12	-4.56	-2.40
2011-11-03 20:46	2	30	30.02	28.78	0.12	0.08	-1.24	-4.10
2011-11-03 21:06	2	90	89.99	87.35	0.12	0.09	-2.64	-2.90
2011-11-03 21:26	3	0	0.32	-0.29	0.18	0.02	-0.61	NA
2011-11-03 21:46	3	190	190.00	185.57	0.12	0.11	-4.43	-2.30
2011-11-03 22:06	3	60	59.99	58.03	0.09	0.10	-1.96	-3.30
2011-11-03 22:26	3	90	89.99	87.62	0.06	0.12	-2.37	-2.60
2011-11-03 22:46	3	30	30.04	28.91	0.29	0.11	-1.13	-3.80
2011-11-03 23:06	3	140	140.00	136.73	0.08	0.14	-3.27	-2.30
2011-11-03 23:26	4	0	0.20	-0.20	0.25	0.03	-0.40	NA
2011-11-03 23:46	4	60	59.97	58.17	0.09	0.10	-1.80	-3.00
2011-11-04 00:06	4	140	140.02	136.64	0.09	0.09	-3.38	-2.40
2011-11-04 00:26	4	30	30.00	28.86	0.21	0.08	-1.14	-3.80
2011-11-04 00:46	4	90	89.97	87.49	0.07	0.08	-2.48	-2.80
2011-11-04 01:06	4	190	189.99	185.92	0.06	0.07	-4.07	-2.10

Ozone Loss over the Inlet Filter and Humidity Trap

An additional comparison run was performed including the instrument inlet filter and humidity trap. The results are shown in shown in Figure 12, and the following equations characterise the instrument bias:

TEI 49C #58547-318 (BKG 0.1 ppb, SPAN 1.014) – main analyser, including filter and water trap:

Unbiased O_3 mixing ratio (ppb): X_{O3} (ppb) = ([OA] + 1.08 ppb) / 0.991 (5a)

Standard uncertainty (ppb): u_{O3} (ppb) = sqrt (0.4 ppb^2 + 2.82e-05 * $X_{O3}{}^2$) (5b)

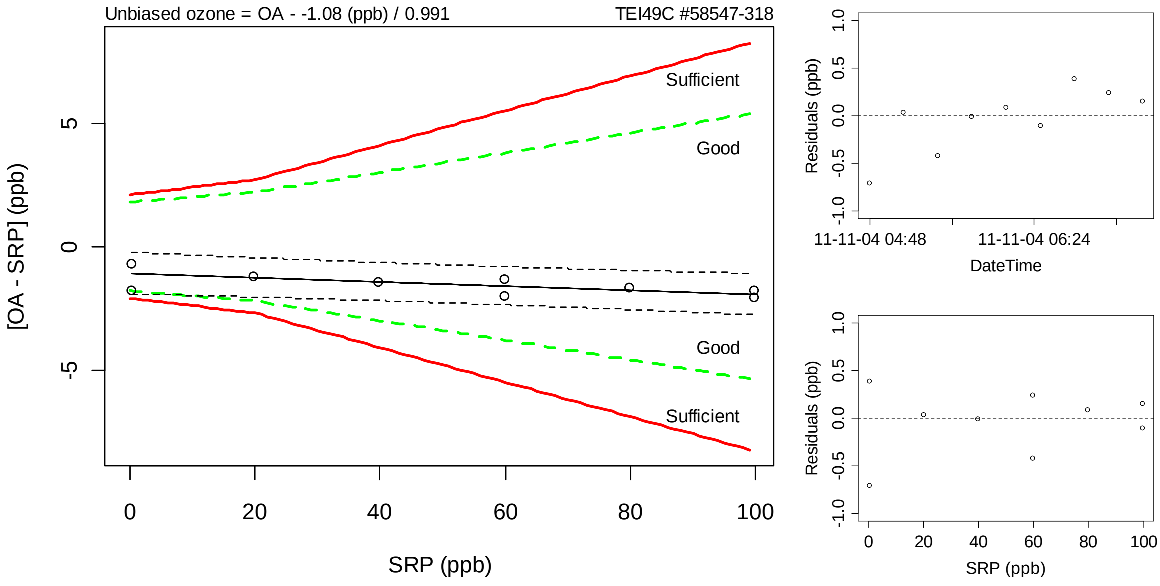

Figure 12. Same as Figure 1, but including the filter and water.

Conclusions

The ozone measurements (TEI 49C) at Bukit Kototabang agreed perfectly with the WCC-Empa travelling standard when the two instruments were directly compared. A slight ozone loss of 1-2% was observed when the inlet filter and the humidity trap was included. This is slightly higher than during previous audits which most likely can be explained be the longer residence time of the air inside the humidity trap. Therefore, it should be considered to remove the humidity trap, since water vapour condensation is less likely with the new inlet set-up.

The ozone calibrator was reading slightly lower compared to the WCC-Empa travelling standard. This result was also confirmed by the calibrations that were performed by BKT staff between the station analyser and the calibrator.

Carbon Monoxide Measurements

Monitoring Set-up and Procedures

Air Conditioning

Same as for surface ozone.

Air Inlet System

The inlet system is identical as for surface ozone, except for the humidity trap (CO: Komatsu Thermo-electric Dehumidifier DH-109) and the flow rate after the tee (ca. 2 l min^{-1}).

Inlet filter:	PFA filter holder with Whatman TE38 PFTE filters (5μm) before Nafion dryer, Horiba paper filter inside CO monitor.
Residence time:	< 10 s

Instrumentation

Bukit Kototabang is equipped with a Horiba APMA360 CO analyser, which was installed at the station in 2007. A Permapure Nafion dryer in split flow mode is used for sample air drying. Instrumental details are listed in Table 7. The TEI 48C-TL analyser was decommissioned after the WCC-Empa audit in 2008 but is still at the station (not running). This instrument should no longer be used.

Standards

The station has been provided with calibration gases by WCC-Empa. Table 6 shows and overview of past and present CO standards at BKT. Two types of calibration standards are available: Low levels (<1.5 ppm) for direct calibrations of the instrument, and higher levels (>15 ppm) for automatic span checks using the dilution system.

Table 6. CO Standards of BKT.

Cylinder ID	Manufacturer	Use	CO (ppb)	U_{CO} (ppb)	Start of use	End of use
76529	Messer	Direct calibration	1015.4	20.3	Jul 01	Jul 08
76527	Messer	Dilution	15000.0	300.0	Jul 01	Dec 04
168878	Messer	Dilution	51100.0	1022.0	Dec 04	NA
D94 4280	Messer	Dilution	49781.0	500.0	NA	Sep 08
D94 4278	Messer	Dilution	49806.0	500.0	Sep 08	Apr 09
D94 4289	Messer	Direct calibration	1016.6	10.2	Jul 08	Apr 09
090325_ CC111787	SMI / Empa	Direct calibration	1029.5	10.3	Apr 09	Sep 09
090325_ CA06490	SMI / Empa	Dilution	44860.0	450.0	Apr 09	Nov 11
100518_CB08830	SMI / Empa	Direct calibration	1175.1	12.3	Nov 11	cont.
101116_CA06476	SMI / Empa	Direct calibration	527.7	5.4	Nov 11	cont.
110818_CB08871	SMI / Empa	Direct calibration	477.3	4.7	Nov 11	cont.
110818_CB08874	SMI / Empa	Dilution	29700.0	294.0	Nov 11	cont.

Operation and Maintenance

Check for general operation:	Daily (Mon – Sun).
Instrument check list:	Weekly check list.
Inlet filter exchange:	Every 2 weeks, more often in case of pollution episodes.
Check of dehumidifier:	Twice per week.
Silicagel replacement (zero air):	As required, ca. 2 times per week.
Span/Zero checks:	Automatic, every 4 h.
Other (cleaning, leak check etc.):	As required.

Data Acquisition and Data Transfer

Same as for surface ozone.

Data Treatment

Same as for surface ozone.

Data Submission

Data have been submitted to the World Data Centre for Greenhouse Gases (WDCGG). Currently in-situ data for carbon monoxide from 2001 to 2007 is available from WDCGG.

Documentation

All information is entered in electronic log books and checklists. The information was sufficiently comprehensive and up-to-date. The instrument manuals were available at the site.

Comparison of the Carbon Monoxide Analyser

All procedures were conducted according to the Standard Operating Procedure [WMO, 2007b] and included comparisons of the travelling standards at Empa before the comparison of the analyser. Details of the traceability of the travelling standards to the WMO/GAW Reference Standard at NOAA/ESRL are given in Table 19 below.

Setup and Connections

Table 14 shows details of the experimental setup during the comparison of the transfer standard and the station analyser. The comparison was made with direct measurements of WCC-Empa travelling standards (direct comparison) as well as by dilution of a standard with a high CO mole fraction (dilution system). The data used for the evaluation was recorded by the BKT data acquisition system.

Table 7. Experimental details of BKT CO comparison.

Travelling standard (TS)	
Direct comparison: WCC-Empa Traveling standards (6 l aluminium cylinder containing a mixture of natural and synthetic air), assigned values and standard uncertainties see Table 19.	
Dilution System: CO standard with a high CO mole fraction and a zero-air generator (silica gel - inlet filter 5 micron - metal bellow pump - Sofnocat - outlet filter 5 micron) custom-built by WCC-Empa, in combination with a dilution system (Red-y MFCs). The dilution system was calibrated at WCC-Empa before the audit using a linear reference instrument (Picarro G1301).	
Station Analyser (AL)	
Model, S/N	Horiba APMA360 #890617034
Principle	NDIR, cross flow modulation
Drying system	PERMAPURE PD-50-24'' Nafion drier, split flow mode using critical orifice and external pump

Calibration settings	Zero -1, SPAN 1. 1035
Comparison procedures	
Connection	Direct comparison: WCC-Empa TS were connected to the Horiba span inlet, including the Nafion drier of the instrument. An overflow of >100 ml/min was provided by adjustment of the flow rate with a needle valve. Dilution system: The air provided by the dilution system was connected to the sample inlet of the Horiba instrument, before the inlet filter of the Nafion dryer; an overflow of >100 ml/min was provided. The comparison included the whole system including filters and Nafion dryer, but without the DH109 dehumidifier.

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 Table 8 and Table 9 (assessment by QA/SAC Switzerland in 2009) and Table 10 to Table 12 (current audit).

Table 8. CO aggregates computed from single analysis (mean and standard deviation of mean) for each level during the comparison of the Horiba APMA360 instrument with the WCC-Empa TS (Dilution system, before adjustments of the calibration settings, results of the comparison by QA/SAC Switzerland in 2009).

Date / Time	TS (ppb)	uTS (ppb)	AL (ppb)	sdAL (ppb)	N	AL-TS (ppb)	AL-TS (%)
(09-10-26 06:28:00)	200	1	178.3	6.0	5.0	-21.7	-10.8
(09-10-26 06:43:30)	50	1	43.4	8.1	14.0	-6.6	-13.2
(09-10-26 07:00:15)	75	1	69.5	11.0	16.0	-5.5	-7.3
(09-10-26 07:31:00)	0	1	-0.4	11.6	39.0	-0.4	NA
(09-10-26 08:01:21)	300	1	266.1	9.7	14.0	-33.9	-11.3
(09-10-26 08:22:00)	100	1	88.5	9.3	17.0	-11.5	-11.5
(09-10-26 08:42:00)	200	1	182.4	7.9	17.0	-17.7	-8.8
(09-10-26 09:01:21)	50	1	48.7	12.3	14.0	-1.3	-2.5
(09-10-26 09:21:00)	75	1	64.8	7.3	19.0	-10.2	-13.6
(09-10-26 09:49:06)	0	1	0.9	8.2	31.0	0.9	NA
(09-10-26 10:28:00)	300	1	267.2	5.3	5.0	-32.8	-10.9
(09-10-26 10:44:30)	100	1	88.0	8.3	14.0	-12.0	-12.0
(09-10-26 11:01:26)	200	1	183.9	7.7	16.0	-16.1	-8.1
(09-10-26 11:23:00)	50	1	45.8	10.2	17.0	-4.2	-8.4
(09-10-26 11:40:00)	75	1	71.2	8.2	11.0	-3.9	-5.1
(09-10-26 11:56:00)	1000	1	899.1	8.4	15.0	-100.9	-10.1
(09-10-26 12:16:40)	0	1	-2.1	10.9	6.0	-2.1	NA

Table 9. Same as Table 8, after adjustment of the calibration settings.

Date / Time	TS (ppb)	uTS (ppb)	AL (ppb)	sdAL (ppb)	N	AL-TS (ppb)	AL-TS (%)
(09-10-27 06:22:56)	0	1	-0.3	10.1	15	-0.3	NA
(09-10-27 06:30:22)	500	1	492.1	5.1	8	-7.9	-1.6
(09-10-27 06:51:30)	100	1	98.6	10.0	18	-1.4	-1.4
(09-10-27 07:11:30)	300	1	292.3	7.4	18	-7.7	-2.6
(09-10-27 07:31:30)	200	1	189.7	12.2	18	-10.3	-5.1
(09-10-27 07:51:30)	1000	1	988.7	8.0	18	-11.4	-1.1
(09-10-27 08:11:47)	0	1	-1.5	8.4	18	-1.5	NA
(09-10-27 08:31:30)	500	1	494.3	9.3	18	-5.7	-1.1
(09-10-27 08:51:07)	100	1	97.0	8.4	17	-3.0	-3.0
(09-10-27 09:12:48)	300	1	300.2	8.6	15	0.2	0.1
(09-10-27 09:31:30)	200	1	200.1	9.9	18	0.1	0.1
(09-10-27 09:51:30)	1000	1	988.2	9.5	18	-11.8	-1.2
(09-10-27 10:14:51)	0	1	2.0	8.7	14	2.0	NA
(09-10-27 10:31:33)	500	1	498.8	8.4	9	-1.3	-0.3
(09-10-27 10:52:00)	100	1	100.6	9.7	19	0.6	0.6
(09-10-27 11:13:19)	300	1	298.6	13.7	16	-1.4	-0.5
(09-10-27 11:30:00)	200	1	199.0	8.8	15	-1.0	-0.5

Table 10. CO aggregates computed from single analysis (mean and standard deviation of mean) for each level during the comparison of the Horiba APMA360 instrument with the WCC-Empa TS (Dilution system using 090325_CA06494).

Date / Time	TS (ppb)	uTS (ppb)	AL (ppb)	sdAL (ppb)	N	AL-TS (ppb)	AL-TS (%)
(11-11-04 09:03:00)	900	1	821.5	6.4	17	-78.5	-8.7
(11-11-04 10:31:40)	0	1	-0.2	3.8	15	-0.2	NA
(11-11-04 12:03:00)	100	1	97.0	5.2	17	-3.0	-3.0
(11-11-04 13:25:30)	800	1	731.1	3.8	12	-68.9	-8.6
(11-11-04 15:05:30)	200	1	187.0	4.2	16	-13.0	-6.5
(11-11-04 16:33:00)	700	1	641.1	3.4	17	-58.9	-8.4
(11-11-04 17:58:55)	300	1	277.4	4.6	11	-22.6	-7.5
(11-11-04 19:33:00)	600	1	550.6	4.8	17	-49.5	-8.2
(11-11-04 21:00:30)	400	1	370.1	4.3	16	-29.9	-7.5
(11-11-04 22:50:30)	500	1	461.4	4.2	10	-38.6	-7.7
(11-11-05 00:03:00)	900	1	820.7	4.9	17	-79.3	-8.8
(11-11-05 01:35:30)	0	1	2.20	5.6	18	2.2	NA
(11-11-05 03:05:30)	100	1	96.0	3.9	16	-4.0	-4.0
(11-11-05 04:33:00)	800	1	732.0	4.7	17	-68.1	-8.5
(11-11-05 05:58:55)	200	1	188.9	4.2	11	-11.1	-5.6

Table 11. Same as Table 10, using 110818_CB08874 as reference).

Date / Time	TS (ppb)	uTS (ppb)	AL (ppb)	sdAL (ppb)	N	AL-TS (ppb)	AL-TS (%)
(11-11-05 09:12:00)	891.0	1	806.8	4.2	17	-84.2	-9.5
(11-11-05 10:37:00)	0.0	1	0.8	5.3	15	0.8	NA
(11-11-05 12:09:30)	99.0	1	94.0	3.8	16	-5.0	-5.0
(11-11-05 13:29:30)	792.0	1	716.2	4.8	10	-75.8	-9.6
(11-11-05 15:14:30)	198.0	1	186.4	4.1	16	-11.6	-5.9
(11-11-05 16:42:00)	693.0	1	628.9	4.9	17	-64.1	-9.3
(11-11-05 18:13:22)	297.0	1	271.8	4.4	11	-25.3	-8.5
(11-11-05 19:42:00)	594.0	1	539.8	5.6	17	-54.2	-9.1
(11-11-05 21:12:00)	396.0	1	360.7	4.2	17	-35.3	-8.9
(11-11-05 22:54:30)	495.0	1	451.2	5.0	12	-43.8	-8.8
(11-11-06 00:12:00)	891.0	1	809.5	5.4	17	-81.6	-9.2

Table 12. CO aggregates computed from single analysis (mean and standard deviation of mean) for each level during the comparison of the Horiba APMA360 instrument with the WCC-Empa TS.

Date / Time	TS Cylinder	TS (ppb)	uTS (ppb)	AL (ppb)	sdAL (ppb)	N	AL-TS (ppb)	AL-TS (%)
(11-11-07 06:57:30)	Zero air	0.0	0.0	0.0	2.8	2	0.0	NA
(11-11-07 06:33:00)	110818_CB08871	477.3	0.1	430.9	0.9	3	-46.4	-9.7
(11-11-07 06:56:30)	100518_CB08830	1174.9	2.4	1068.0	7.0	4	-107.2	-9.1
(11-11-07 07:18:30)	101116_CA06476	527.7	0.7	478.4	4.5	4	-49.3	-9.3

Conclusions

The current audit of the BKT Horiba APMA360 confirmed a drift (loss of sensitivity) over time, and replacement of the instrument should be considered.

The standard deviation of the Horiba APMA360 instrument for 1-min values was within the range of 4-12 ppb (5- and 95% percentile), independent of the mole fraction range. This is a typical value for NDIR instruments; however, the noise of the analyser clearly limits the accurate detection of CO especially at lower mole fractions.

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 tower at 10 m, 20 m and 32 m above ground.
Inlet protection:	Funnel as rainwater protection.
Tubing / Material:	Approx. 40 meters 1/4 inch Eaton Synflex 1300 tubing to valve box, flow rate approx. 3 l/min.
Inlet filter:	Inline particle filter inside valve box (7µm, Swagelok SS-2F-K4-7), plus Picarro internal filter.
Residence time:	Approx. 10 s

Instrumentation

A Picarro G1301 CO_2, CH_4 and H_2O analyser is available at BKT. The air is dried using to Permapure PD-50T-24MPP Nafion driers. The instrument set-up is illustrated in Figure 13.

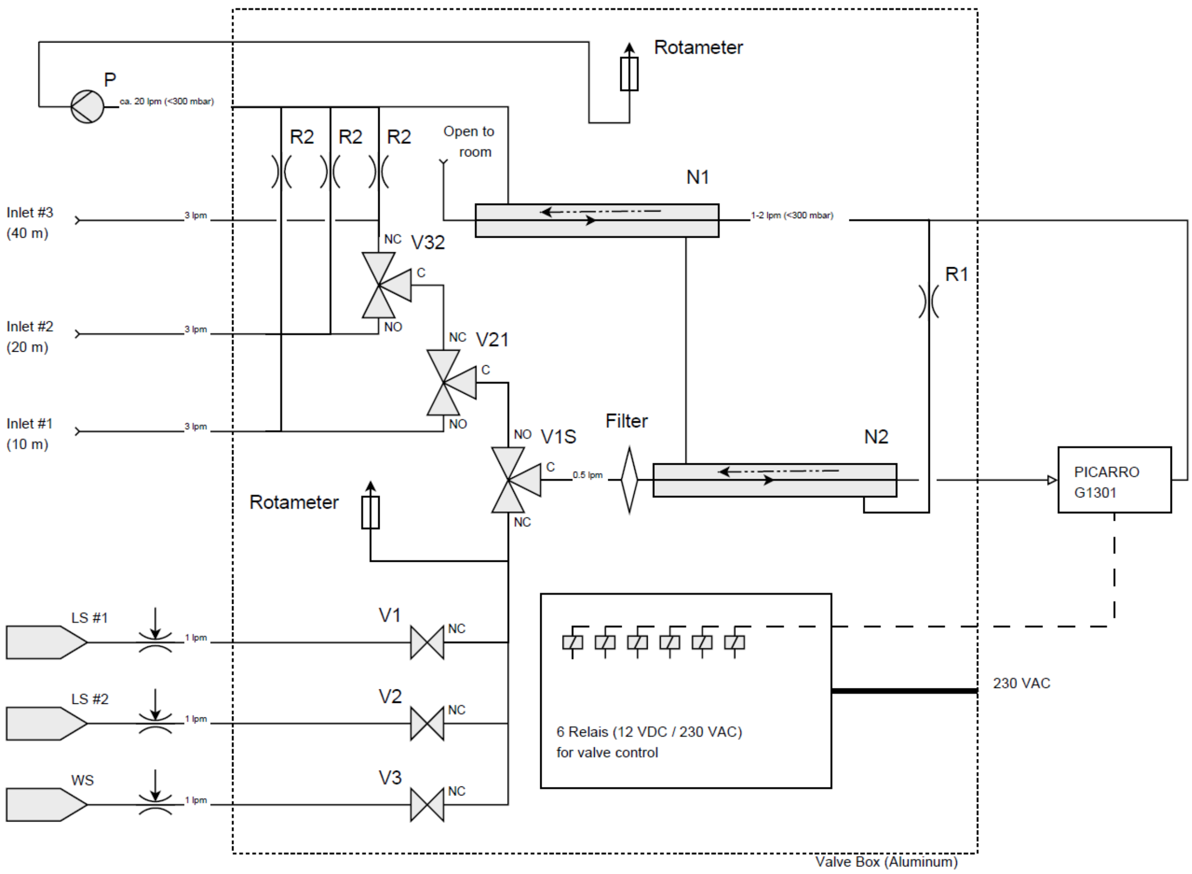

Figure 13. Picarro G1301 set-up at BKT.

The readings of the Picarro instrument need to be corrected for water vapour interference, especially if the sampled air is not dried. However, a correction is also recommended with the current instrument set-up, since the air is not completely dry after the Nafion driers. The correction function was determined by WCC-Empa during the audit (see Figure 14), and it is recommended that this function is confirmed by similar experiments by BKT staff.

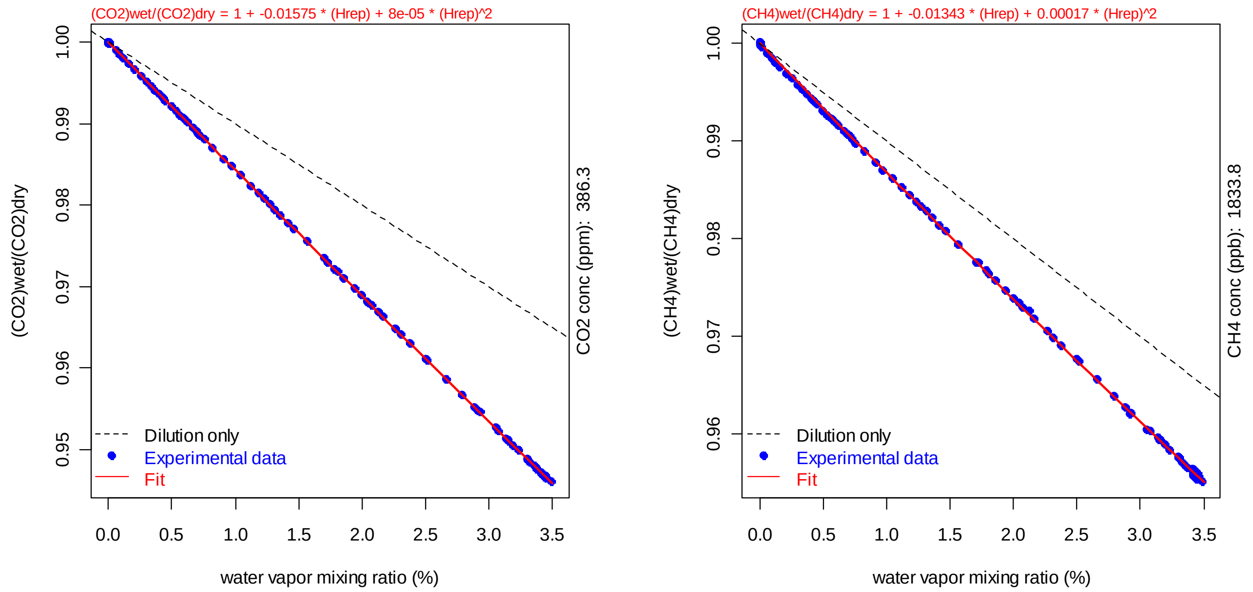

Figure 14. Quadratic fits for the BKT Picarro G1301 instrument of CO_2wet/CO_2dry and CH_4wet/CH_4dry vs. H_2O mixing ratios.

The following functions (6a-b) were obtained to compensate for the humidity interference:

$CO_2(dry) = CO_2(wet) / (1 – 0.01575 * H_{rep} – 0.00008 * H_{rep}^2)$ (6a)

$CH_4(dry) = CH_4 (wet) / (1 – 0.01343 * H_{rep} – 0.00017 * H_{rep}^2)$ (6b)

Where H_{rep} corresponds to the Picarro reported water mixing ratio in %

These functions are usually stable over time but should be confirmed in regular intervals. The obtained coefficients compare well to other instruments of this type [*Chen et al.*, 2010].

Standards

The station was initially provided with a set of four NOAA/ESRL standards; these standards were used for regular calibrations until the current audit. Consequently, the remaining pressure in these standards is relatively low. WCC-Empa provided an additional set of 3 working standards, which are now used for regular calibrations. Table 13 lists the currently available CH_4 and CO_2 standards at BKT.

Table 13. CO_2 and CH_4 Standards available at BKT.

Cylinder ID	Type	CH_4 (ppb)	U_{CH4} (ppb)	CO_2 (ppm)	U_{CO2} (ppm)	$CO_2^{\#}$ (ppm)	$U_{CO2}^{\#}$ (ppm)	Start of use	End of use
CB08900	NOAA/ESRL	1843.26	0.60	389.08	0.14	389.14	0.17	Oct 09	cont.
CB08853	NOAA/ESRL	1805.59	0.60	379.11	0.14	379.06	0.17	Oct 09	cont.
CB08806	NOAA/ESRL	1790.62	0.60	377.78	0.14	377.77	0.17	Oct 09	cont.
CB08819	NOAA/ESRL	1743.37	0.60	369.13	0.14	NA	NA	Oct 09	Nov 09
100518_CB08830	WCC-Empa	1987.42	0.33	293.16	0.15	NA	NA	Nov 11	cont.
101116_CA06476	WCC-Empa	2437.15	0.44	394.67	0.17	NA	NA	Nov 11	cont.
110818_CB08871	WCC-Empa	2631.77	0.45	403.87	0.17	NA	NA	Nov 11	cont.

Operation and Maintenance

Check for general operation: Daily (Mon – Sun).

No other regular maintenance has been made until now. The instrument was returned to Picarro Inc. in May 2010 after a hardware problem in the warm chamber occurred; it could only be re-installed in March 2011, since it hold up at the customs after repair in the US.

Data Acquisition and Data Transfer

The data of the Picarro system is acquired using the internal LabView based data acquisition system. The software version was upgraded (host 3.5.7.2, interface 550, mcn 11.06) during repair of the instrument at Picarro. Remote access is possible through the internet for instrument maintenance.

Data Treatment

Until now the Picarro data has not been systematically evaluated by the station staff. Currently, Excel is used for data evaluation, which however is not optimal due to the high temporal resolution and large data files. Alternative software, e.g. R, should be used.

Data Submission

Data of the Picarro instrument have not yet been submitted to the World Data Centre for Greenhouse Gases (WDCGG) due to the relative recent start of the measurements.

Documentation

All information is entered in electronic log books and checklists. The instrument manual is available at the site.

Comparison of the Picarro G1301 instrument with WCC-Empa travelling standards

All procedures were conducted according to the Standard Operating Procedure [WMO, 2007b] and included comparisons of the travelling standards at Empa before and after the comparison of the analyser. Details of the traceability of the travelling standards to the WMO/GAW Reference Standard at NOAA/ESRL are given in Table 19 below.

Setup and Connections

Table 14 shows details of the experimental setup during the comparison of the transfer standard and the station analyser. The data used for the evaluation was recorded by the Picarro data acquisition system.

Table 14. Experimental details of the Picarro G1301 comparison.

Travelling standard (TS)	
WCC-Empa Traveling standards (6 l aluminium cylinder containing a mixture of natural and synthetic air), assigned values and standard uncertainties see Table 19. The TS were connected to the BKT valve control box using 1/16 inch SS tubing.	
Station Analyser (OA)	
Model, S/N	Picarro G1301 #CFADS-020 Software version: host 3.5.7.2, interface 550, mcn 11.06.
Principle	Cavity Ring Down Spectroscopy (CRDS)
Comparison procedures	
Connection	The TS were connected to a sampling unit using 1/16 inch SS tubing.

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 15. CH_4 aggregates computed from single analysis (mean and standard deviation of mean using 1-min data) for each level during the comparison of the Picarro G1301 instrument (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 (%)
(11-11-05 04:32:30)	110818_CB08874	2297.41	0.08	2296.78	0.11	18	-0.63	-0.03
(11-11-05 04:47:30)	110818_CB08871	2631.77	0.08	2631.19	0.19	18	-0.58	-0.02
(11-11-05 05:02:30)	101116_CA06476	2437.15	0.17	2436.64	0.15	18	-0.51	-0.02
(11-11-05 05:17:30)	100518_CB08830	1987.42	0.04	1986.85	0.15	18	-0.57	-0.03

Table 16. CO_2 aggregates computed from single analysis (mean and standard deviation of mean using 1-min data) for each level during the comparison of the Picarro G1301 instrument (OA) with the WCC-Empa TS.

Date / Time	TS Cylinder	TS (ppm)	sdTS (ppm)	OA (ppm)	sd OA (ppm)	N	OA-TS (ppb)	OA-TS (%)
(11-11-05 04:32:30)	110818_CB08874	137.02	0.01	138.86	0.03	18	1.84	1.34
(11-11-05 04:47:30)	110818_CB08871	403.78	0.03	403.71	0.04	18	-0.07	-0.02
(11-11-05 05:02:30)	101116_CA06476	394.58	0.01	394.58	0.02	18	0.00	0.00
(11-11-05 05:17:30)	100518_CB08830	293.09	0.02	293.82	0.03	18	0.73	0.25

Conclusions

The Picarro G1301 instrument installed at Bukit Kototabang is a very valuable addition to the existing measurement programme. The instrumental set-up proved to be fully adequate for the measurements of methane and carbon dioxide.

For CH_4, the Picarro results were within the WMO GAW DQOs. The relative standard deviation of the multiple analysis of the TS was 0.006% based on 1-min averages. This is approx. 10 times better compared to single injections of an optimised GC/FID system.

For CO_2, the deviation between the BKT and WCC-Empa results were larger than the WMO GAW DQOs of 0.1 ppm for mole fractions below and above the levels of ambient background mole fractions. This was caused by the very small CO_2 mole fraction of the BKT NOAA standards. Based on the audit results, new results were assigned to the BKT NOAA standards. These values were within the assigned uncertainties of the NOAA standards. The relative standard deviation of the multiple analysis of the TS was 0.010% based on 1-min averages. This repeatability is sufficient to reach the GAW DQOs.

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 49i-PS #0810-153, BKG -0.2, COEF 1.009

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 17. The TS passed the assessment criteria defined for maximum acceptable bias before and after the audit [*Klausen et al.*, 2003] (cf. Figure 15). 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]).

$$X_{TS}\ (\text{ppb}) = ([\text{TS}] - 0.14\ \text{ppb}) / 1.0020 \qquad (6a)$$

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

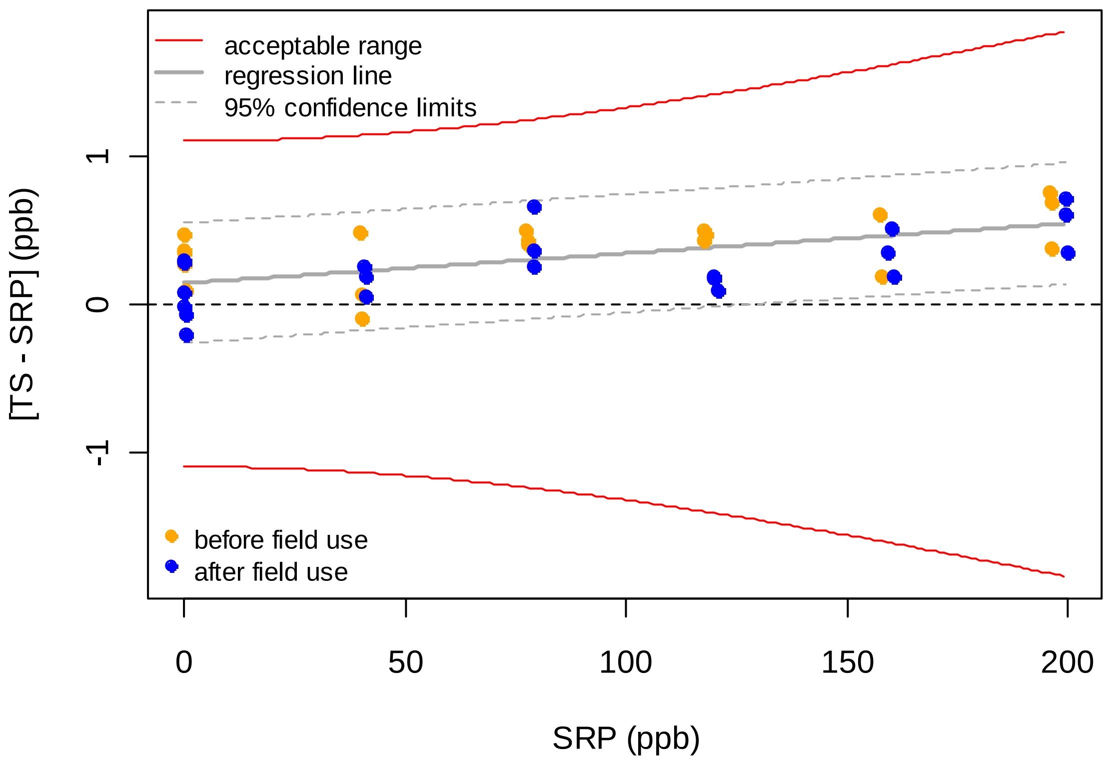

Figure 15. Deviations between traveling standard (TS) and Standard Reference Photometer (SRP) before and after use of the TS at the field site.

Table 17. 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)
2011-07-12	1	0	0.03	0.32	0.38	0.26
2011-07-12	1	80	77.92	0.26	78.35	0.24
2011-07-12	1	160	157.31	0.43	157.91	0.39
2011-07-12	1	120	117.78	0.27	118.25	0.15
2011-07-12	1	200	196.54	0.23	196.92	0.26
2011-07-12	1	40	39.96	0.25	39.86	0.20
2011-07-12	1	0	-0.19	0.32	0.07	0.23
2011-07-12	2	0	0.07	0.24	0.17	0.20
2011-07-12	2	40	40.04	0.40	40.10	0.21
2011-07-12	2	160	157.92	0.21	158.11	0.26
2011-07-12	2	200	196.51	0.42	197.20	0.17
2011-07-12	2	120	117.58	0.20	118.08	0.23
2011-07-12	2	80	77.20	0.37	77.69	0.21
2011-07-12	2	0	-0.22	0.14	0.15	0.15
2011-07-12	3	0	0.24	0.17	0.03	0.28
2011-07-12	3	80	77.67	0.31	78.06	0.19
2011-07-12	3	40	39.82	0.41	40.29	0.25
2011-07-12	3	160	157.18	0.22	157.79	0.23
2011-07-12	3	200	195.98	0.32	196.74	0.14
2011-07-12	3	120	117.44	0.40	117.87	0.16
2011-07-12	3	0	-0.20	0.36	0.27	0.16
2011-12-20	4	0	0.27	0.23	0.06	0.13
2011-12-20	4	80	41.05	0.20	41.22	0.18
2011-12-20	4	160	160.53	0.27	160.72	0.26
2011-12-20	4	120	199.80	0.32	200.15	0.30
2011-12-20	4	200	78.98	0.24	79.35	0.20
2011-12-20	4	40	119.91	0.27	120.09	0.17
2011-12-20	4	0	-0.14	0.33	0.14	0.11
2011-12-20	5	0	-0.07	0.54	0.01	0.22
2011-12-20	5	40	79.27	0.48	79.93	0.18
2011-12-20	5	160	160.12	0.40	160.64	0.34
2011-12-20	5	200	40.78	0.62	41.04	0.20
2011-12-20	5	120	199.40	0.26	200.11	0.15
2011-12-20	5	80	119.85	0.30	120.02	0.12
2011-12-20	5	0	0.02	0.35	0.01	0.14
2011-12-20	6	0	-0.13	0.28	0.16	0.22
2011-12-20	6	80	120.76	0.15	120.86	0.18
2011-12-20	6	40	79.16	0.20	79.42	0.15
2011-12-20	6	160	159.32	0.22	159.67	0.35
2011-12-20	6	200	199.31	0.26	199.91	0.23
2011-12-20	6	120	41.03	0.27	41.08	0.20
2011-12-20	6	0	0.15	0.25	0.08	0.23

#the level is only indicative.

Greenhouse gases and carbon monoxide

WCC-Empa refers to the primary reference standards maintained by the Central Calibration Laboratory (CCL) for Carbon Monoxide, Carbon Dioxide and Methane. NOAA/ESRL was assigned by WMO as the CCL for the above parameters. WCC-Empa maintains a set of laboratory standards obtained from the CCL that are regularly compared with the CCL by way of traveling standards and by addition of new laboratory standards from the CCL. For the assignment of the mole fractions to the TS, the following calibration scales were used:

CO: WMO-2000/2004 scale [Novelli, et al., 2003]

CO_2: WMOX2007 scale [*Zhao and Tans*, 2006]

CH_4: NOAA04 scale [Dlugokencky, et al., 2005]

N_2O: WMO2006A

More information about the NOAA/ESRL calibration scales can be found on the GMD website (www.esrl.noaa.gov/gmd/ccl). The scales were transferred to the TS using the following instruments at WCC-Empa:

CO: Aerolaser AL5001 (Vacuum UV Fluorescence) and Aerodyne mini-cw (Mid-IR Spectroscopy using a Quantum Cascade Laser).

CO_2 and CH_4: Picarro G1301 (Cavity Ring Down Spectroscopy).

Table 18 gives an overview of the WCC-Empa laboratory standards that were used for transferring the CCL calibration scales to the WCC-Empa TS. For internal consistency among the available LS at WCC-Empa, new values have been assigned to the NOAA standards for some tanks. The results including estimated standard uncertainties of the WCC-Empa TS are listed in Table 19, and Figure 16 shows the analysis of the TS over time. Usually, a number of individual analysis results dating from before and after the audit was averaged. During these periods, the standards remained usually stable with no significant drift. If drift is present, this will lead to an increased uncertainty of the TS.

Table 18. NOAA/ESRL laboratory standards at WCC-Empa.

Cylinder	CO	sd	CH_4	sd	N_2O	sd	CO_2	sd	CO	sd	CH_4	sd	N_2O	sd	CO_2	sd
	NOAA assigned values								WCC-Empa assigned values							
	(ppb)		(ppb)		(ppb)		(ppm)		(ppb)		(ppb)		(ppb)		(ppm)	
CA05373	130.0*	0.4	1608.57	0.08	NA	NA	326.96	0.00	131.7	0.2	1607.82	0.04	294.43	0.03	326.77	0.01
CC339523	347.9*	0.3	1854.60	0.13	322.52	0.12	396.88	0.06	352.2	0.3	1855.31	0.03	322.66	0.02	396.97	0.02
CC339524	390.7*	0.2	1980.28	0.30	355.24	0.16	795.42	0.06	395.4	0.4	1981.77	0.04	355.32	0.02	796.60	0.04
CC311846	166.4*	0.1	1805.24	0.12	317.24	0.11	377.86	0.04	168.9	0.3	1805.61	0.11	317.40	0.01	377.86	0.02
CA02854	295.5#	3.0	NA	NA	NA	NA	NA	NA	295.3	0.6	1677.14	0.08	NA	NA	347.36	0.03

*WMO-2004, #WMO-2000

Table 19. Calibration summary of the WCC-Empa travelling standards.

TS	CO	uCO	CH_4	uCH_4	CO_2	uCO_2	N_2O	uN_2O
	(ppb)	(ppb)	(ppb)	(ppb)	(ppm)	(ppm)	(ppb)	(ppb)
101116_CA06476	527.68	0.67	2437.15	0.17	394.58	0.01	358.56	0.08
100518_CB08830	1174.88	2.36	1987.42	0.04	293.09	0.02	299.15	0.01
110818_CB08871	477.28	0.09	2631.77	0.08	403.78	0.03	321.80	0.03
110818_CB08874	29700.00	297.00	2297.41	0.08	137.02	0.01	297.31	0.09

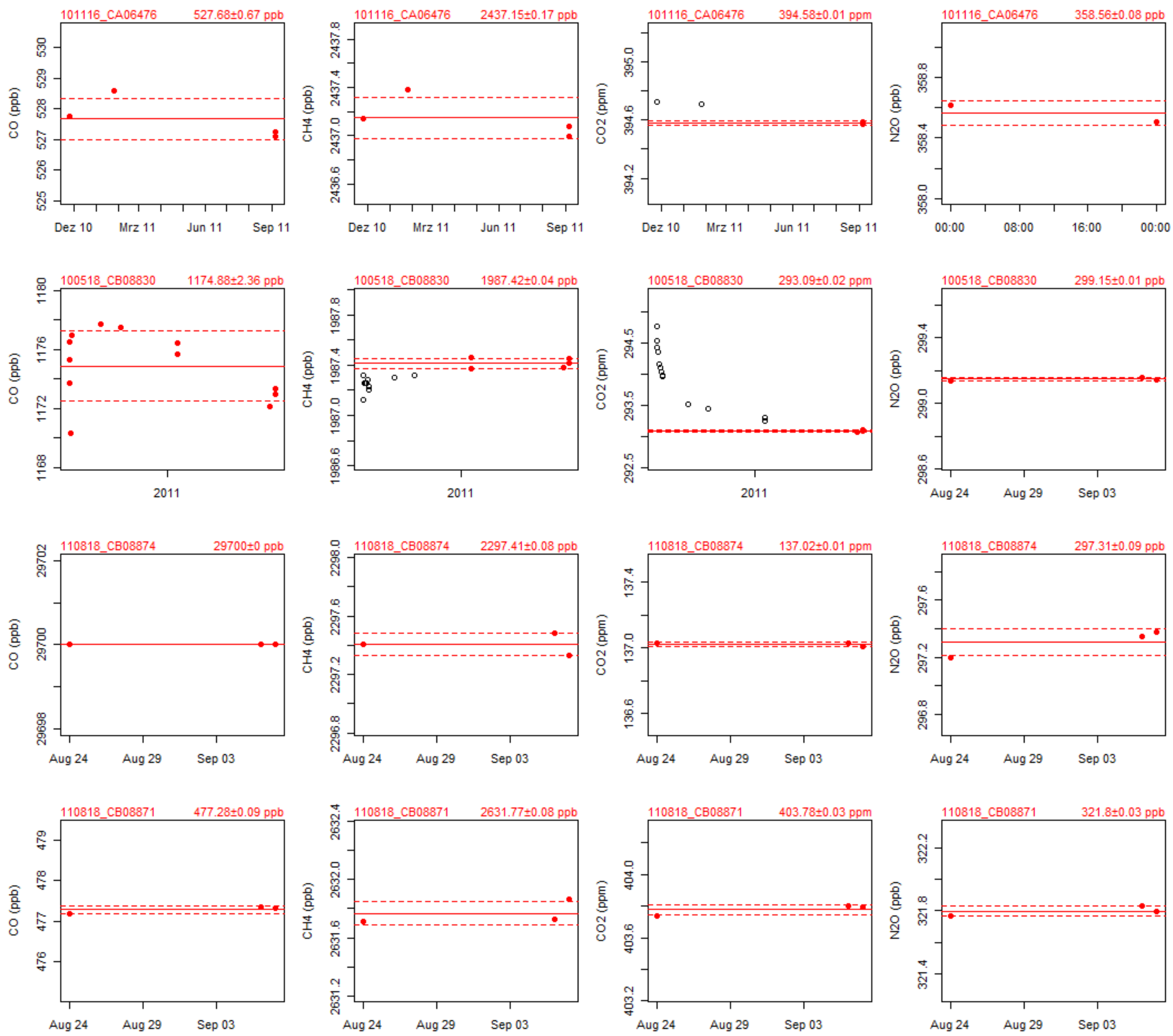

Figure 16. Results of the WCC-Empa TS calibrations. The red solid line is the average of the points that were considered for the assignment of the values; the red dotted line corresponds to the standard deviation of the measurement.

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Ozone Audit Executive Summary (BKT)

0.1	Station Name:	Bukit Kototabang
0.2	GAW ID:	BKT
0.3	Coordinates/Elevation:	0.20194°S 100.31810°E (864 m a.s.l.)
Parameter:		Surface Ozone

1.1	Date of Audit:	2011-11-01 to 2011-11-05
1.2	Auditor:	Dr. C. Zellweger, Dr. M. Steinbacher
1.3	Station staff involved in audit:	Mr. Herizal, Mr. Asep F. Ilahi, Mr. Carles Siregar, Mr. Alberth C. Nahas, Mr. Agusta Kurniawan
1.4	Ozone Reference [SRP]:	NIST SRP#15
1.5	Ozone Transfer Standard [TS]	
1.5.1	Model and serial number:	TEI 49i PS #0810-153, BKG -0.2, COEF 1.009
1.5.2	Range of calibration:	0 – 200 ppb
1.5.3	Mean calibration (ppb):	(1.0020±0.0010) • [SRP] + (0.14±0.10)
1.6	Ozone Analyser [OA]	
1.6.1	Model:	TEI 49C #58547-318
1.6.2	Range of calibration:	0 – 100 ppb
1.6.3	Coefficients at start of audit	BKG = -0.1; COEFF = 1.005
1.6.4	Calibration at start of audit (ppb):	[OA] = (1.0022±0.0008) • [SRP] + (0.0±0.1)
1.6.5	Unbiased ozone mixing ratio (ppb) at start of audit:	X_{O3} (ppb) = ([OA] + 0.0 ppb) / 1.0022
1.6.6	Standard uncertainty remaining after compensation of calibration bias (ppb):	u_{O3} (ppb) = sqrt (0.3 ppb^2 + 2.65e-05 * X_{O3}^2)
1.6.7	Coefficients after audit	unchanged
1.6.8	Calibration after audit (ppb):	unchanged
1.6.9	Unbiased ozone mixing ratio (ppb) after audit:	unchanged
1.6.10	Standard uncertainty remaining after compensation of calibration bias (ppb):	unchanged
1.7	Comments: Main ozone analyser	
1.8	Reference:	WCC-Empa Report 11/4

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

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Ozone Audit Executive Summary (BKT)

0.1	Station Name:	Bukit Kototabang
0.2	GAW ID:	BKT
0.3	Coordinates/Elevation:	0.20194°S 100.31810°E (864 m a.s.l.)
Parameter:		Surface Ozone

1.1	Date of Audit:	2011-11-01 to 2011-11-05
1.2	Auditor:	Dr. C. Zellweger, Dr. M. Steinbacher
1.3	Station staff involved in audit:	Mr. Herizal, Mr. Asep F. Ilahi, Mr. Carles Siregar, Mr. Alberth C. Nahas, Mr. Agusta Kurniawan
1.4	Ozone Reference [SRP]:	NIST SRP#15
1.5	Ozone Transfer Standard [TS]	
1.5.1	Model and serial number:	TEI 49i PS #0810-153, BKG -0.2, COEF 1.009
1.5.2	Range of calibration:	0 – 200 ppb
1.5.3	Mean calibration (ppb):	(1.0020±0.0010) • [SRP] + (0.14±0.10)
1.6	Ozone Calibrator [OC]	
1.6.1	Model:	TEI 49i-PS #0917736398
1.6.2	Range of calibration:	0 – 100 ppb
1.6.3	Coefficients at start of audit	BKG = 0.1; COEF = 1.024
1.6.4	Calibration at start of audit (ppb):	[OC] = (0.9825±0.001) • [SRP] - (0.6±0.1)
1.6.5	Unbiased ozone mixing ratio (ppb) at start of audit:	X_{O3} (ppb) = ([OC] + 0.6 ppb) / 0.9825
1.6.6	Standard uncertainty remaining after compensation of calibration bias (ppb):	u_{O3} (ppb) = sqrt (0.3 ppb^2 + 2.71e-05 * $X_{O3}{}^2$)
1.6.7	Coefficients after audit	unchanged
1.6.8	Calibration after audit (ppb):	unchanged
1.6.9	Unbiased ozone mixing ratio (ppb) after audit:	unchanged
1.6.10	Standard uncertainty remaining after compensation of calibration bias (ppb):	unchanged
1.7	Comments: Station calibrator	
1.8	Reference:	WCC-Empa Report 11/4

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

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Carbon Monoxide Audit Executive Summary (BKT)

0.1	Station Name:	Bukit Kototabang
0.2	GAW ID:	BKT
0.3	Coordinates/Elevation:	0.20194°S 100.31810°E (864 m a.s.l.)
Parameter:		Carbon Monoxide

1.1	Date of Audit:	2009-10-26 to 2009-10-27
1.2	Auditor:	Dr. J. Klausen
1.3	Station staff involved in audit:	Mr. Herizal, Mr. Asep F. Ilahi, Mr. Carles Siregar, Mr. Alberth C. Nahas, Mr. Agusta Kurniawan
1.4	WCC-Empa CO Reference:	NOAA laboratory standards (WMO-2000 scale)
1.5	CO Transfer Standard [TS]	WCC-Empa dilution system, zero air, 090325_CA06494 44.86 ppm CO in air WMO-2000 scale
1.6	Station Analyser:	
1.6.1	Analyser Model:	Horiba APMA360 #890617034
1.6.2	Range of calibration:	0 – 1000 ppb
1.6.3	Coefficients at start of audit	Zero -1, SPAN 1.0338
1.6.4	Calibration at start of audit (ppb):	CO = (0.8982±0.0027) • X_{CO} + (0.2±0.8)
1.6.5	Unbiased CO mixing ratio (ppb) at start of audit:	X_{CO} (ppb) = (CO – 0.2) / 0.8982
1.6.6	Standard uncertainty after compensation of calibration bias at start of audit (ppb):	u_{CO} (ppb) = sqrt (3.4 ppb^2 + 1.01e-04 * X_{CO}^2)
1.6.7	Coefficients after audit	Zero -1, SPAN 1. 1035
1.6.8	Calibration after audit (ppb):	CO = (0.9891±0.0025) • X_{CO} - (0.2±1.1)
1.6.9	Unbiased CO mixing ratio (ppb) after audit:	X_{CO} (ppb) = (CO + 0.2) / 0.9891
1.6.10	Standard uncertainty after compensation of calibration bias after audit(ppb):	u_{CO} (ppb) = sqrt (5.8 ppb^2 + 1.01e-04 * X_{CO}^2)
1.7	Comments:	NA
1.8	Reference:	WCC-Empa Report 11/4

[CO]: Instrument readings; X: mixing ratios on the WMO-2000 CO scale.

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Carbon Monoxide Audit Executive Summary (BKT)

0.1	Station Name:	Bukit Kototabang
0.2	GAW ID:	BKT
0.3	Coordinates/Elevation:	0.20194°S 100.31810°E (864 m a.s.l.)
Parameter:		Carbon Monoxide

1.1	Date of Audit:	2011-11-05 to 2011-11-07
1.2	Auditor:	Dr. C. Zellweger, Dr. M. Steinbacher
1.3	Station staff involved in audit:	Mr. Herizal, Mr. Asep F. Ilahi, Mr. Carles Siregar, Mr. Alberth C. Nahas, Mr. Agusta Kurniawan
1.4	WCC-Empa CO Reference:	NOAA laboratory standards (WMO-2000 scale)
1.5	CO Transfer Standard [TS]	WCC-Empa dilution system, zero air, 090325_CA06494 44.86 ppm CO in air WMO-2000 scale
1.6	Station Analyser:	
1.6.1	Analyser Model:	Horiba APMA360 #890617034
1.6.2	Range of calibration:	0 – 900 ppb
1.6.3	Coefficients at start of audit	Zero -1, SPAN 1. 1035
1.6.4	Calibration at start of audit (ppb):	CO = (0.9092±0.0016) • X_{CO} + (4.5±0.9)
1.6.5	Unbiased CO mixing ratio (ppb) at start of audit:	X_{CO} (ppb) = (CO – 4.5) / 0.9092
1.6.6	Standard uncertainty after compensation of calibration bias at start of audit (ppb):	u_{CO} (ppb) = sqrt (4.2 ppb^2 + 1.01e-04 * X_{CO}^2)
1.6.7	Coefficients after audit	NA
1.6.8	Calibration after audit (ppb):	NA
1.6.9	Unbiased CO mixing ratio (ppb) after audit:	NA
1.6.10	Standard uncertainty after compensation of calibration bias after audit(ppb):	NA
1.7	Comments:	First comparison with dilution system
1.8	Reference:	WCC-Empa Report 11/4

[CO]: Instrument readings; X: mixing ratios on the WMO-2000 CO scale.

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Carbon Monoxide Audit Executive Summary (BKT)

0.1	Station Name:	Bukit Kototabang
0.2	GAW ID:	BKT
0.3	Coordinates/Elevation:	0.20194°S 100.31810°E (864 m a.s.l.)
Parameter:		Carbon Monoxide

1.1	Date of Audit:	2011-11-05 to 2011-11-07
1.2	Auditor:	Dr. C. Zellweger, Dr. M. Steinbacher
1.3	Station staff involved in audit:	Mr. Herizal, Mr. Asep F. Ilahi, Mr. Carles Siregar, Mr. Alberth C. Nahas, Mr. Agusta Kurniawan
1.4	WCC-Empa CO Reference:	NOAA laboratory standards (WMO-2000 scale)
1.5	CO Transfer Standard [TS]	WCC-Empa dilution system, zero air, 110818_CB08874 29.70 ppm CO in air WMO-2000 scale
1.6	Station Analyser:	
1.6.1	Analyser Model:	Horiba APMA360 #890617034
1.6.2	Range of calibration:	0 – 900 ppb
1.6.3	Coefficients at start of audit	Zero -1, SPAN 1. 1035
1.6.4	Calibration at start of audit (ppb):	CO = (0.9019±0.0019) • X_{CO} + (4.0±1.1)
1.6.5	Unbiased CO mixing ratio (ppb) at start of audit:	X_{CO} (ppb) = (CO – 4.0) / 0.9019
1.6.6	Standard uncertainty after compensation of calibration bias at start of audit (ppb):	u_{CO} (ppb) = sqrt (6.2 ppb^2 + 1.01e-04 * X_{CO}^2)
1.6.7	Coefficients after audit	NA
1.6.8	Calibration after audit (ppb):	NA
1.6.9	Unbiased CO mixing ratio (ppb) after audit:	NA
1.6.10	Standard uncertainty after compensation of calibration bias after audit(ppb):	NA
1.7	Comments:	Second comparison with dilution system
1.8	Reference:	WCC-Empa Report 11/4

[CO]: Instrument readings; X: mixing ratios on the WMO-2000 CO scale.

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Carbon Monoxide Audit Executive Summary (BKT)

0.1	Station Name:	Bukit Kototabang
0.2	GAW ID:	BKT
0.3	Coordinates/Elevation:	0.20194°S 100.31810°E (864 m a.s.l.)
Parameter:		Carbon Monoxide

1.1	Date of Audit:	2011-11-07
1.2	Auditor:	Dr. C. Zellweger, Dr. M. Steinbacher
1.3	Station staff involved in audit:	Mr. Herizal, Mr. Asep F. Ilahi, Mr. Carles Siregar, Mr. Alberth C. Nahas, Mr. Agusta Kurniawan
1.4	WCC-Empa CO Reference:	NOAA laboratory standards (WMO-2000 scale)
1.5	CO Transfer Standard [TS]	WCC-Empa TS, WMO-2000 scale
1.6	Station Analyser:	
1.6.1	Analyser Model:	Horiba APMA360 #890617034
1.6.2	Range of calibration:	0 – 900 ppb
1.6.3	Coefficients at start of audit	Zero -1, SPAN 1. 1035
1.6.4	Calibration at start of audit (ppb):	CO = (0.9093±0.0020) $\cdot$ X_{CO} - (1.2±1.4)
1.6.5	Unbiased CO mixing ratio (ppb) at start of audit:	X_{CO} (ppb) = (CO + 1.2) / 0.9093
1.6.6	Standard uncertainty after compensation of calibration bias at start of audit (ppb):	u_{CO} (ppb) = sqrt (9.3 ppb^2 + 1.01e-04 * X_{CO}^2)
1.6.7	Coefficients after audit	NA
1.6.8	Calibration after audit (ppb):	NA
1.6.9	Unbiased CO mixing ratio (ppb) after audit:	NA
1.6.10	Standard uncertainty after compensation of calibration bias after audit(ppb):	NA
1.7	Comments:	Comparison with TS
1.8	Reference:	WCC-Empa Report 11/4

[CO]: Instrument readings; X: mixing ratios on the WMO-2000 CO scale.

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Methane Audit Executive Summary (BKT)

0.1	Station Name:	Bukit Kototabang
0.2	GAW ID:	BKT
0.3	Coordinates/Elevation:	0.20194°S 100.31810°E (864 m a.s.l.)
Parameter:		Methane

1.1	Date of Audit:	2011-11-03 to 2011-11-07
1.2	Auditor:	Dr. C. Zellweger, Dr. M. Steinbacher
1.3	Station staff involved in audit:	Mr. Herizal, Mr. Asep F. Ilahi, Mr. Carles Siregar, Mr. Alberth C. Nahas, Mr. Agusta Kurniawan
1.4	WCC-Empa CH_4 Reference:	NOAA laboratory standards (NOAA04 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 # CFADS-027
1.6.2	Range of calibration:	1986 – 2632 ppb
1.6.3	Coefficients at start of audit	NA
1.6.4	Calibration at start of audit (ppb):	$CH_4 = (1.00003 \pm 0.00012) \cdot X_{CH4} - (0.63 \pm 0.30)$
1.6.5	Unbiased CH_4 mixing ratio (ppb) at start of audit:	X_{CH4} (ppb) = $(CH_4 + 0.63) / 1.00003$
1.6.6	Standard uncertainty after compensation of calibration bias at start of audit (ppb):	u_{CH4} (ppb) = sqrt (0.11 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 11/4

[CH_4]: Instrument readings; X: mixing ratios on the NOAA04 CH_4 scale.

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Carbon Dioxide Audit Executive Summary (BKT)

0.1	Station Name:	Bukit Kototabang
0.2	GAW ID:	BKT
0.3	Coordinates/Elevation:	0.20194°S 100.31810°E (864 m a.s.l.)
Parameter:		Carbon Dioxide

1.1	Date of Audit:	2011-11-03 to 2011-11-07
1.2	Auditor:	Dr. C. Zellweger, Dr. M. Steinbacher
1.3	Station staff involved in audit:	Mr. Herizal, Mr. Asep F. Ilahi, Mr. Carles Siregar, Mr. Alberth C. Nahas, Mr. Agusta Kurniawan
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 # CFADS-027
1.6.2	Range of calibration:	137 – 404 ppm
1.6.3	Coefficients at start of audit	NA
1.6.4	Calibration at start of audit (ppm):	CO_2 = (0.99285±0.00002) · X_{CO2} + (2.81±0.01)
1.6.5	Unbiased CO_2 mixing ratio (ppm) at start of audit:	X_{CO2} (ppm) = (CO_2 – 2.82) / 0.99285
1.6.6	Standard uncertainty after compensation of calibration bias at start of audit (ppm):	u_{CO2} (ppm) = sqrt (0.00 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:	Calibration based on NOAA assignments of BKT laboratory standards; perfect agreement can be obtained by very small adjustments of the NOAA values, see full report for details.
1.8	Reference:	WCC-Empa Report 11/4

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

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LIST OF ABBREVIATIONS

BKG	Background
BKT	Bukit Kototabang
BMKG	Badan Meteorologi Klimatologi dan Geofisika (Meteorological, Climatological and Geophysical Agency)
COEF	Coefficient
CRDS	Cavity Ring-Down Spectroscopy
DAQ	Data Acquisition System
DQO	Data Quality Objective
dtm	Date/Time
ECD	Electron Capture Detector
GAWSIS	GAW Station Information System
GC	Gas Chromatograph
LAPAN	National Institute of Aeronautics and Space
LS	Laboratory Standard
MFC	Mass Flow Controller
NDIR	Non-Dispersive Infrared
OA	Ozone Analyser
OC	Ozone Calibrator
PFA	Perfluoroalkoxy
PTFE	Polytetrafluoroethylene
SOP	Standard Operating Procedure
SRP	Standard Reference Photometer
SS	Stainless Steel
TS	Traveling Standard
UPS	Uninterruptible Power Supply
UV	Ultra Violet
WCC-Empa	World Calibration Centre for Surface Ozone, Carbon Monoxide and Methane
WDCGG	World Data Centre for Greenhouse Gases
WMO	World Meteorological Organization
WS	Working Standard