SYSTEM AND PERFORMANCE AUDIT OF SURFACE OZONE, METHANE, CARBON DIOXIDE, NITROUS OXIDE AND CARBON MONOXIDE

AT THE

GLOBAL GAW STATION BUKIT KOTOTABANG MAY 2014

Submitted to the World Meteorological Organization by

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EXECUTIVE SUMMARY AND RECOMMENDATIONS

The seventh system and performance audit by WCC-Empa[1] at the Global GAW station Bukit Kototabang was conducted from 20 - 27 May 2014 in agreement with the WMO/GAW quality assurance system (WMO, 2007a). Monitoring and research activities at the Bukit Kototabang (BKT) global GAW station are 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], in July 2008 (Zellweger et al., 2008) and in November 2011 (Zellweger et al., 2011).

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, carbon monoxide and nitrous oxide measurements in particular. The ozone assessment was made according to the method developed by WCC-Empa and QA/SAC Switzerland (Klausen et al., 2003).

The report is distributed to the BKT station manager, the Indonesian 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 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.

Further information is available from GAWSIS (http://gaw.empa.ch/gawsis) and the station web site (http://gaw-kototabang.com/index_en.php).

[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. Internet connection (shared with BMKG Jakarta) is available; however, the bandwidth is low for the transfer of larger files and remote access. The power supply to the station has frequent short term outages, which are bridged by an uninterruptable power supply (UPS) unit and a large diesel generator located at the junction to the main road (approx. 2 km from the station). This backup system was working fine during the audit, and no power outages that affected the instruments occurred.

Recommendation 1 (, important, 2015)**
An internet connection has been established at BKT. However, there are still some issues with the reliability of this connection. Additionally, the internet has a slow connection speed that impedes data transfer, particularly for large files. Establishing an independent internet connection is strongly encouraged.

Station Management and Operation

Bukit Kototabang is visited during weekdays by approximately 10 -15 scientists, technical and administrational staff. During weekends, one to three operators are present during working hours (07:30-16:00). The operation and maintenance of the station and the measurements improved significantly over the past few years however, data analysis and evaluation capabilities of the station staff need to be improved. It remains important that staff with a scientific background is directly involved with the daily operation of the BKT station. In addition, the financial planning has to take the instrument maintenance costs as well as needed peripherals into consideration.

Recommendation 2 (*, critical, ongoing)**
The use of data produced by BKT has yet to be optimized for scientific purposes. A joint collaboration research between BKT and BMKG Jakarta (and other institutions) might be a good avenue to make the most of data to be utilized. At the moment, engaging to research activities is bureaucratically limited for BKT and therefore, bridging the station with the headquarter seems to be worthy of consideration.

Recommendation 3 (*, critical, ongoing)**
In the past few years, the BKT station has received significant support from BMKG Jakarta in terms of purchasing instruments and setting up new monitoring parameters; the instruments have been valuable additions for observational activities. Such support, however, is often not accompanied with relevant peripheral needs, such as calibration and maintenance cost and operational trainings. The financial planning for the BKT operation must include these additional expenses for a successful and sustainable operation of BKT.

Recommendation 4 (*, critical, ongoing)**
In case of instrument failures, a budget must be available to solve instrumental issues in due time.

Recommendation 5 (*, critical, ongoing)**
BMKG 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 BMKG staff. Highest priority has currently the training in data evaluation tools, e.g. appropriate statistical software such as R (www.r-project.org) or similar tools.

Air Inlet System

In 2010, a common air inlet system for surface O_3, CO, NO_x and SO_2 was installed. The inlet system was found to be adequate during the WCC-Empa audit in 2011. During the current audit, a problem with the common manifold was identified for surface ozone measurements. A significant signal of a UV-absorbing contaminant resulting in ozone readings of approx. 200 ppb was observed when the air was sampled from the common inlet. Approximately the same signal was also measured when the ozone analyser sampled directly laboratory air. The inlet was briefly checked for leaks, but further test will be necessary to confirm suitability of the current set-up.

Recommendation 6 (*, critical, 2014)**
The current PTFE/PFA inlet system is potentially leaking or contaminated with a UV absorbing pollutant. Further leak checks will be needed. In case of contamination, the inlet lines should be completely replaced. It is further recommended to move the location of the water trap to the end of the inlet line. All connections should face upward to minimize the risk of water entering the instruments.

Recommendation 7 (*, critical, 2014)**
The laboratory needs to be kept clean from any potential pollution sources. One potential contaminant, an automatic perfume spray, has been removed during the audit. It should not be re-installed inside the laboratory.

Recommendation 8 (*, critical, 2014)**
The problem with the current inlet system could not be solved during the audit. As a solution, an independent inlet line bypassing also the fridge was installed during the audit. Ozone measurements should be continued using this new inlet line; however, measures should be taken to avoid water condensation in the tubing. The air conditioning units should never blow cool air directly to the instruments and inlet systems. It is further recommended to keep the laboratory at a warm temperature of +27°C.

The Picarro G1301 CH_4/CO_2 and the Thermo Iris 4600 N_2O analysers are sharing direct Eaton Synflex 1300 sampling lines to three different levels of the tower (10m, 20m and 32m). The lines are continuously flushed to minimise the residence time. This inlet is adequate for the CH_4/CO_2 and N_2O measurements when appropriate maintenance is performed. At the time of the audit, all critical orifices of the control unit were blocked due to pollution. Furthermore, the 10 m inlet line was completely blocked and was replaced.

Recommendation 9 (*, critical, ongoing)**
The flow in the inlet lines and the calibration unit of the Picarro analyser need to be regularly checked. Cleaning should be done in regular intervals (monthly check recommended). It is further recommended to use inlet filters at the air intakes of the Picarro valve box (e.g. Swagelok inline or tee-type filters).

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 periods between August 1999 and July 2001, and November 2013 and May 2014.

Instrumentation. The station is equipped with one ozone analysers (TEI 49C). The instrumentation is adequate for its intended purpose; however, the instrument is reaching the end of its expected lifetime. At the time of the audit, the ozone instrument was found to be in bad condition. The instrument was measuring significantly too high ozone mole fractions of approx. 200 ppb since November 2013. Several instrument tests were made, and the following problems were identified:

- The ozone scrubber of the analyser was not working properly. It was replaced with the scrubber of the old TEI 49 ozone instrument.
- The inlet line (manifold) was either leaking or contaminated. It was replaced by an independent separate inlet line during the audit.

Recommendation 10 (, important, 2015/16)**
The current ozone instrument is reaching the end of its expected lifetime. Replacement should be considered in the near future to ensure continuous ozone time series.

Recommendation 11 (, important, 2014)**
The scrubber from the old TEI 49 instrument is only a temporary solution. Replacement with an original TEI 49C ozone scrubber is required.

Standards. The station is equipped with an ozone standard (TEI 49i-PS) and a Thermo TEI 111 zero air generator. With this instrumentation, adequate ozone calibrations are possible. Comparisons are performed every 3 months.

Recommendation 12 (*, minor, ongoing)
The current practice should be continued. Adjustments of the calibration settings should never be made based upon the 3-monthly comparisons.

Intercomparison (Performance Audit). The ozone analyser and calibrator of BKT 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 (TS), and no further corrections were applied. The following equations characterise the bias of the instruments:

TEI 49C #58547-318 (BKG +0.1 ppb, COEF 1.014):

Unbiased O_3 mixing ratio (ppb): X_{O3} (ppb) = ([OA] + 0.86 ppb) / 0.9989 (1a)

Standard uncertainty (ppb): u_{O3} (ppb) = sqrt (0.27 ppb^2 + 2.59e-05 * X_{O3}^2) (1b)

TEI 49i-PS #0917736398 (BKG +0.0 ppb, COEF 1.012, initial comparison):

Unbiased O_3 mixing ratio (ppb): X_{O3} (ppb) = ([OC] + 0.79 ppb) / 0.9890 (1b)

Standard uncertainty (ppb): u_{O3} (ppb) = sqrt (0.27 ppb^2 + 2.64e-05 * X_{O3}^2) (1c)

TEI 49i-PS #0917736398 (BKG -0.5 ppb, COEF 1.023, after adjustment):

Unbiased O_3 mixing ratio (ppb): X_{O3} (ppb) = ([OC] + 0.06 ppb) / 1.0022 (1d)

Standard uncertainty (ppb): u_{O3} (ppb) = sqrt (0.27 ppb^2 + 2.54-05 * X_{O3}^2) (1e)

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

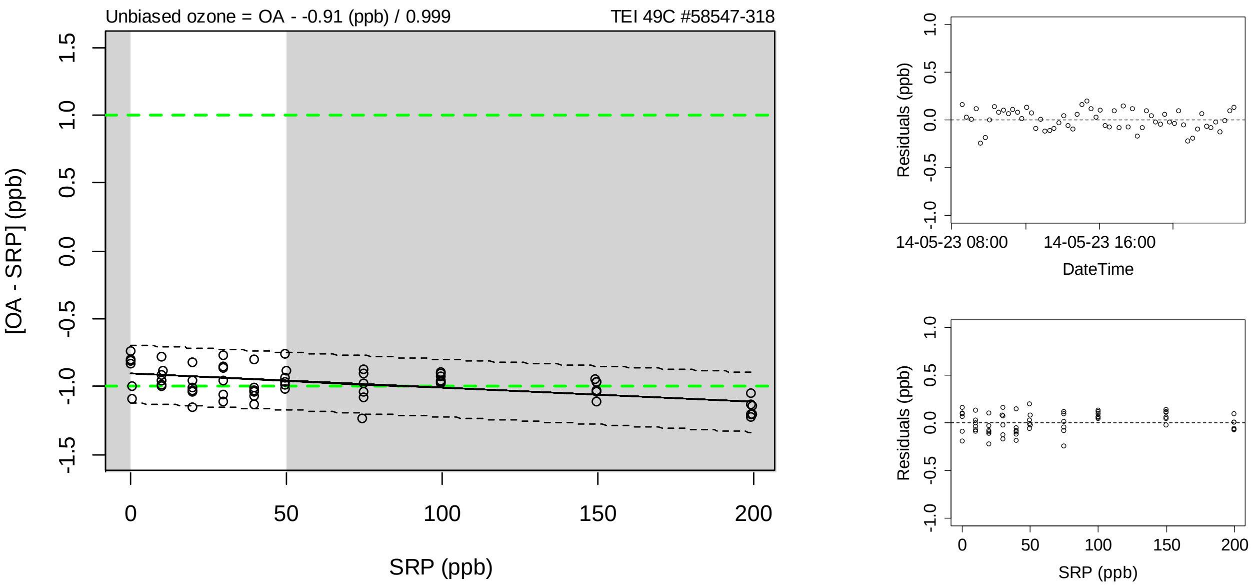

Figure 1. *Left: Bias of the BKT ozone analyser (TEI 49C #58547-318) with respect to the SRP as a function of mole fraction. Each point represents the average of the last 10 one-minute values at a given level. The white area represents the mole fraction range relevant for BKT, whereas the green lines correspond to the DQOs. 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).*

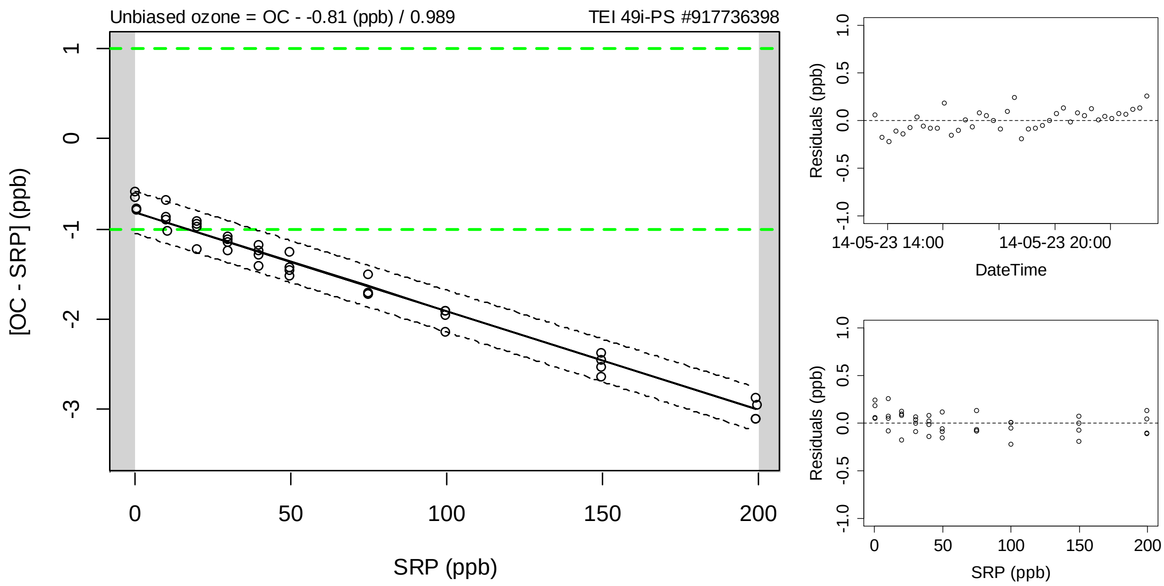

Figure 2. *Same as above for the BKT ozone calibrator TEI 49i-PS #0917736398 before adjustment of the calibration factors.*

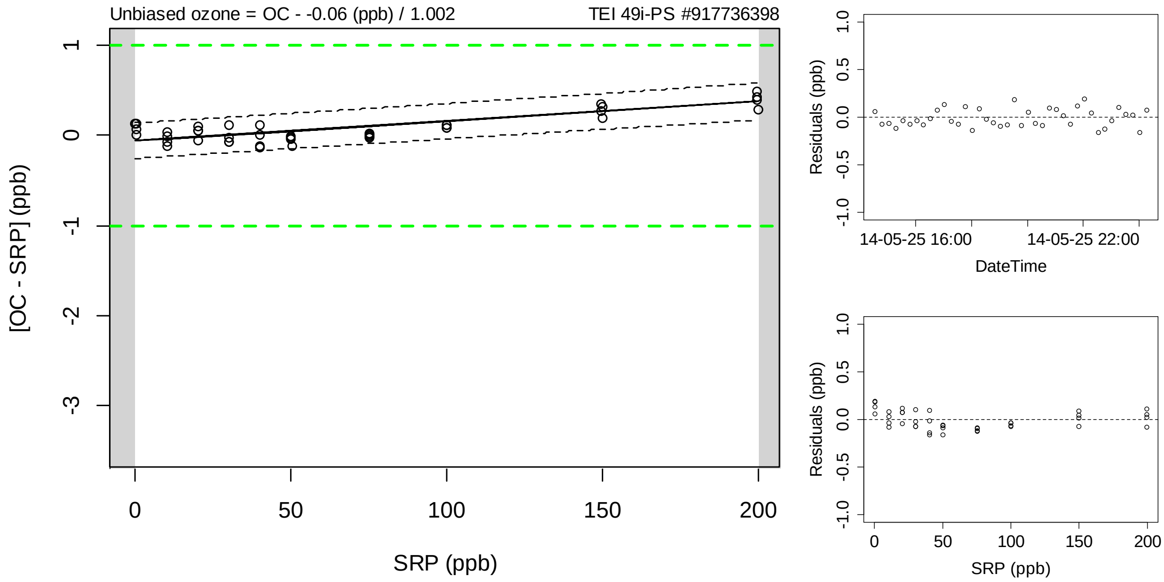

Figure 3. *Same as above for the BKT ozone calibrator TEI 49i-PS #0917736398 after adjustment of the calibration factors.*

The results of the comparison can be summarised as follows:

The TEI 49C #58547-318 ozone analyser is in good calibration and the bias is within the WMO/GAW DQOs for the relevant mole fraction range. A small negative bias was observed. This was not corrected because it potentially will disappear after longer operation with the replacement scrubber.

Initial calibration of the BKT ozone calibrator confirmed the comparison made by WCC-Empa in 2011. Since the instrument remained stable, the calibration factors were adjusted to have direct traceability to the SRP of WCC-Empa.

The instrumentation at BKT is adequate for ozone measurements.

> **Recommendation 13 (*, minor, 2014)**
> *If the bias of -1 ppb of the ozone calibrator will be confirmed by future comparison, adjustment should be considered.*

Carbon Monoxide Measurements

On-going measurement of carbon monoxide at Bukit Kototabang commenced in July 2001, and continuous data series are available since then. Carbon monoxide measurements at Bukit Kototabang are made using NDIR technique. The system has not changed since the last audit by WCC-Empa in 2011.

Instrumentation. Bukit Kototabang is equipped with a Horiba APMA 360 NDIR CO analyser.

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. WCC-Empa recommended the use of the standards of the Picarro system for regular direct calibrations of the instrument every three months. However, these calibrations were never made since the last WCC-Empa audit. Furthermore, most Picarro standards were found to be empty at the time of the audit (see also further below). Regular automatic zero and span (at approx. 260 ppb) checks are performed every 4 hours.

> **Recommendation 14 (***, critical, ongoing)**
> *3-monthly direct calibrations using one of the Picarro standards (preferably with high CO between 400 and 1000 ppb) must be re-initiated.*

Intercomparison (Performance Audit). The comparison involved repeated challenges of the BKT instruments with randomised carbon monoxide levels using WCC-Empa travelling standards. The following equations characterise the instrument bias, and the results are further illustrated in Figure 4 with respect to the WMO GAW DQOs (WMO, 2010, 2011):

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

Unbiased CO mixing ratio: X_{CO} (ppb) = (CO + 0.4) / 0.8728 (2a)

Remaining standard uncertainty: u_{CO} (ppb) = sqrt (2.0 ppb^2 + 1.01e-04 * X_{CO}^2) (2b)

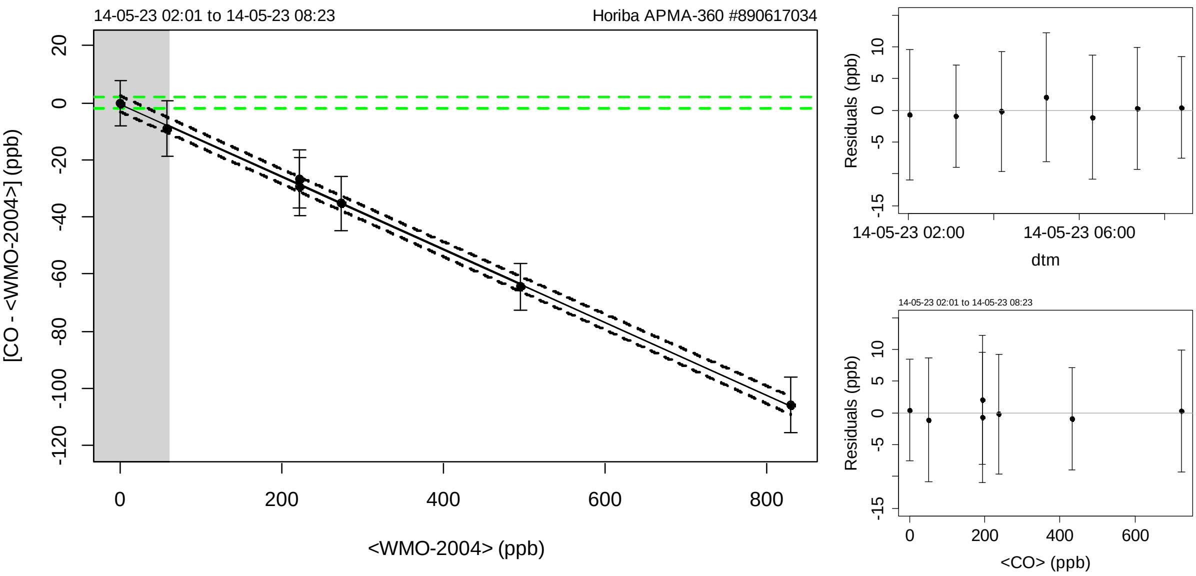

Figure 4. *Left: Bias of the BKT Horiba APMA360 carbon monoxide instrument with respect to the WMO2004 reference scale as a function of mole fraction. The white area represents the mole fraction range relevant for BKT, whereas the green lines correspond to the DQOs. Each point represents the average of data at a given level from a specific run. The error bars show the standard deviation of individual measurement points. The dashed lines around the regression lines are the Working-Hotelling 95% confidence bands. Right: Regression residuals (time dependence and mole fraction dependence).*

The results of the comparisons can be summarised as follows:

Compared to the last audit by WCC-Empa in 2011, the analyser lost approx. 2.6% sensitivity. This corresponds to an average daily loss of sensitivity of -0.004%. It seems that the loss of sensitivity decreased compared to previous audits, where a loss of -0.008% per day was observed between 2008 and 2009, and -0.010% per day between 2009 and 2011. Nevertheless the new results still indicate that the instrument is drifting over time. A similar loss of sensitivity was also observed in the automatic span checks performed between 2011 and now. 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. The decrease of sensitivity is also clearly indicating that the instrument has reached the end of its expected lifetime.

Recommendation 15 (*, critical, 2014/15)**
Due to the age of the analyser and instrument drift, replacement with a new instrument is needed in the very near future. 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

On-going measurement of methane and carbon dioxide at Bukit Kototabang commenced in 2009, and continuous data series are available since then. The measurements at BKT are made using Cavity Ringdown Spectroscopy (CRDS). The system has not significantly changed since the last audit by WCC-Empa.

Instrumentation. Picarro G1301 with custom made valve box, including Nafion drying system. Ambient air is sampled from the tower at three different levels (10, 20, 32 m). During the current audit, the sampling frequency of the 10 and 20 m inlet lines was reduced. The instrument samples now for 5 days from the 32 m level. On every 6^{th} day, the sampling sequence is 20 min at 10 m, 20 min at 20 m followed by 80 min at 32 m. One standard is also measured on this day; every 24 days, all three standards are measured.

Standards. Initially 4 NOAA standards and three working standards provided by WCC-Empa were available for the calibration of the Picarro instrument. At the time of the current audit, only one NOAA tank (550 psi) and one working standard (950 psi) were still containing air. All other NOAA as and working standards were completely empty. WCC-Empa tried to find out why these standards were empty, but no clear answer was received. The working standards could have been used up due to small leaks or excessive overflow during the automatic measurements on the Picarro system. However, the NOAA standards were not connected to an instrument and therefore the consumption of the air cannot be explained.

Recommendation 16 (*, critical, ongoing)**
Calibration gas (both working and NOAA standards) need to be handled with great care. Any unusually high consumption of standard gas requires immediate action such as leak checks etc. The reason of any detected loss must be identified and needs to be documented in the corresponding log files.

BKT ordered another working standard from WCC-Empa before the audit. This standard was delivered to the station at the time of the audit. In addition, the four standards that were used as travelling standards to perform the audit will also remain at the station. In total, 6 working tanks and one NOAA standard are available as after the audit. A complete list of the standards is given in the Appendix.

Intercomparison (Performance Audit). The comparison involved repeated challenges of the BKT instruments with randomised CH_4 and CO_2 levels from traveling standards. The results of the comparison measurements for the individual measurement parameters are summarised and illustrated below.

For the comparison, data of the instrument was corrected based on two working standards with CH_4 and CO_2 numbers assigned by WCC-Empa (130822_CB10280, 120307_CB08975). These two standards were purchased by BKT from Empa before the audit. It should be noted that the instrument itself has no user calibration implemented, which means that the reported values always need to be corrected based on reference gas measurements.

Recommendation 17 (*, minor, 2014)

It could be considered to apply a user calibration to the Picarro instrument. This would require changes in the calibration file. The numbers reported by the instrument would be closer to the accurate values, but a correction based on standard tank measurements would have to be applied anyway. If BMKG wishes to apply a user calibration, WCC-Empa would be willing to supervise the procedure remotely in collaboration with the station staff.

The following equation characterises the instrument bias. The result is further illustrated in Figure 5 to Figure 6 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 + 0.0) / 0.99989	(3a)
Remaining standard uncertainty:	u_{CH4} (ppb) = sqrt (0.1 ppb^2 + 1.30e-07 * $X_{CH4}{}^2$)	(3b)
Unbiased CO_2 mixing ratio:	X_{CO2} (ppm) = (CO_2 – 0.91) / 0.99742	(3c)
Remaining standard uncertainty:	u_{CO2} (ppm) = sqrt (0.01 ppm^2 + 3.28e-08 * $X_{CO2}{}^2$)	(3d)

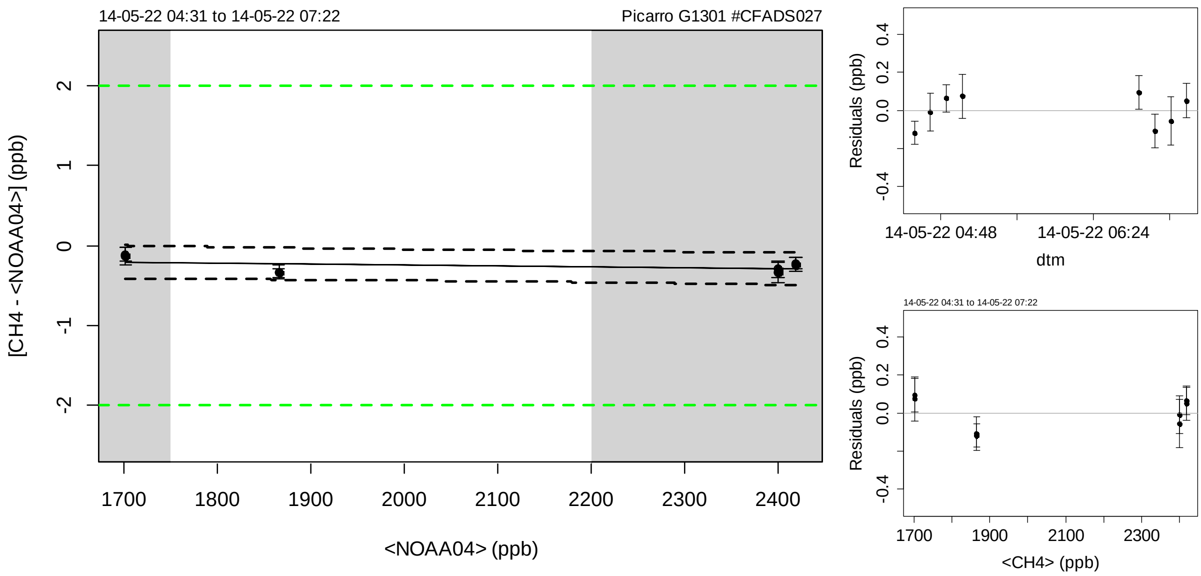

Figure 5. *Left: Bias of the PICARRO G1301 #CFADS-027 methane instrument with respect to the NOAA04 reference scale as a function of mole fraction. The white area represents the mole fraction range relevant for BKT, whereas the red and green lines correspond to the DQOs. Each point represents the average of data at a given level from a specific run. The error bars show the standard deviation of individual measurement points. The dashed lines around the regression lines are the Working-Hotelling 95% confidence bands. Right: Regression residuals (time dependence and mole fraction dependence).*

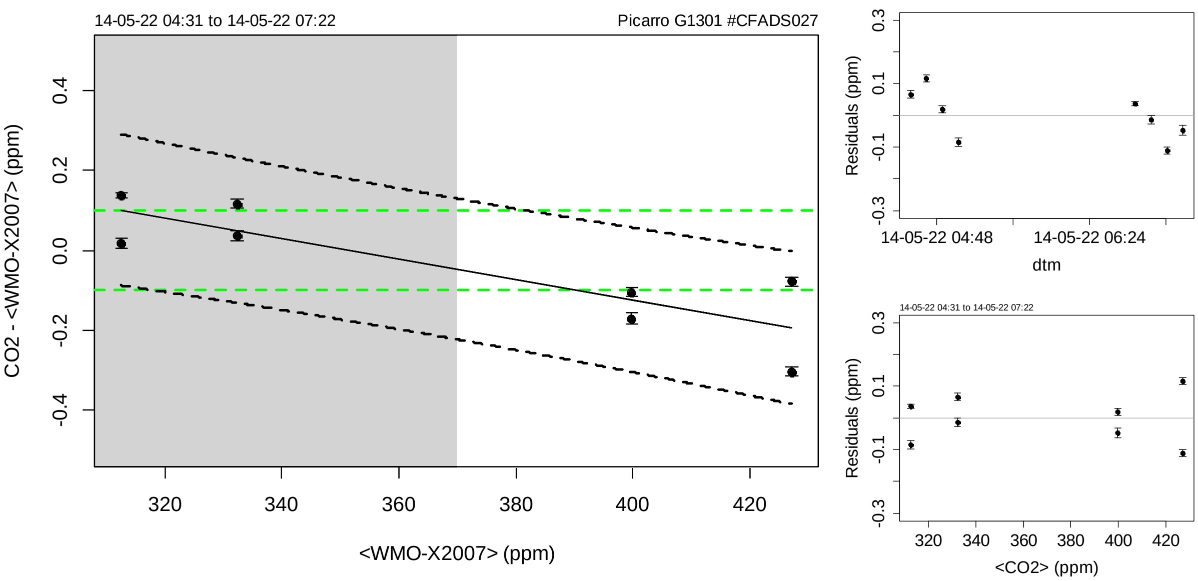

Figure 6. *Same as above for CO_2.*

The results of the comparisons can be summarised as follows:

Agreement within the WMO/GAW DQOs of ±2 ppb was found in the relevant mole fraction range of methane. The bias was slightly larger for CO_2. The larger deviation at CO_2 mole fractions above 400 ppm is probably due to small uncertainties of the two standards used to assign CO_2 values. The standards had low CO_2 of 332.18 and 361.70 ppm respectively, which required extrapolation to the values above 400 ppm. It is expected that calibration improves again with the availability of more CO_2 standards at BKT.

Recommendation 18 (, important, ongoing)**
The standards used to calibrate the Picarro instrument must 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 is regarded as optimal.

The results of the comparison show that the CO_2/CH_4 instrumentation is fully adequate. However, the current instrument is now 5 years old, and future support by the manufacturer might not be guaranteed. The instrument is still relying on Windows XP, which is no longer supported by Microsoft. A factory upgrade to a newer operating system is also not possible, since this version is no longer supported by Picarro. Therefore, long-term planning needs to allocated funds for a replacement of the instrument.

Recommendation 19 (, important, 2016/17)**
The current CO_2/CH_4 instrument will reach the end of its expected lifetime in a few years. Since significant financial resources will be necessary for a replacement, long-term financial planning needs to allocate funds for replacement in the future. The expected lifetime however is difficult to predict. Furthermore, the replacement process should also take into consideration that combined CO_2, CH_4, CO analysers are available.

Recommendation 20 (, important, 2014)**
The Windows XP operating system running on the Picarro instrument is no longer supported by Microsoft and vulnerable to security threads. It should be considered to clone the hard drive of the instrument to another disk, which could be used in case of instrument failure.

Recommendation 21 (*, critical, ongoing)**
In case of instrument failures, a budget must be available to solve instrumental issues. It must be possible to contact e.g. Picarro support for remote diagnostics of the instrument.

Nitrous Oxide Measurements

Nitrous oxide measurements started at BKT in June 2013, and N_2O time series are available since then.

Instrumentation. Thermo IRIS 4600 Mid- IR Laser Based Spectroscopy. The instrumentation is adequate for the measurement of N_2O.

Standards. No dedicated N_2O standards are available at BKT. As an intermediate solution, the working tanks of the Picarro system are also used to perform calibrations of the N_2O instrument. These standards have N_2O numbers that were assigned by WCC-Empa.

Recommendation 22 (, important, 2015)**
The current N_2O instrument is currently connected to the valve box of the Picarro system and measures the same calibration sequence as the Picarro. It is not yet clear if these infrequent measurements of standard gases will be sufficient to account for potential drift of the N_2O analyser. Therefore, a dedicated calibration scheme for the Thermo IRIS 4600 might be needed. Funding to purchase the required peripherals and calibration gases need to be allocated by BMKG.

Intercomparison (Performance Audit).

The comparison involved repeated challenges of the BKT instrument with randomised nitrous oxide levels using WCC-Empa travelling standards. The following equations characterise the instrument bias, and the results are further illustrated in Figure 7 with respect to the WMO GAW DQOs (WMO, 2009, 2011):

For the comparison, data of the instrument was corrected based on two working standards with N_2O numbers assigned by WCC-Empa (130822_CB10280, 120307_CB08975). These two standards were purchased by BKT from Empa before the audit. It should be noted that the instrument itself has no user calibration implemented, which means that the reported values always need to be corrected based on reference gas measurements.

Thermo IRIS 4600 #1210052268:

Unbiased N_2O mixing ratio:	X_{N2O} (ppb) = (N_2O + 8.86) / 1.0259	(5a)
Remaining standard uncertainty:	u_{N2O} (ppb) = sqrt (0.14 ppb^2 + 1.01e-07 * X_{N2O}^2)	(5b)

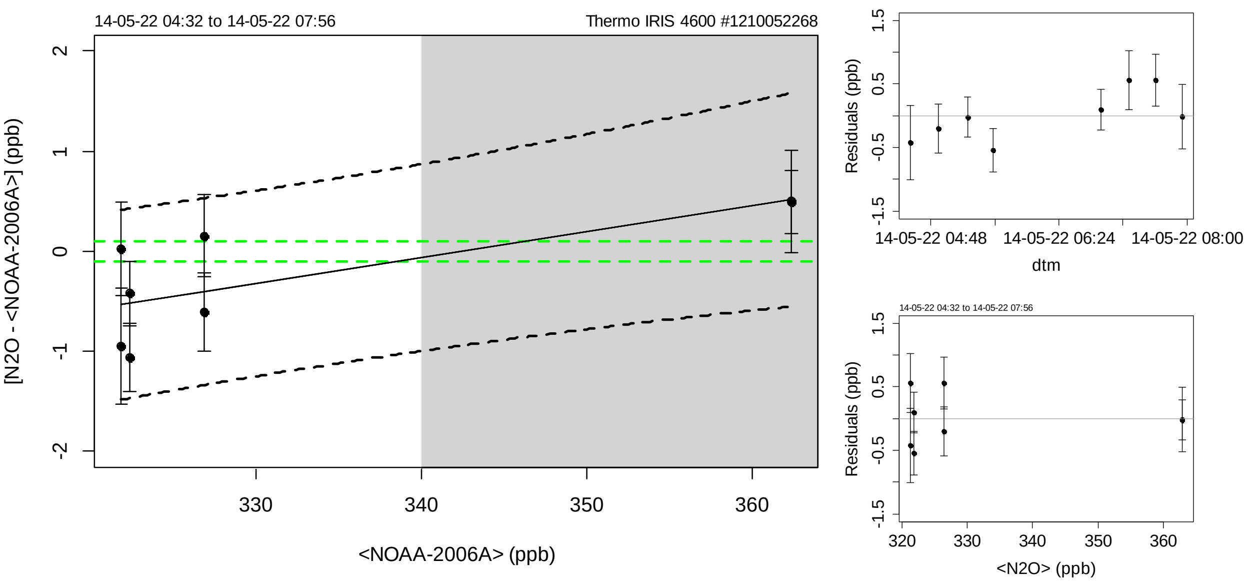

Figure 7. *Left: Bias of the BKT Thermo IRIS 4600 #1210052268 nitrous oxide instrument with respect to the WMO-2006A reference scale as a function of mole fraction. The white area represents the mole fraction range relevant for BKT, whereas the green lines correspond to the DQOs. Each point represents the average of data at a given level from a specific run. The error bars show the standard deviation of individual measurement points. The dashed lines around the regression lines are the Working-Hotelling 95% confidence bands. Right: Regression residuals (time dependence and mole fraction dependence).*

The results of the comparisons can be summarised as follows:

The result of the BKT Thermo IRIS 4600 instrument exceeded the WMO/GAW DQOs of ±0.1 ppb for N_2O. The reason is the relatively poor stability of the instrument during the comparison. The averaging time was also relatively short (10 min). Longer averaging times of one hour will further improve the agreement if no significant drift is observed.

Recommendation 23 (, important, ongoing)**
The standards used to calibrate the N_2O instrument should span a mole fraction range that exceeds the range of observed values. A range of 320 – 360 ppb N_2O is regarded as optimal.

Recommendation 24 (, important, 2014)**
The BKT station staff is encouraged to run experiments on the Thermo IRIS 4600 instrument to better characterise the instrument performance, e.g. precision and drift (determination of Allan variances), water correction/interference etc.

Recommendation 25 (, important, 2015)**
A N_2O audit by the World Calibration Centre for N_2O (WCC-N_2O) is recommended.

The results of the comparison show that the N_2O instrumentation is adequate to monitor background N_2O at BKT, although the bias of the individual hourly values most likely will exceed the WMO/GAW DQOs. Nevertheless, continuation of these measurements is highly recommended.

Parallel Measurements of Ambient Air

The audit included parallel measurements of CO, CH_4 and CO_2 with a WCC-Empa travelling instrument (TI) (Picarro G2401). The TI was running from 24 May through 04 June 2014; however, the TI had a serious problem which could not be identified during the comparison campaign. It therefore is questionable if the data acquired by the TI is of good quality. The TI was connected to the 32 m inlet line, and the air sampled with the WCC TI was not dried. To account for the effect of water vapour a correction function as described by Rella et al. (2013) was applied to the WCC-Empa Picarro data. Instead of the original Picarro G2401 pump unit, a KNF pump (N 920 AP.29.18) was used. For CH_4 and CO_2, the Picarro G2401 was calibrated using one working standard, and two additional tanks were used as target cylinders. The average of all three WCC-Empa cylinders was used for the CO calibration of the TI. Based on the measurements of the working standards, a drift correction using a loess fit was applied to the data. The following figures show the results of the ambient air comparisons.

Carbon monoxide:

Figure 8 shows the comparison of the Horiba AMPA360 instrument (BKT) with the WCC-Empa Picarro G2401. 10-min running means of the TI and the Horiba AMPA360 are shown. A zero correction based on the automatic zero checks was applied to the Horiba data. No further corrections were made. The bias between the two instruments shows significant variation, which most likely can be attributed to instrument noise. It further seems that the TI showed significantly more drift and noise compared to the Horiba APMA360, which might be attributed to the malfunction of the instrument. Nevertheless, the average bias of the Horiba instrument was small (mean -1.57 ppb, median -0.04 ppb), indicating that the instrument is still in a good working condition.

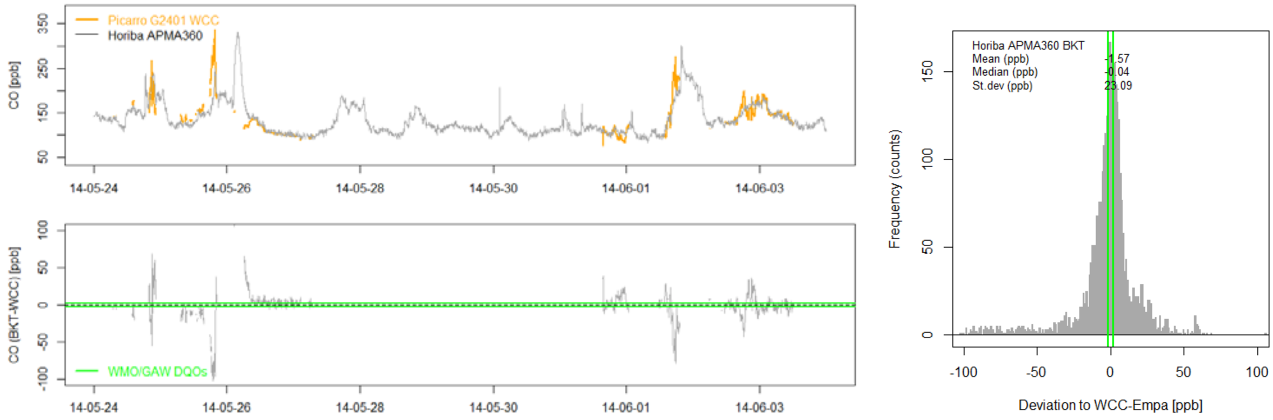

Figure 8. *Upper left panel: CO time series measured at BKT with the Picarro G2401 travelling instrument and the Horiba AMPA360 analyser of BKT (10-min running means). Lower left panel: Deviation of the BKT system compared to the travelling instrument. Right panel: Frequency distribution of the deviations. The green lines refer to the WMO/GAW DQOs.*

Methane:

The following figure shows the comparison of the BKT methane instruments with the WCC-Empa TI. The average bias was small and within the WMO/GAW DQOs; however, a relatively large scatter was observed. The results of the methane ambient air comparison confirmed the results of the TS comparisons.

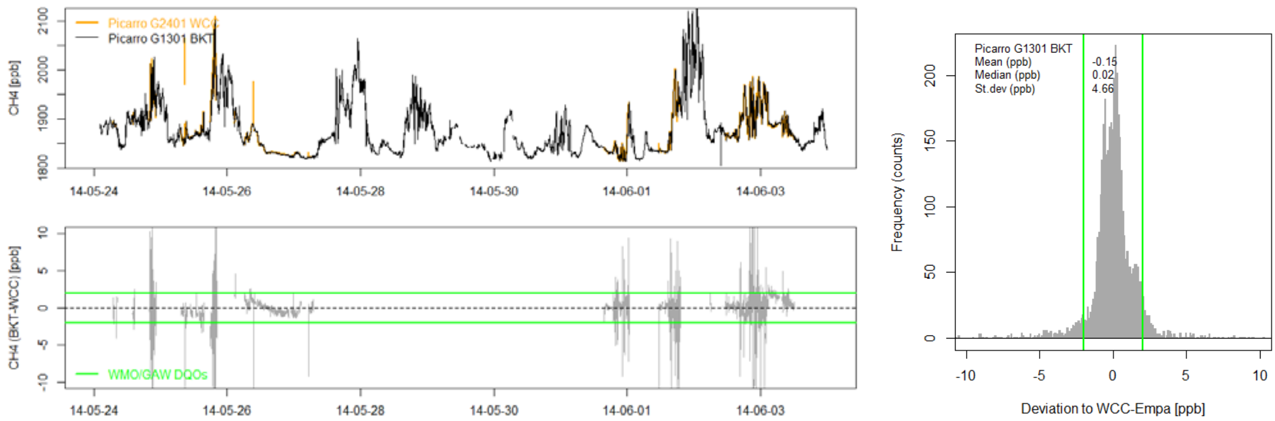

Figure 9. *Upper left panel: CH_4 time series (1-min averages) measured at BKT with the Picarro G2401 travelling instrument and the Picarro G1301 analyser. The sample air of the Picarro G1301 was dried, whereas a water vapour correction was applied to the Picarro G2401. Lower left panel: Deviation of the BKT system compared to the travelling instrument. Right panel: Frequency distribution of the deviations. The green lines refer to the WMO/GAW DQOs.*

Carbon dioxide:

Figure 10 shows the comparison of the Picarro G1301 analyser with the WCC-Empa TI. In comparison to methane, the agreement was significantly worse. Part of this might be caused by instrument malfunction (TI), but it cannot be excluded that the bias is due to the measurement setup of BKT. The current version of the BKT valve box has still issues with potential leaks, and also the sample air drying may cause problems. It therefore should be considered to change to a setup without sample air drying.

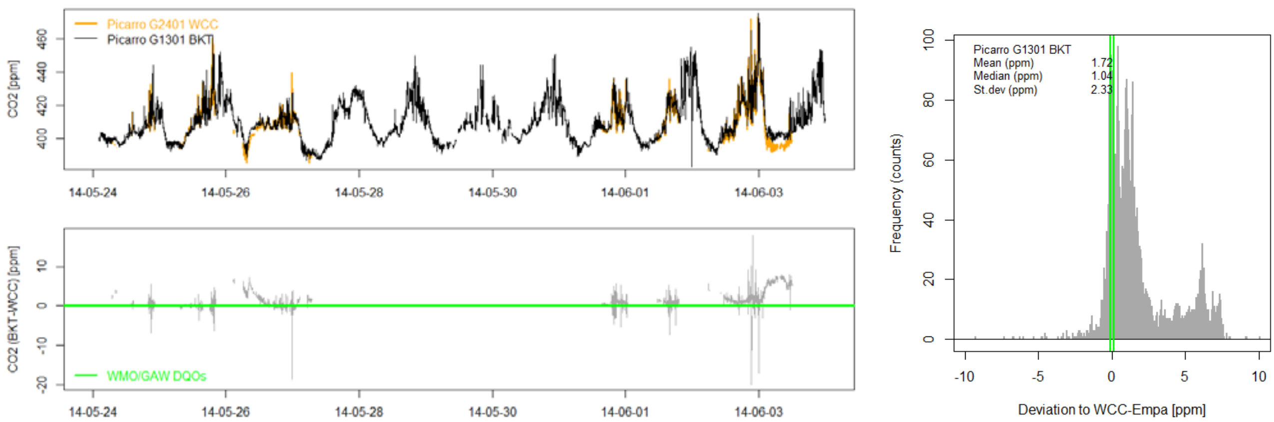

Figure 10. *Upper left panel: CO_2 time series (hourly averages) measured at BKT with the Picarro G2401 travelling instrument (humid) and the Picarro G1301 (dry). Lower left panel: Deviation of the BKT system compared to the travelling instrument. Right panel: Frequency distribution of the deviations. The green lines refer to the WMO/GAW DQOs.*

> **Recommendation 26 (*, minor, 2014)**
> *It should be considered to modify the Picarro valve box in a way that the sample air is not dried. Alternatively, a complete replacement of the valve box by a newer version might be considered.*

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 and the Thermo Iris 4600 instrument are acquired using the internal software of these systems. The data is manually transferred to the GAWDAQ computer and is also automatically transferred to Empa. Data of the other Thermo Instruments (NO_x and SO_2) is acquired on a self-programmed software that automatically transfers data as well as auxiliary instrument parameters to a data base. Furthermore, the data is displayed in near real-time on the BKT webpage (http://gaw-kototabang.com/index_en.php).

For each instrument, 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; in some cases, important information on instrument failures (e.g. for surface ozone) was missing.

> **Recommendation 27 (**, important, 2015)**
> *The GAWDAQ system cannot be supported by QA/SAC Switzerland in future. It should be considered to extend the system that has been set-up for the NO_x and SO_2 instruments also to the analysers currently connected to GAWDAQ (CO. O_3).*
>
> **Recommendation 28 (**, important, ongoing)**
> *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

For the parameters of the audit scope, in-situ data for CO (2001-2007), CO_2 and CH_4 (2009-2012) and O_3 (1996-2007) was submitted to the World Data Centre for Greenhouse Gases (WDCGG). Currently submission of the remaining data is foreseen to be completed by the end of 2014.

Recommendation 29 (, 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 30 (, important, ongoing)**
GAWSIS entries need to be regularly updated by the BKT station staff.

Conclusions

The Global GAW station Bukit Kototabang has significantly enlarged its measurement programme over the past year and comprises now a very comprehensive set of measurements. The combination of long-term measurements, the large number of measured parameters and the location of the site make the BKT station a very important contribution to the GAW programme. The assessed parameters were mostly of high quality; however, ongoing investments in instrument replacement as well as in peripherals such as calibration gases and other consumables will be needed to sustain the measurements in future.

Compared to the last audit by WCC-Empa in 2011, significant progress has been made concerning the measurement programme with the addition of N_2O measurements. Furthermore, the data is now actively used and near real-time data is displayed on the BKT webpage. However, funding issues remain a problem for the sustainable operation of the measurements.

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 BMKG 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 Bukit Kototabang measurement series is highly recommended.

Summary Ranking of the Bukit Kototabang GAW Station

System Audit Aspect	Adequacy#	Comment
Access	(5)	All year access possible
Facilities		
Laboratory and office space	(5)	Large laboratory facilities
Internet access	(3)	Unreliable, low bandwidth
Air Conditioning	(4)	Direct cooling of instruments / inlet lines needs to be avoided
Power supply	(4)	Mostly reliable, backup UPS and generator
General Management and Operation		
Organisation	(4)	Well organised, but bureaucracy and funding issues
Competence of staff	(3)	Both technical and scientific training needed
Air Inlet System	(4)	Adequate system, regular leak checks and maintenance required
Instrumentation		
Ozone (TEI 49C)	(4)	Instrument becoming old
CO (Horiba APMA-360)	(2)	Replacement needed due to drift
N_2O (Thermo IRIS4600)	(4)	Relatively poor repeatability
CO_2/CH_4 (Picarro G1301)	(5)	Adequate instrumentation
Standards		
Ozone	(5)	TEI 49i-PS with SRP traceability
CO_2, CH_4, N_2O	(4)	Standards provided by WCC-Empa, NOAA standards needed
CO	(3)	Direct calibrations discontinued
Data Management		
Data acquisition	(4)	Adequate systems but GAWDAQ no longer supported
Data processing	(3)	Training of staff needed
Data submission	(3)	Partly submitted, regular updates are needed

#0: inadequate thru 5: adequate.

Dübendorf, September 2014

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WCC-Empa

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QA/SAC Switzerland

Dr. B. Buchmann
Head of Department

APPENDIX

Global GAW Station Bukit Kototabang

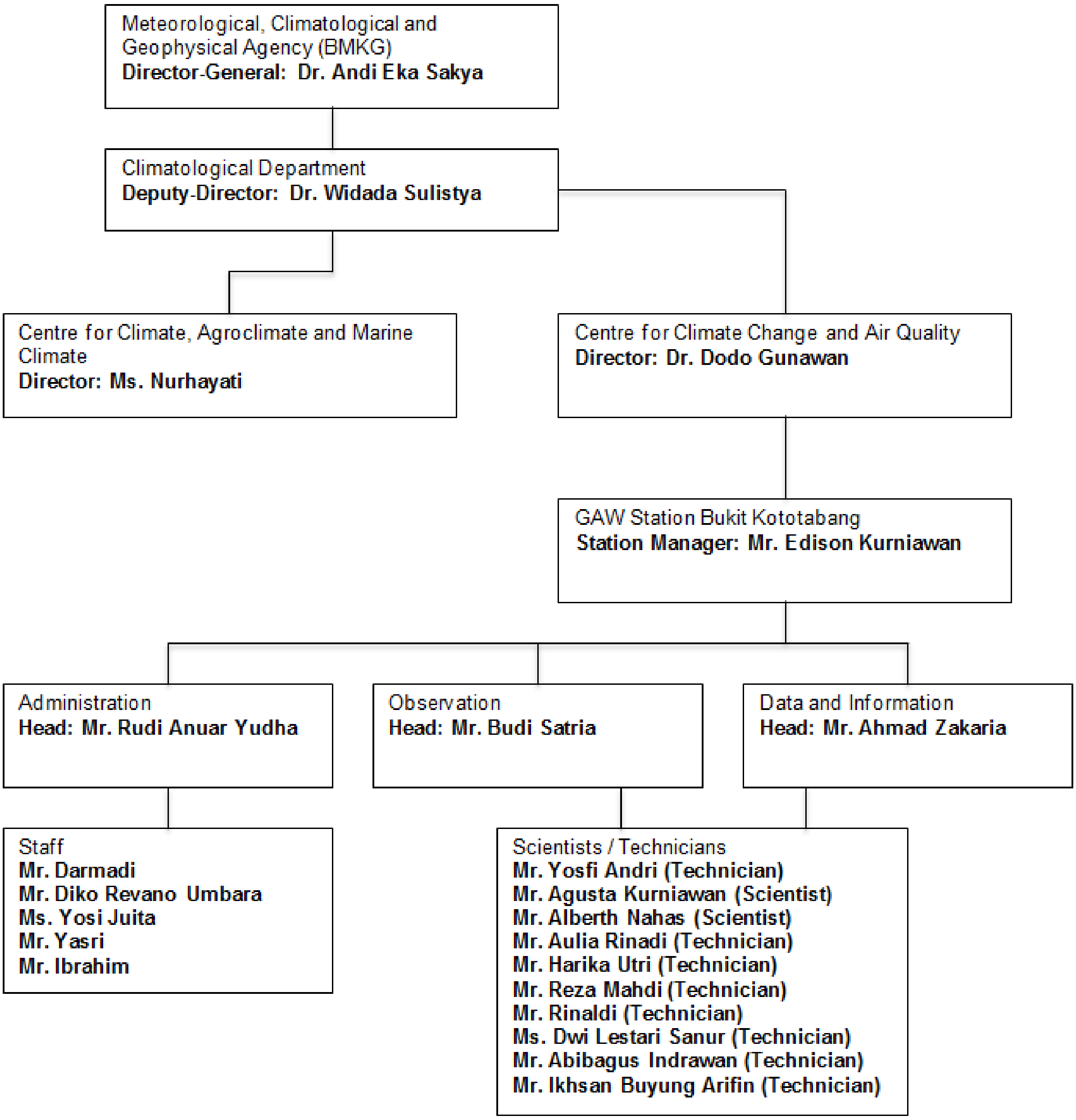
Site description and measurement programme

Information about the Bukit Kototabang GAW station is available on the internet and the station is also registered in GAWSIS.

http://gaw-kototabang.com/index_en.php
http://gaw.empa.ch/gawsis/reports.asp?StationID=5

Organisation and Contact Persons

The BKT GAW station is coordinated by BMKG. An organisational chart is given below.



Surface Ozone Measurements

Monitoring Set-up and Procedures

Air Conditioning

The ozone laboratory at BKT is air conditioned to approx. 25°C. Three wall mounted air-conditioning units are used. It must be made sure that instruments and inlet lines are not directly cooled by these units.

Air Inlet System

It was necessary to change the inlet line for surface ozone during the current audit (see Executive Summary for details).

Instrumentation

Ozone analyser (TEI 49C). Instrumental details are summarised in Table 1.

Standards

Ozone standard (TEI 49i-PS). Instrumental details are summarised in Table 1.

Operation and Maintenance

Check for general operation:	Daily (Mon – Sun) by the station operators. The station is normally staffed with 10-15 people from Monday to Friday, and at least 2 persons during weekends.
Zero / Span check:	None.
Calibration/checks with standard:	Usually every 3 months. No adjustments of calibration settings.
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

Unchanged since the WCC-Empa audit in 2009 (Zellweger et al., 2011).

Data Treatment

Data is evaluated by the station staff using Excel, and monthly summary reports are prepared. It was recognised during past WCC-Empa audits that more careful data evaluation needs to be done, and QA/SAC developed a software tool for this purpose. However, this tool was not regularly used in the past; it is therefore important that more effort is made by the station staff concerning data validation (see also recommendations in the Station Management and Operation section).

Documentation

All information is entered in electronic log books and checklists. 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 #54509-300 (WCC-Empa)
Settings	BKG = -0.3; COEFF = 1.009
Station Analyser (OA)	
Model, S/N	TEI 49C #58547-318
Principle	UV absorption
Range	0-1 ppm
Settings	BKG = 0.1; COEFF = 1.014
Pressure readings (hPa)	Ambient 915.8, OA 913.9, adjusted to 915.8 before comparison
Station Calibrator (OC)	
Model, S/N	TEI 49i-PS #0917736398
Principle	UV absorption
Range	0-1 ppm
Settings	BKG = 0.0; COEFF = 1.012 (initial) BKG = -0.5; COEFF = 1.023 (after calibration with TS)
Pressure readings (mmHg)	Ambient 914.6, OC 915.6, adjusted to 914.7 before comparisons

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. 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 main BKT ozone analyser (OA) TEI 49C #58547-318 with the WCC-Empa travelling standard (TS) before adjustment of the calibration factors.

Date - Time (UTC)	Run #	Level (ppb)	TS (ppb)	OA (ppb)	sdTS (ppb)	sdOA (ppb)	OA-TS (ppb)	OA-TS (%)
2014-05-23 08:33	1	0	-0.08	-0.60	0.15	0.04	-0.52	NA
2014-05-23 08:48	1	50	49.37	48.62	0.03	0.03	-0.75	-1.5
2014-05-23 09:03	1	200	199.20	198.12	0.10	0.07	-1.08	-0.5
2014-05-23 09:18	1	100	99.40	98.63	0.09	0.02	-0.77	-0.8
2014-05-23 09:33	1	75	74.42	73.35	0.10	0.07	-1.07	-1.4
2014-05-23 09:48	1	40	39.45	38.50	0.14	0.04	-0.95	-2.4

Date - Time (UTC)	Run #	Level (ppb)	TS (ppb)	OA (ppb)	sdTS (ppb)	sdOA (ppb)	OA-TS (ppb)	OA-TS (%)
2014-05-23 10:03	1	10	9.75	9.05	0.04	0.04	-0.70	-7.2
2014-05-23 10:18	1	150	149.25	148.40	0.14	0.05	-0.85	-0.6
2014-05-23 10:33	1	30	29.55	28.89	0.11	0.04	-0.66	-2.2
2014-05-23 10:48	1	20	19.54	18.92	0.05	0.06	-0.62	-3.2
2014-05-23 11:03	2	0	-0.01	-0.63	0.07	0.06	-0.62	NA
2014-05-23 11:18	2	150	149.29	148.42	0.12	0.05	-0.87	-0.6
2014-05-23 11:33	2	50	49.64	48.94	0.09	0.08	-0.70	-1.4
2014-05-23 11:48	2	75	74.59	73.77	0.09	0.04	-0.82	-1.1
2014-05-23 12:03	2	100	99.52	98.77	0.06	0.07	-0.75	-0.8
2014-05-23 12:18	2	30	29.64	28.97	0.05	0.08	-0.67	-2.3
2014-05-23 12:33	2	10	9.80	9.02	0.16	0.07	-0.78	-8.0
2014-05-23 12:48	2	200	199.38	198.29	0.16	0.02	-1.09	-0.5
2014-05-23 13:03	2	40	39.60	38.72	0.15	0.05	-0.88	-2.2
2014-05-23 13:18	2	20	19.76	18.93	0.07	0.07	-0.83	-4.2
2014-05-23 13:33	3	0	0.05	-0.72	0.07	0.05	-0.77	NA
2014-05-23 13:48	3	20	19.73	18.98	0.11	0.08	-0.75	-3.8
2014-05-23 14:03	3	100	99.47	98.63	0.05	0.01	-0.84	-0.8
2014-05-23 14:18	3	200	199.29	198.14	0.04	0.06	-1.15	-0.6
2014-05-23 14:33	3	40	39.62	38.76	0.09	0.04	-0.86	-2.2
2014-05-23 14:48	3	150	149.40	148.47	0.13	0.04	-0.93	-0.6
2014-05-23 15:03	3	30	29.65	29.07	0.08	0.06	-0.58	-2.0
2014-05-23 15:18	3	50	49.57	48.99	0.06	0.04	-0.58	-1.2
2014-05-23 15:33	3	75	74.56	73.84	0.10	0.04	-0.72	-1.0
2014-05-23 15:48	3	10	10.05	9.39	0.16	0.02	-0.66	-6.6
2014-05-23 16:03	4	0	0.00	-0.57	0.10	0.04	-0.57	NA
2014-05-23 16:18	4	50	49.52	48.69	0.05	0.06	-0.83	-1.7
2014-05-23 16:33	4	200	199.23	198.07	0.15	0.04	-1.16	-0.6
2014-05-23 16:48	4	100	99.57	98.78	0.10	0.06	-0.79	-0.8
2014-05-23 17:03	4	75	74.64	73.72	0.09	0.02	-0.92	-1.2
2014-05-23 17:18	4	40	39.55	38.94	0.11	0.04	-0.61	-1.5
2014-05-23 17:33	4	10	9.90	9.13	0.23	0.04	-0.77	-7.8
2014-05-23 17:48	4	150	149.30	148.44	0.14	0.04	-0.86	-0.6
2014-05-23 18:03	4	30	29.74	28.83	0.06	0.07	-0.91	-3.1
2014-05-23 18:18	4	20	19.64	18.84	0.12	0.07	-0.80	-4.1
2014-05-23 18:33	5	0	-0.04	-0.63	0.13	0.10	-0.59	NA
2014-05-23 18:48	5	150	149.42	148.48	0.08	0.06	-0.94	-0.6
2014-05-23 19:03	5	50	49.59	48.79	0.13	0.03	-0.80	-1.6
2014-05-23 19:18	5	75	74.50	73.63	0.08	0.03	-0.87	-1.2
2014-05-23 19:33	5	100	99.56	98.74	0.05	0.06	-0.82	-0.8
2014-05-23 19:48	5	30	29.69	28.93	0.07	0.06	-0.76	-2.6
2014-05-23 20:03	5	10	9.86	9.12	0.11	0.03	-0.74	-7.5
2014-05-23 20:18	5	200	199.21	198.22	0.10	0.06	-0.99	-0.5
2014-05-23 20:33	5	40	39.70	38.89	0.18	0.02	-0.81	-2.0
2014-05-23 20:48	5	20	19.71	18.77	0.07	0.06	-0.94	-4.8
2014-05-23 21:03	6	0	0.08	-0.78	0.11	0.02	-0.86	NA
2014-05-23 21:18	6	20	19.78	18.96	0.09	0.07	-0.82	-4.1
2014-05-23 21:33	6	100	99.53	98.72	0.07	0.03	-0.81	-0.8
2014-05-23 21:48	6	200	199.31	198.16	0.02	0.03	-1.15	-0.6

Date - Time (UTC)	Run #	Level (ppb)	TS (ppb)	OA (ppb)	sdTS (ppb)	sdOA (ppb)	OA-TS (ppb)	OA-TS (%)
2014-05-23 22:03	6	40	39.69	38.84	0.10	0.03	-0.85	-2.1
2014-05-23 22:18	6	150	149.38	148.37	0.05	0.05	-1.01	-0.7
2014-05-23 22:33	6	30	29.71	28.85	0.07	0.05	-0.86	-2.9
2014-05-23 22:48	6	50	49.54	48.75	0.08	0.07	-0.79	-1.6
2014-05-23 23:03	6	75	74.59	73.86	0.09	0.04	-0.73	-1.0
2014-05-23 23:18	6	10	9.93	9.37	0.13	0.09	-0.56	-5.6

Table 3. Ten-minute aggregates computed from the last 10 of a total of 15 one-minute values for the comparison of the main BKT ozone calibrator (OC) TEI 49i-PS #0917736398 with the WCC-Empa travelling standard (TS) before adjustment of the calibration factors.

Date - Time (UTC)	Run #	Level (ppb)	TS (ppb)	OC (ppb)	sdTS (ppb)	sdOC (ppb)	OC-TS (ppb)	OC-TS (%)
2014-05-23 13:33	1	0	0.05	-0.50	0.07	0.03	-0.55	NA
2014-05-23 13:48	1	20	19.73	18.71	0.11	0.06	-1.02	-5.2
2014-05-23 14:03	1	100	99.47	97.47	0.05	0.05	-2.00	-2.0
2014-05-23 14:18	1	200	199.29	196.24	0.04	0.06	-3.05	-1.5
2014-05-23 14:33	1	40	39.62	38.40	0.09	0.05	-1.22	-3.1
2014-05-23 14:48	1	150	149.40	146.97	0.13	0.05	-2.43	-1.6
2014-05-23 15:03	1	30	29.65	28.73	0.08	0.03	-0.92	-3.1
2014-05-23 15:18	1	50	49.57	48.32	0.06	0.03	-1.25	-2.5
2014-05-23 15:33	1	75	74.56	73.00	0.10	0.04	-1.56	-2.1
2014-05-23 15:48	1	10	10.05	9.24	0.16	0.07	-0.81	-8.1
2014-05-23 16:03	2	0	0.00	-0.43	0.10	0.04	-0.43	NA
2014-05-23 16:18	2	50	49.52	48.18	0.05	0.05	-1.34	-2.7
2014-05-23 16:33	2	200	199.23	196.19	0.15	0.04	-3.04	-1.5
2014-05-23 16:48	2	100	99.57	97.80	0.10	0.04	-1.77	-1.8
2014-05-23 17:03	2	75	74.64	73.09	0.09	0.01	-1.55	-2.1
2014-05-23 17:18	2	40	39.55	38.56	0.11	0.05	-0.99	-2.5
2014-05-23 17:33	2	10	9.90	9.23	0.23	0.06	-0.67	-6.8
2014-05-23 17:48	2	150	149.30	146.95	0.14	0.06	-2.35	-1.6
2014-05-23 18:03	2	30	29.74	28.69	0.06	0.05	-1.05	-3.5
2014-05-23 18:18	2	20	19.64	18.90	0.12	0.05	-0.74	-3.8
2014-05-23 18:33	3	0	-0.04	-0.41	0.13	0.05	-0.37	NA
2014-05-23 18:48	3	150	149.42	146.88	0.08	0.06	-2.54	-1.7
2014-05-23 19:03	3	50	49.59	48.31	0.13	0.06	-1.28	-2.6
2014-05-23 19:18	3	75	74.50	72.94	0.08	0.02	-1.56	-2.1
2014-05-23 19:33	3	100	99.56	97.74	0.05	0.07	-1.82	-1.8
2014-05-23 19:48	3	30	29.69	28.73	0.07	0.03	-0.96	-3.2
2014-05-23 20:03	3	10	9.86	9.21	0.11	0.04	-0.65	-6.6
2014-05-23 20:18	3	200	199.21	196.40	0.10	0.06	-2.81	-1.4
2014-05-23 20:33	3	40	39.70	38.61	0.18	0.05	-1.09	-2.7
2014-05-23 20:48	3	20	19.71	18.95	0.07	0.04	-0.76	-3.9
2014-05-23 21:03	4	0	0.08	-0.48	0.11	0.04	-0.56	NA
2014-05-23 21:18	4	20	19.78	19.07	0.09	0.05	-0.71	-3.6
2014-05-23 21:33	4	100	99.53	97.77	0.07	0.02	-1.76	-1.8
2014-05-23 21:48	4	200	199.31	196.42	0.02	0.02	-2.89	-1.5
2014-05-23 22:03	4	40	39.69	38.63	0.10	0.05	-1.06	-2.7

Date - Time (UTC)	Run #	Level (ppb)	TS (ppb)	OC (ppb)	sdTS (ppb)	sdOC (ppb)	OC-TS (ppb)	OC-TS (%)
2014-05-23 22:18	4	150	149.38	147.10	0.05	0.03	-2.28	-1.5
2014-05-23 22:33	4	30	29.71	28.82	0.07	0.07	-0.89	-3.0
2014-05-23 22:48	4	50	49.54	48.47	0.08	0.05	-1.07	-2.2
2014-05-23 23:03	4	75	74.59	73.25	0.09	0.02	-1.34	-1.8
2014-05-23 23:18	4	10	9.93	9.47	0.13	0.06	-0.46	-4.6

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 calibrator (OC) TEI 49i-PS #0917736398 with the WCC-Empa travelling standard (TS) after adjustment of the calibration factors.

Date - Time (UTC)	Run #	Level (ppb)	TS (ppb)	OC (ppb)	sdTS (ppb)	sdOC (ppb)	OC-TS (ppb)	OC-TS (%)
2014-05-25 14:32	1	0	0.14	0.36	0.07	0.12	0.22	NA
2014-05-25 14:47	1	150	149.85	150.14	0.09	0.08	0.29	0.2
2014-05-25 15:02	1	50	49.93	50.09	0.09	0.09	0.16	0.3
2014-05-25 15:17	1	75	74.95	75.09	0.10	0.13	0.14	0.2
2014-05-25 15:32	1	100	99.91	100.17	0.07	0.06	0.26	0.3
2014-05-25 15:47	1	30	30.08	30.21	0.05	0.08	0.13	0.4
2014-05-25 16:02	1	10	10.23	10.36	0.10	0.10	0.13	1.3
2014-05-25 16:17	1	200	199.75	200.10	0.10	0.17	0.35	0.2
2014-05-25 16:32	1	40	40.06	40.26	0.09	0.11	0.20	0.5
2014-05-25 16:47	1	20	20.12	20.37	0.10	0.09	0.25	1.2
2014-05-25 17:02	2	0	0.11	0.40	0.12	0.07	0.29	NA
2014-05-25 17:17	2	20	19.99	20.13	0.04	0.04	0.14	0.7
2014-05-25 17:32	2	100	99.76	99.98	0.19	0.23	0.22	0.2
2014-05-25 17:47	2	200	199.58	200.11	0.06	0.04	0.53	0.3
2014-05-25 18:02	2	40	40.09	40.16	0.12	0.08	0.07	0.2
2014-05-25 18:17	2	150	149.65	150.09	0.05	0.11	0.44	0.3
2014-05-25 18:32	2	30	30.17	30.34	0.07	0.09	0.17	0.6
2014-05-25 18:47	2	50	49.99	50.15	0.11	0.11	0.16	0.3
2014-05-25 19:02	2	75	74.97	75.14	0.06	0.09	0.17	0.2
2014-05-25 19:17	2	10	10.32	10.41	0.11	0.11	0.09	0.9
2014-05-25 19:32	3	0	0.08	0.42	0.06	0.09	0.34	NA
2014-05-25 19:47	3	50	49.96	50.10	0.07	0.12	0.14	0.3
2014-05-25 20:02	3	200	199.73	200.21	0.11	0.24	0.48	0.2
2014-05-25 20:17	3	100	99.95	100.18	0.08	0.06	0.23	0.2
2014-05-25 20:32	3	75	74.96	75.13	0.05	0.09	0.17	0.2
2014-05-25 20:47	3	40	40.02	40.33	0.07	0.05	0.31	0.8
2014-05-25 21:02	3	10	10.22	10.47	0.09	0.10	0.25	2.4
2014-05-25 21:17	3	150	149.63	150.00	0.09	0.14	0.37	0.2
2014-05-25 21:32	3	30	30.07	30.20	0.09	0.11	0.13	0.4
2014-05-25 21:47	3	20	20.06	20.36	0.07	0.07	0.30	1.5
2014-05-25 22:02	4	0	-0.01	0.34	0.05	0.09	0.35	NA
2014-05-25 22:17	4	150	149.77	150.18	0.12	0.18	0.41	0.3
2014-05-25 22:32	4	50	50.16	50.22	0.05	0.18	0.06	0.1
2014-05-25 22:47	4	75	75.03	75.17	0.16	0.09	0.14	0.2
2014-05-25 23:02	4	100	99.81	100.06	0.08	0.16	0.25	0.3
2014-05-25 23:17	4	30	30.06	30.37	0.10	0.14	0.31	1.0

Date - Time (UTC)	Run #	Level (ppb)	TS (ppb)	OC (ppb)	sdTS (ppb)	sdOC (ppb)	OC-TS (ppb)	OC-TS (%)
2014-05-25 23:32	4	10	10.23	10.43	0.08	0.13	0.20	2.0
2014-05-25 23:47	4	200	199.71	200.16	0.10	0.10	0.45	0.2
2014-05-26 00:02	4	40	40.07	40.12	0.07	0.11	0.05	0.1
2014-05-26 00:17	4	20	20.06	20.32	0.11	0.08	0.26	1.3

Carbon Monoxide Measurements

Monitoring Set-up and Procedures

Air Conditioning

Same as for surface ozone.

Air Inlet System

Unchanged since the WCC-Empa audit in 2011 (Zellweger et al., 2011).

Instrumentation

Bukit Kototabang is equipped with a Trace Analytical Horiba AMPA360 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 using one of the gases that are primarily used for the GHG measurements. It is recommended to use the standards with higher CO mole fractions (101116_CC311964) for direct calibrations.

Table 5. CO Standards available at BKT. The standards in blue colour are mainly for GHG calibrations but can be used to calibrate the CO analyser in 3-monthly intervals.

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	empty
101116_CA06476	SMI / Empa	Direct calibration	527.7	5.4	Nov 11	empty
110818_CB08871	SMI / Empa	Direct calibration	477.3	4.7	Nov 11	empty
110818_CB08874	SMI / Empa	Dilution	29700.0	294.0	Nov 11	cont.
120307_CB08975	SMI / Empa	Direct calibration	495.8	10.0	Aug 13	cont.
130822_CB10280	SMI / Empa	Direct calibration	222.1	4.6	May 14	cont.
101116_CC311964	SMI / Empa	Direct calibration	830.6	16.7	May 14	cont.
130822_CB10216	SMI / Empa	Direct calibration	221.9	4.5	May 14	cont.
130822_CB10184	SMI / Empa	Direct calibration	272.9	5.5	May 14	cont.
120614_CB09195	SMI / Empa	Direct calibration	57.9	1.2	May 14	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.

Documentation

Same as for surface ozone.

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 analysers. Details of the traceability of the travelling standards to the WMO/GAW Reference Standard at NOAA/ESRL are given in Table 16 below.

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 BKT data acquisition system.

Table 6. Experimental details of BKT CO comparison.

Travelling standard (TS)	
WCC-Empa Travelling standards (30 l aluminium cylinder containing a mixture of natural and synthetic air), assigned values and standard uncertainties see Table 16.	
Station Analyser BKT (AL)	
Model, S/N	Horiba APMA360 #890617034
Principle	NDIR, cross flow modulation
Drying system	PERMAPURE Nafion drier
Comparison procedures	
Connection	The TS were 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 Table 7.

Table 7. CO aggregates computed from single analysis (mean and standard deviation of mean) for each level during the comparison of the Horiba AMPA360 instrument (AL) with the WCC-Empa TS (WMO-2004 CO scale).

Date / Time	TS Cylinder	TS (ppb)	sdTS (ppb)	AL (ppb)	sdAL (ppb)	N	AL-TS (ppb)	AL-TS (%)
(14-05-23 02:01:30)	130822_CB10280	222.1	0.1	192.7	10.2	60.0	-29.4	-13.2
(14-05-23 03:07:00)	120307_CB08975	495.8	0.1	431.4	8.1	65.0	-64.4	-13.0
(14-05-23 04:11:00)	130822_CB10184	272.9	0.1	237.6	9.4	57.0	-35.3	-12.9
(14-05-23 05:13:30)	130822_CB10216	221.9	0.1	195.4	10.1	60.0	-26.5	-12.0
(14-05-23 06:18:30)	120614_CB09195	57.9	0.1	49.0	9.7	58.0	-8.9	-15.3
(14-05-23 07:21:00)	101116_CC31196	830.6	0.1	724.8	9.6	59.0	-105.8	-12.7
(14-05-23 08:23:30)	Zero Air	0.0	0.1	0.0	8.0	52.0	0.0	NA

Methane and Carbon Dioxide Measurements

Monitoring Set-up and Procedures

Air Conditioning

Same as for surface ozone.

Air Inlet System

Unchanged since the last WCC-Empa audit in 2011 (Zellweger et al., 2011). The 10 m inlet line was replaced during the current audit.

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

Unchanged since the last audit. A Picarro G1301 CO_2, CH_4 and H_2O analyser is available at BKT. Instrumental details are listed in Table 9.

Standards

Table 8 lists current and past standards for GHG calibrations available at BKT.

Table 8. Standards available at BKT for the calibration of GHG analysers.
Calibration scales: CH_4: WMO-X2004, CO_2: WMO-X2007, N_2O: WMO-X2006A

Cylinder ID	Type	CH_4 (ppb)	U_{CH4} (ppb)	CO_2 (ppm)	U_{CO2} (ppm)	N_2O (ppb)	U_{N2O} (ppb)	Start of use	End of use
CB08900	NOAA/ESRL	1843.26	0.60	389.08	0.14	389.14	0.17	Oct 09	empty
CB08853	NOAA/ESRL	1805.59	0.60	379.11	0.14	NA	NA	Oct 09	cont.
CB08806	NOAA/ESRL	1790.62	0.60	377.78	0.14	377.77	0.17	Oct 09	empty
CB08819	NOAA/ESRL	1743.37	0.60	369.13	0.14	NA	NA	Oct 09	Nov 09
100518_CB08830	SMI/Empa	1987.42	0.33	293.16	0.15	NA	NA	Nov 11	empty
101116_CA06476	SMI/Empa	2437.15	0.44	394.67	0.17	NA	NA	Nov 11	empty
110818_CB08871	SMI/Empa	2631.77	0.45	403.87	0.17	NA	NA	Nov 11	empty
120307_CB08975	SMI/Empa	1861.61	1.54	332.28	0.14	321.78	0.30	Aug 13	cont.
130822_CB10280	SMI/Empa	2436.29	1.54	361.70	0.14	316.08	0.30	May 14	cont.
101116_CC311964	SMI/Empa	2418.69	1.53	399.82	0.15	362.39	0.34	May 14	cont.
130822_CB10216	SMI/Empa	1865.93	1.17	332.28	0.13	321.82	0.31	May 14	cont.
130822_CB10184	SMI/Empa	2399.3	1.52	427.23	0.17	326.85	0.31	May 14	cont.
120614_CB09195	SMI/Empa	1702.49	1.08	312.55	0.12	322.34	0.31	May 14	cont.

Operation and Maintenance

Check for general operation: Daily (Mon – Sun) by the station operator.

Other (filter change etc.): As required.

In case of instrumental problems, Picarro support is contacted. Picarro recently changed its support organisation, with different support package options. BMKG does not have any of these packages, and will be required to pay for support on an individual case basis. A budget needs to be available for such events, as recommended in the Executive Summary.

Data Acquisition and Data Transfer

The data of the Picarro system is acquired using the internal LabView based data acquisition system. Remote access is possible through the internet (TeamViewer) for instrument maintenance.

Data Treatment

QA/SAC provided an R script which reads raw data, applies calibration and water vapour corrections, and produces averaged data (1, 10, 60 min) for the different inlet heights. The station staff was using this script, but more programming knowledge in R is needed to modify the script in case this is required (e.g. changing number of working standards).

Documentation

Electronic station and instrument logbooks were available at the site. The information was only partly comprehensive and up-to-date. The instrument manuals were available at the site.

Comparison 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 16 below.

Setup and Connections

Table 9 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 9. Experimental details of the comparison.

Travelling standard (TS)	
WCC-Empa Traveling standards (30 l aluminium cylinder containing a mixture of natural and synthetic air), assigned values and standard uncertainties see Table 16.	
Station Analysers (OA)	
Model, S/N	PICARRO G1301 #CFADS-027
Principle	CRDS
Drying system	Nafion dryer
Comparison procedures	
Connection	The TS were connected to the sample inlet at the Picarro valve box.

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 10. CH_4 aggregates computed from single analysis (1-min mean and standard deviation) for each level during the comparison of the Picarro G1301 #CFADS-027 (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 (%)
(14-05-22 04:31:30)	130822_CB10216	1865.93	0.07	1865.59	0.06	10	-0.34	-0.02
(14-05-22 04:41:30)	130822_CB10184	2399.30	0.05	2399.00	0.10	10	-0.30	-0.01
(14-05-22 04:51:30)	101116_CC311964	2418.69	0.13	2418.47	0.07	10	-0.22	-0.01
(14-05-22 05:01:30)	120614_CB09195	1702.49	0.08	1702.36	0.12	10	-0.13	-0.01
(14-05-22 06:52:30)	130822_CB10216	1702.49	0.08	1702.38	0.09	10	-0.11	-0.01
(14-05-22 07:02:30)	130822_CB10184	1865.93	0.07	1865.60	0.09	10	-0.33	-0.02
(14-05-22 07:12:30)	101116_CC311964	2399.30	0.05	2398.96	0.13	10	-0.34	-0.01
(14-05-22 07:22:30)	120614_CB09195	2418.69	0.13	2418.45	0.09	10	-0.24	-0.01

Table 11. CO_2 aggregates computed from single analysis (1-min mean and standard deviation) for each level during the comparison of the Picarro G1301 #CFADS-027 (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 (%)
(14-05-22 04:31:30)	130822_CB10216	332.28	0.02	332.40	0.01	10	0.12	0.04
(14-05-22 04:41:30)	130822_CB10184	427.23	0.04	427.15	0.01	10	-0.08	-0.02
(14-05-22 04:51:30)	101116_CC311964	399.82	0.04	399.72	0.01	10	-0.10	-0.03
(14-05-22 05:01:30)	120614_CB09195	312.55	0.03	312.57	0.01	10	0.02	0.01
(14-05-22 06:52:30)	130822_CB10216	312.55	0.03	312.69	0.01	10	0.14	0.04
(14-05-22 07:02:30)	130822_CB10184	332.28	0.02	332.32	0.01	10	0.04	0.01
(14-05-22 07:12:30)	101116_CC311964	427.23	0.04	426.93	0.01	10	-0.30	-0.07
(14-05-22 07:22:30)	120614_CB09195	399.82	0.04	399.65	0.02	10	-0.17	-0.04

Nitrous Oxide Measurements

Monitoring Set-up and Procedures

Air Conditioning

Same as for surface ozone.

Air Inlet System

The nitrous oxide instrument was connected to the Picarro infrastructure, using the same inlet lines and calibration standards. The new set-up of is shown in the below Figure.

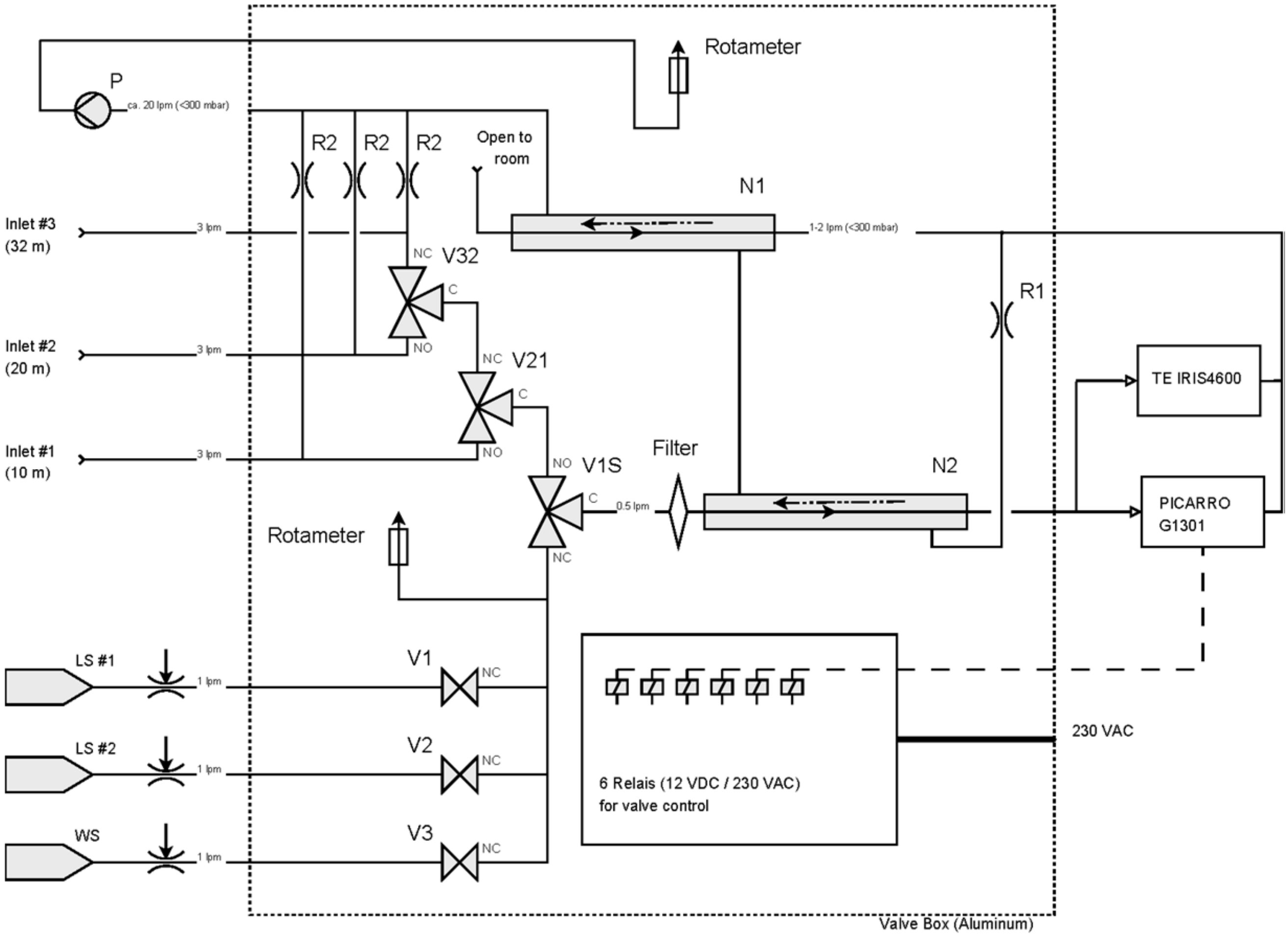


Figure 11. *Set-up of the Picarro CO_2 and CH_4 and the TE IRIS 4600 N_2O measurements at BKT.*

Instrumentation

Thermo IRIS 4600 Mid- IR Laser Based Spectroscopy.

Standards

Refer to Table 8 for N_2O standards available at BKT.

Operation and Maintenance

Check for general operation:	Daily (Mon – Sun) by the station operator.
Other (filter change etc.):	As required.

In case of instrumental problems, The Thermo local representative is contacted. A budget needs to be available for instrument maintenance and repair, as recommended in the Executive Summary.

Data Acquisition and Data Transfer

Data is acquired using the internal LabView based data acquisition system of the Thermo IRIS 4600 analyser. Remote access is possible through the internet (TeamViewer) for instrument maintenance.

Data Treatment

QA/SAC provided an R script for basic data analysis. The station staff was using this script, but more programming knowledge in R is needed to modify the script. Data need to be synchronized with the Picarro system, since no calibration gas and inlet line flags are available in the N_2O raw data.

Documentation

Electronic station and instrument logbooks were available at the site. The information was only partly comprehensive and up-to-date. The instrument manuals were available at the site.

Comparison 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 16 below.

Setup and Connections

Table 12 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 12. Experimental details of the comparison.

Travelling standard (TS)	
WCC-Empa Traveling standards (30 l aluminium cylinder containing a mixture of natural and synthetic air), assigned values and standard uncertainties see Table 16.	
Station Analysers (OA)	
Model, S/N	THERMO IRIS 4600 #1210052268-128/83
Principle	Mid Infrared Absorption Spectroscopy
Drying system	Nafion dryer (from Picarro valve box)
Comparison procedures	
Connection	The TS were connected to the sample inlet at the Picarro valve box.

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 13.

Table 13. N_2O aggregates computed from single analysis (mean and standard deviation of mean) for each level during the comparison of the THERMO IRIS 4600 #1210052268 (AL) with the WCC-Empa TS (WMO-2006A N_2O scale).

Date / Time	TS Cylinder	TS (ppb)	sdTS (ppb)	AL (ppb)	sdAL (ppb)	N	AL-TS (ppb)	AL-TS (%)
(14-05-22 04:32:30)	130822_CB10216	321.82	0.03	320.87	0.58	10	-0.95	-0.30
(14-05-22 04:53:30)	130822_CB10184	326.85	0.02	326.24	0.39	10	-0.61	-0.19
(14-05-22 05:15:30)	101116_CC311964	362.39	0.10	362.88	0.31	10	0.49	0.14
(14-05-22 05:34:30)	120614_CB09195	322.34	0.04	321.27	0.34	10	-1.07	-0.33
(14-05-22 06:55:30)	130822_CB10216	322.34	0.04	321.91	0.32	10	-0.43	-0.13
(14-05-22 07:16:30)	130822_CB10184	321.82	0.03	321.84	0.46	10	0.02	0.01
(14-05-22 07:36:30)	101116_CC311964	326.85	0.02	327.00	0.41	10	0.15	0.05
(14-05-22 07:56:30)	120614_CB09195	362.39	0.10	362.89	0.51	10	0.50	0.14

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 #54509-300, BKG -03, 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 14. The TS passed the assessment criteria defined for maximum acceptable bias before and after the audit (Klausen et al., 2003) (cf. Figure 12). 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)).

$$X_{TS}\text{ (ppb)} = ([TS] + 0.18\text{ ppb}) / 1.0007 \quad (6a)$$

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

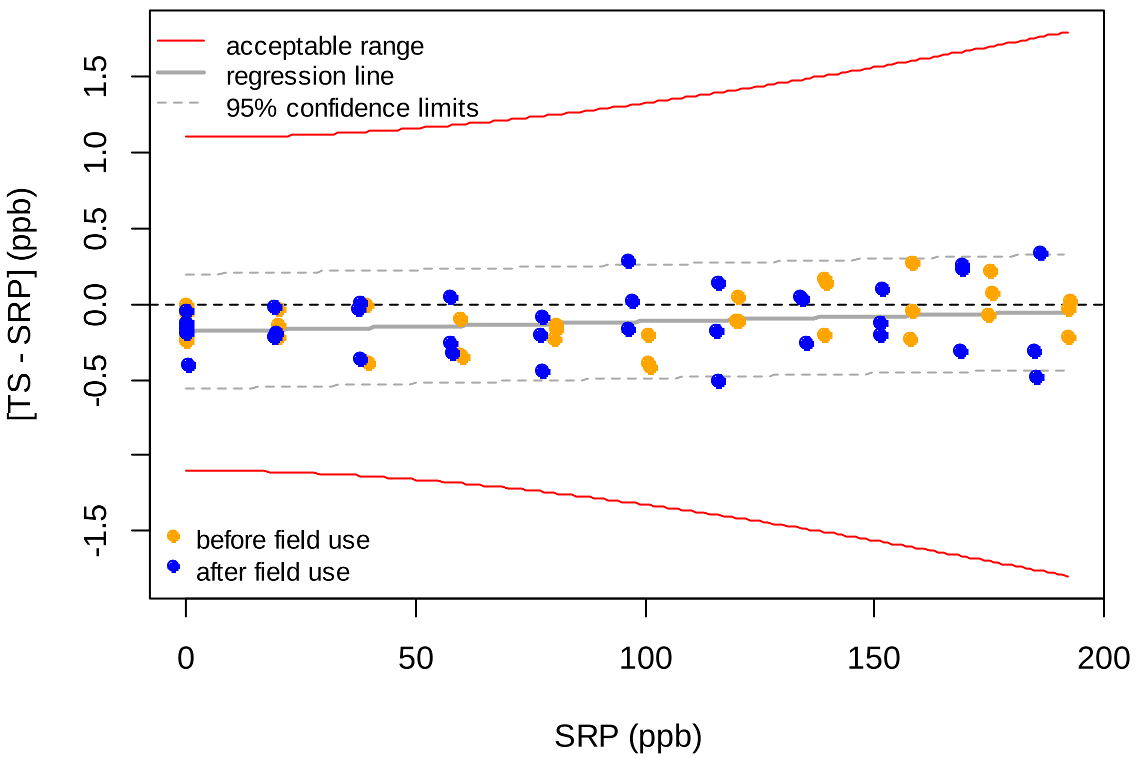


Figure 12. *Deviations between traveling standard (TS) and Standard Reference Photometer (SRP) before and after use of the TS at the field site.*

Table 14. 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)
2014-03-07	1	0	0.04	0.30	-0.16	0.10
2014-03-07	1	160	158.32	0.23	158.59	0.09
2014-03-07	1	140	139.23	0.39	139.37	0.16
2014-03-07	1	80	80.35	0.26	80.22	0.07
2014-03-07	1	180	175.05	0.43	175.27	0.06
2014-03-07	1	190	192.16	0.18	192.13	0.08
2014-03-07	1	120	119.68	0.34	119.58	0.08
2014-03-07	1	20	20.10	0.23	19.88	0.07
2014-03-07	1	40	39.22	0.26	39.22	0.11
2014-03-07	1	100	100.47	0.28	100.27	0.08
2014-03-07	1	60	59.72	0.32	59.38	0.11
2014-03-07	1	0	-0.16	0.27	-0.16	0.10
2014-03-07	2	0	-0.05	0.22	-0.18	0.13
2014-03-07	2	100	101.04	0.35	100.64	0.13
2014-03-07	2	160	157.81	0.35	157.57	0.14
2014-03-07	2	40	39.61	0.33	39.23	0.12
2014-03-07	2	120	120.12	0.35	120.01	0.11
2014-03-07	2	80	80.31	0.35	80.09	0.09
2014-03-07	2	60	59.98	0.25	59.63	0.16
2014-03-07	2	190	192.50	0.50	192.53	0.06
2014-03-07	2	20	19.87	0.29	19.84	0.09
2014-03-07	2	180	175.47	0.30	175.55	0.22
2014-03-07	2	140	138.92	0.41	139.09	0.06
2014-03-07	2	0	-0.12	0.36	-0.17	0.08
2014-03-07	3	0	-0.07	0.33	-0.30	0.10
2014-03-07	3	80	80.50	0.23	80.34	0.15
2014-03-07	3	160	157.98	0.25	157.93	0.20
2014-03-07	3	120	120.14	0.34	120.18	0.08
2014-03-07	3	100	100.65	0.25	100.27	0.13
2014-03-07	3	140	139.14	0.22	138.94	0.09
2014-03-07	3	180	174.85	0.47	174.78	0.20
2014-03-07	3	20	19.91	0.36	19.77	0.15
2014-03-07	3	40	39.62	0.09	39.23	0.07
2014-03-07	3	60	59.65	0.21	59.55	0.12
2014-03-07	3	190	192.31	0.23	192.10	0.13
2014-03-07	3	0	0.04	0.23	-0.20	0.10
2014-08-15	4	0	-0.13	0.45	-0.18	0.07
2014-08-15	4	60	57.78	0.28	57.46	0.10
2014-08-15	4	190	186.06	0.31	186.41	0.23
2014-08-15	4	120	115.75	0.58	115.90	0.09
2014-08-15	4	140	134.13	0.23	134.17	0.10
2014-08-15	4	40	38.04	0.25	37.68	0.09
2014-08-15	4	80	77.31	0.20	77.22	0.09
2014-08-15	4	20	19.28	0.21	19.07	0.09
2014-08-15	4	170	168.90	0.52	169.14	0.33
2014-08-15	4	150	151.64	0.19	151.74	0.05
2014-08-15	4	100	96.40	0.32	96.68	0.08
2014-08-15	4	0	0.21	0.33	-0.19	0.08
2014-08-15	5	0	-0.07	0.35	-0.19	0.08
2014-08-15	5	140	134.98	0.25	134.73	0.13

Date	Run	Level#	SRP (ppb)	sdSRP (ppb)	TS (ppb)	sdTS (ppb)
2014-08-15	5	80	77.52	0.18	77.09	0.13
2014-08-15	5	20	19.34	0.25	19.16	0.09
2014-08-15	5	190	185.31	0.36	184.83	0.24
2014-08-15	5	60	57.51	0.55	57.25	0.08
2014-08-15	5	120	115.86	0.21	115.36	0.09
2014-08-15	5	40	37.52	0.20	37.49	0.04
2014-08-15	5	170	168.80	0.31	168.49	0.05
2014-08-15	5	150	151.41	0.43	151.28	0.07
2014-08-15	5	100	96.36	0.27	96.19	0.07
2014-08-15	5	0	-0.04	0.23	-0.20	0.13
2014-08-15	6	0	-0.08	0.21	-0.22	0.07
2014-08-15	6	40	37.86	0.45	37.86	0.07
2014-08-15	6	100	97.09	0.16	97.12	0.12
2014-08-15	6	170	169.22	0.40	169.48	0.14
2014-08-15	6	20	19.04	0.37	19.03	0.04
2014-08-15	6	60	57.41	0.27	57.45	0.08
2014-08-15	6	80	77.26	0.36	77.06	0.07
2014-08-15	6	120	115.61	0.29	115.44	0.08
2014-08-15	6	140	133.71	0.43	133.76	0.11
2014-08-15	6	150	151.25	0.15	151.05	0.10
2014-08-15	6	190	184.69	0.22	184.38	0.11
2014-08-15	6	0	0.04	0.28	-0.15	0.05

#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-X2004 scale (Novelli et al., 2003)
CO_2: WMO-X2007 scale (Zhao and Tans, 2006)
CH_4: WMO-X2004 scale (Dlugokencky et al., 2005)
N_2O: WMO-X2006A scale (http://www.esrl.noaa.gov/gmd/ccl/n2o_scale.html)

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:

CO and N_2O: Aerodyne mini-cw (Mid-IR Spectroscopy using a Quantum Cascade Laser).
CO_2 and CH_4: Picarro G1301 (Cavity Ring Down Spectroscopy).

Table 15 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 16, and Figure 13 shows the analysis of the TS over time. A number of individual analysis results dating from before the audit was averaged. During this period, the standards remained usually stable with no significant drift. If drift is present, this will lead to an increased uncertainty of the TS.

Table 15. 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)	
CC339523	347.9	0.3	1854.60	0.13	322.52	0.12	396.88	0.06	350.9	0.3	1855.31	0.03	322.52	0.02	396.94	0.02
CC339524	390.7	0.2	1980.28	0.30	355.42	0.16	795.42	0.06	394.1	0.4	1981.77	0.04	355.42	0.02	796.36	0.04
CC311846	166.4	0.1	1805.24	0.12	338.27	0.11	377.86	0.04	167.2	0.3	1805.31	0.11	338.27	0.01	377.84	0.02

Table 16. Calibration summary of the WCC-Empa travelling standards.

TS	CO (ppb)	sdCO (ppb)	CH_4 (ppb)	$sdCH_4$ (ppb)	CO_2 (ppm)	$sdCO_2$ (ppm)	N_2O (ppb)	sdN_2O (ppb)
101116_CC311964	830.56	0.14	2418.69	0.13	399.82	0.04	362.39	0.1
130822_CB10216	221.94	0.09	1865.93	0.07	332.28	0.02	321.82	0.03
130822_CB10184	272.87	0.07	2399.3	0.05	427.23	0.04	326.85	0.02
120614_CB09195	57.86	0.08	1702.49	0.08	312.55	0.03	322.34	0.04

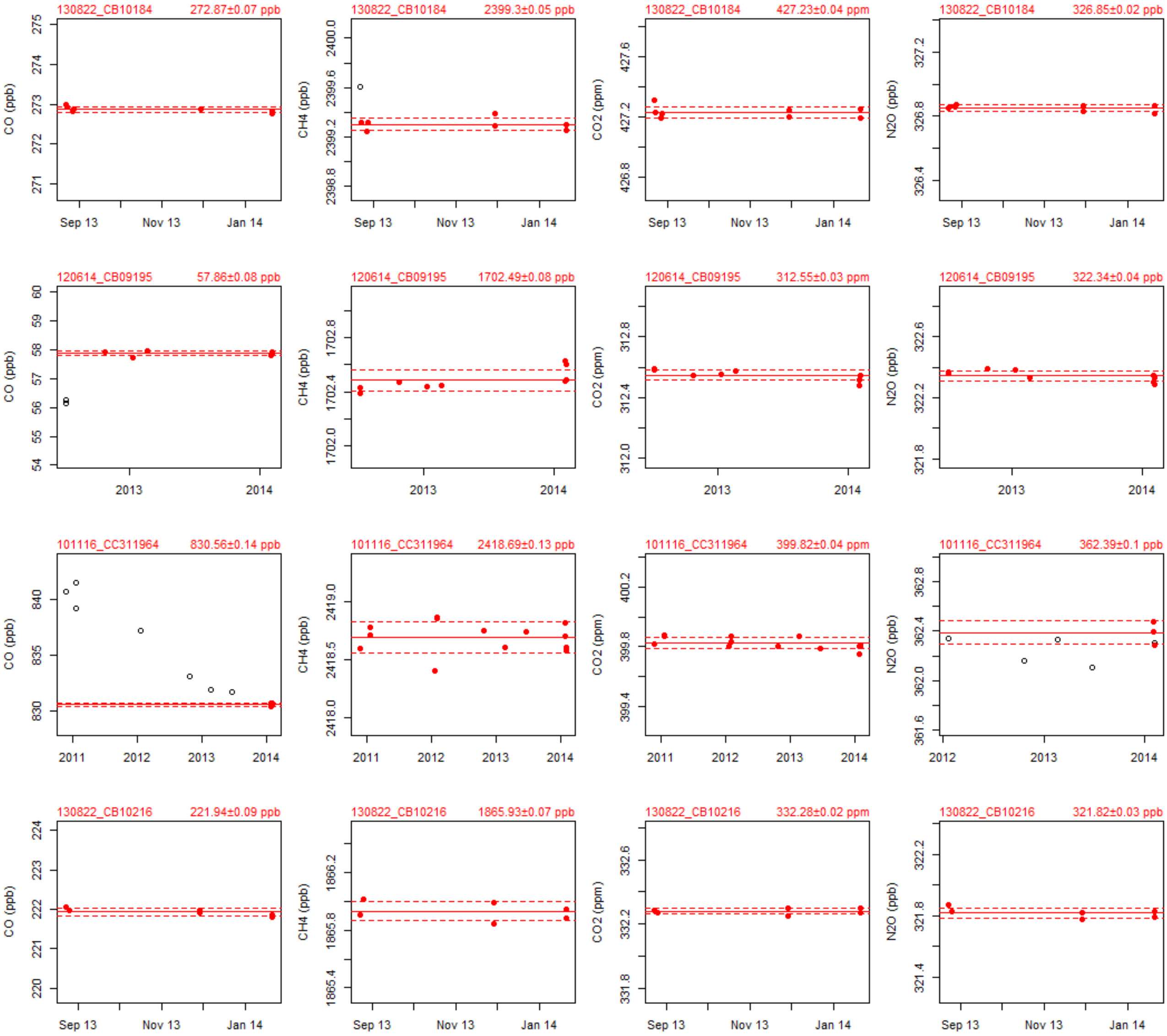


Figure 13. *Results of the WCC-Empa TS calibrations. Only the values of the red solid circles were considered for averaging. The red solid line is the average of the points that were considered for the assignment of the values; the red dotted line corresponds to the standard deviation of the measurement.*

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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 100.31805°E (864 m a.s.l.)
Parameter:		Surface Ozone

1.1	Date of Audit:	2014-05-23
1.2	Auditor:	Christoph Zellweger and Beat Schwarzenbach
1.3	Station staff involved in audit:	Agusta Kurniawan, Edison Kurniawan, Yosfi Andri, Alberth C. Nahas, Budi Satria, Rinaldi
1.4	Ozone Reference [SRP]:	NIST SRP#15
1.5	Ozone Transfer Standard [TS]	
1.5.1	Model and serial number:	TEI 49C-PS #54509-300, BKG -0.3, COEF 1.009
1.5.2	Range of calibration:	0 – 200 ppb
1.5.3	Mean calibration (ppb):	(1.0007±0.0009) • [SRP] - (0.18±0.07)
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	Offset = -0.1; Span = 1.014
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] + 0.86 ppb) / 0.9986
1.6.6	Standard uncertainty remaining after compensation of calibration bias (ppb):	u_{O3} (ppb) = sqrt (0.27 ppb^2 + 2.59e-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 14/1

[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 100.31805°E (864 m a.s.l.)
Parameter:		Surface Ozone

1.1	Date of Audit:	2014-05-25 through 2014-05-26
1.2	Auditor:	Christoph Zellweger and Beat Schwarzenbach
1.3	Station staff involved in audit:	Agusta Kurniawan, Edison Kurniawan, Yosfi Andri, Alberth C. Nahas, Budi Satria, Rinaldi
1.4	Ozone Reference [SRP]:	NIST SRP#15
1.5	Ozone Transfer Standard [TS]	
1.5.1	Model and serial number:	TEI 49C-PS #54509-300, BKG -0.3, COEF 1.009
1.5.2	Range of calibration:	0 – 200 ppb
1.5.3	Mean calibration (ppb):	(1.0007±0.0009) • [SRP] - (0.18±0.07)
1.6	Ozone Analyser [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	Offset = 0.0; Span = 1.012
1.6.4	Calibration at start of audit (ppb):	[OC] = (0.9890±0.0002) • [SRP] - (0.79±0.02)
1.6.5	Unbiased ozone mixing ratio (ppb) at start of audit:	X_{O3} (ppb) = ([OC] + 0.79 ppb) / 0.9890
1.6.6	Standard uncertainty remaining after compensation of calibration bias (ppb):	u_{O3} (ppb) = sqrt (0.27 ppb^2 + 2.64e-05 * X_{O3}^2)
1.6.7	Coefficients after audit	Offset = -0.5; Span = 1.023
1.6.8	Calibration after audit (ppb):	[OC] = (1.0022±0.0004) • [SRP] - (0.06±0.03)
1.6.9	Unbiased ozone mixing ratio (ppb) after audit:	X_{O3} (ppb) = ([OC] + 0.06 ppb) / 1.0022
1.6.10	Standard uncertainty remaining after compensation of calibration bias (ppb):	u_{O3} (ppb) = sqrt (0.27 ppb^2 + 2.54e-05 * X_{O3}^2)
1.7	Comments:	NA
1.8	Reference:	WCC-Empa Report 14/1

[OA]: 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 100.31805°E (864 m a.s.l.)
Parameter:		Carbon Monoxide

1.1	Date of Audit:	2014-05-23
1.2	Auditor:	Christoph Zellweger and Beat Schwarzenbach
1.3	Station staff involved in audit:	Agus Kurniawan, Edison Kurniawan, Budi Satria, Alberth Christian Nahas
1.4	WCC-Empa CO Reference:	NOAA laboratory standards (WMO-2004 scale)
1.5	CO Transfer Standard [TS]	TS calibrated against the WCC-Empa laboratory standards, WMO-2004 scale
1.6	Station Analyser:	
1.6.1	Analyser Model:	Horiba APMA360 #890617034
1.6.2	Range of calibration:	57 – 831 ppb
1.6.3	Coefficients at start of audit	Zero -1, SPAN 1. 1035
1.6.4	Calibration at start of audit (ppb):	CO = (0.87275±0.00174) • X_{CO} - (0.4±0.7)
1.6.5	Unbiased CO mixing ratio (ppb) at start of audit:	X_{CO} (ppb) = (CO + 0.4 / 0.87275
1.6.6	Standard uncertainty after compensation of calibration bias at start of audit (ppb):	u_{CO} (ppb) = sqrt (2.0 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:	NA
1.8	Reference:	WCC-Empa Report 14/1

[CO]: Instrument readings; X: mixing ratios on the WMO-2004 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 100.31805°E (864 m a.s.l.)
Parameter:		Methane

1.1	Date of Audit:	2014-05-22
1.2	Auditor:	Christoph Zellweger and Beat Schwarzenbach
1.3	Station staff involved in audit:	Edison Kurniawan, Alberth Christian Nahas, Budi Satria
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:	1702 – 2419 ppb
1.6.3	Coefficients at start of audit	NA
1.6.4	Calibration at start of audit (ppb):	$CH_4 = (0.99989 \pm 0.00010) \cdot X_{CH4} - (0.0 \pm 0.2)$
1.6.5	Unbiased CH_4 mixing ratio (ppb) at start of audit:	X_{CH4} (ppb) = $(CH_4 + 0.0) / 0.99989$
1.6.6	Standard uncertainty after compensation of calibration bias at start of audit (ppb):	u_{CH4} (ppb) = sqrt (0.1 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 14/1

[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 100.31805°E (864 m a.s.l.)
Parameter:		Carbon Dioxide

1.1	Date of Audit:	2014-05-22
1.2	Auditor:	Christoph Zellweger and Beat Schwarzenbach
1.3	Station staff involved in audit:	Edison Kurniawan, Alberth Christian Nahas, Budi Satria
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 #163-CFADS046
1.6.2	Range of calibration:	324 – 410 ppm
1.6.3	Coefficients at start of audit	NA
1.6.4	Calibration at start of audit (ppm):	$CO_2 = (0.99742 \pm 0.00061) \cdot X_{CO2} + (0.91 \pm 0.23)$
1.6.5	Unbiased CO_2 mixing ratio (ppm) at start of audit:	X_{CO2} (ppm) = $(CO_2 - 0.91) / 0.99742$
1.6.6	Standard uncertainty after compensation of calibration bias at start of audit (ppm):	u_{CO2} (ppm) = $\text{sqrt}(0.01\ \text{ppm}^2 + 3.28\text{e-}08 * X_{CO2}^2)$
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 14/1

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

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Nitrous Oxide Audit Executive Summary (BKT)

0.1	Station Name:	Bukit Kototabang
0.2	GAW ID:	BKT
0.3	Coordinates/Elevation:	0.20194°S 100.31805°E (864 m a.s.l.)
Parameter:		Nitrous Oxide

1.1	Date of Audit:	2014-05-22
1.2	Auditor:	Christoph Zellweger and Beat Schwarzenbach
1.3	Station staff involved in audit:	Edison Kurniawan, Alberth Christian Nahas, Budi Satria
1.4	WCC-Empa N_2O Reference:	NOAA laboratory standards (WMO-2006A scale)
1.5	N_2O Transfer Standard [TS]	TS calibrated against the WCC-Empa laboratory standards
1.6	Station Analyser:	
1.6.1	Analyser Model:	Thermo IRIS 4600 #1210052268-128/83
1.6.2	Range of calibration:	320 – 363 ppb
1.6.3	Coefficients at start of audit	NA
1.6.4	Calibration at start of audit (ppb):	$N_2O = (1.0259 \pm 0.0091) \cdot X_{N2O} - (8.86 \pm 3.05)$
1.6.5	Unbiased N_2O mixing ratio (ppb) at start of audit:	X_{N2O} (ppb) = $(N_2O + 8.86) / 1.0259$
1.6.6	Standard uncertainty after compensation of calibration bias at start of audit (ppb):	u_{N2O} (ppb) = sqrt (0.14 ppb^2 + 1.01e-07 * X_{N2O}^2)
1.6.7	Coefficients after audit	NA
1.6.8	Calibration after audit (ppb):	NA
1.6.9	Unbiased N_2O mixing ratio (ppb) after audit:	NA
1.6.10	Standard uncertainty after compensation of calibration bias after audit(ppb):	NA
1.7	Comments:	
1.8	Reference:	WCC-Empa Report 14/1

[N_2O]: Instrument readings; X: mixing ratios on the WMO-2006A N_2O scale.

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LIST OF ABBREVIATIONS

AL	Analyser
BKG	Background
BKT	Bukit Kototabang GAW Station
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
ESRL	Earth System and Research Laboratory
GAW	Global Atmosphere Watch
GAWSIS	GAW Station Information System
GAWTEC	GAW Training and Education Centre
LS	Laboratory Standard
NA	Not Applicable
NOAA	National Oceanic and Atmospheric Administration
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
TI	Travelling Instrument
TS	Traveling Standard
UPS	Uninterruptible Power Supply
UV	Ultra Violet
WCC-Empa	World Calibration Centre Empa
WDCGG	World Data Centre for Greenhouse Gases
WMO	World Meteorological Organization