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SYSTEM AND PERFORMANCE AUDIT OF SURFACE OZONE AND CARBON MONOXIDE AT THE GLOBAL GAW STATION BUKIT KOTO TABANG INDONESIA, JULY 2008

Submitted by

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CONTENTS

ASSESSMENT AND RECOMMENDATIONS

The fifth system and performance audit at the Global GAW station Bukit Koto Tabang (BKT) was conducted by WCC-Empa[1] from 4 thru 10 July 2008 in agreement with the WMO/GAW quality assurance system [*WMO*, 2007b]. The BKT observatory is operated by the Meteorological, Climatological and Geophysical Agency (BMKG). The audit was jointly conducted with the World Calibration Centre for Aerosol Physics (WCCAP).

Previous audits at the Bukit Koto Tabang 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], and in February 2007 [*Zellweger, et al.*, 2007].

The following people contributed to the audit:

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Dr Jörg Klausen	Empa Dübendorf, QA/SAC Switzerland
Ms Nurhayati	BMKG Jakarta, GAW Country Contact
Mr Herizal	BMKG, Station Manager
Mr Sugeng Nugroho	BMKG, Chief of Data and Information
Mr Asep Firman Ilahi	BMKG, Station Operator
Mr Carles Siregar	BMKG, Station Operator
Mr Budi Satria	BMKG, Station Operator
Mr Budi Setiawan	BMKG, Station Operator
Mr Yosfi Andri	BMKG, Station Operator
Mr Agusta Kurniawan	BMKG, Station Operator
Mr Alberth Christian Nahas	BMKG, Station Operator
Ms Firda Amalia Maslakha	BMKG, Station Operator
Mr Darmadi	BMKG, Financial Officer
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Our assessment of the Bukit Koto Tabang observatory in general, as well as the surface ozone and carbon monoxide measurements in particular, is summarised below. The assessment criteria for the ozone inter-comparison were developed by WCC-Empa and QA/SAC Switzerland [*Hofer, et al.*, 2000; *Klausen, et al.*, 2003].

This report is distributed to the GAW Country Contact (BMKG, Ms Nurhayati), the station manager (BMKG, Mr Herizal) and the World Meteorological Organization in Geneva. The executive summaries will be posted on the internet.

The recommendations found in this report are complemented with a priority (*** indicating highest priority) and a suggested completion date.

Station Location and Access

The global GAW station Bukit Kototabang is located on the island Sumatra, Indonesia. The station 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.

[1] WMO/GAW 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. No changes were made since the last audit in 2007. The recommendations of the last audit concerning air-conditioning and facility maintenance have been mostly completed, but internet access still depends on LAPAN infrastructure.

> **Recommendation 1 (**, ongoing)**
> *All air-conditioning systems should be running and immediately be repaired in case of failure. The laboratory door should be kept closed at all times.*
>
> **Recommendation 2 (**, 2009)**
> *An internet access independent from LAPAN should be set-up at the site.*

Station Management and Operation

The station is managed by the Meteorological and Geophysical Agency (BMKG) and is visited daily by station operators. The situation concerning responsibility and organisation clearly improved since the audit in 2007; however, communication among staff members needs still to be improved, and knowledge must be shared.

> **Recommendation 3 (**, ongoing)**
> *Continuation of the weekly meetings of all station staff for the discussion of all issues related to the station, instrument and measurement is encouraged. Recent data should be presented and discussed during these meetings.*
>
> **Recommendation 4 (**, ongoing)**
> *WCC-Empa and QA/SAC Switzerland recommend to have yearly internal inspection by BMKG Jakarta by someone 'with a sense of good laboratory practice' and some technical expertise (already recommended in 2007).*

Air Inlet System

Unchanged since last audit. Each instrument has its own air inlet system or inlet line. The design of these systems is adequate for its intended purpose.

Surface Ozone Measurements

Instrumentation. At the time of the audit the stations was equipped with two ozone analysers (TEI 49 and TEI 49C instruments). Both instruments were assessed during the audit, but the TEI 49 instrument was moved to Padang after the audit. The instrumentation (TEI 49C) is adequate for its intended purpose.

Standards. The station is equipped with a TEI 49-PS ozone calibrator. This instrument was not working during the previous audit but could be repaired in the meantime with assistance of the WCC-Empa storehouse project. Nevertheless it should not be used to actually calibrated ozone analyzers. The recommendation made in the previous audit report remains still valid.

Intercomparison (Performance Audit). The inter-comparisons extended over a period of several days. Both analysers and the calibrator were inter-compared during the audit. The results are summarised below and the following equations characterise the instrument bias:

TEI 49C:

This instrument was installed at BKT in 2006 and has been the main station analyser since then. The TEI 49C analyser was found to be in good calibration, as summarised below (1). [OA] represents surface ozone readings as delivered by the instrument.

TEI49C #58547-318: 0 – 90 ppb, good agreement

Unbiased O_3 mixing ratio (ppb) X_{O3} (ppb) = ([OA] - 0.03 ppb) / 1.003 (1)

The result of the inter-comparison is presented in Figure 1. This result confirmed the calibration of the previous audit in 2007.

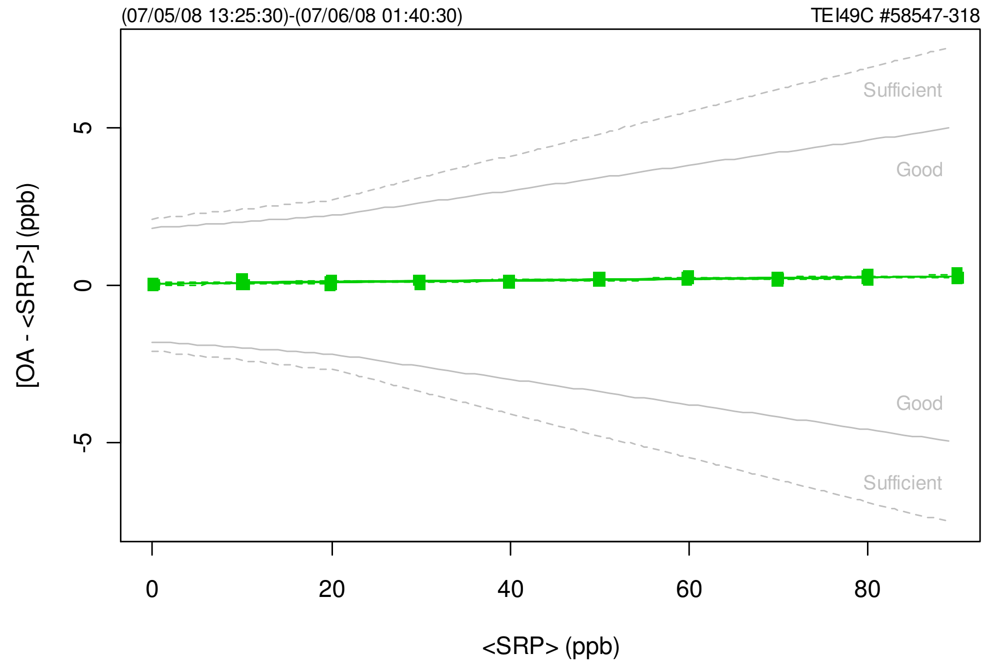

Figure 1. Bias of the Bukit Koto Tabang ozone analyser (TEI 49C) with respect to the SRP as a function of concentration. Each point represents the average of the last 10 one-minute values at a given level. Areas defining 'good' and 'sufficient' agreement according to GAW assessment criteria [Klausen, et al., 2003] are delimited by gray lines. The dashed lines about the regression lines are the Working-Hotelling 95% confidence bands.

TEI 49:

This instrument was in operation at the site since 1996 and was moved to Padang after the audit. The TEI 49 analyser was found to be in good calibration, and the result of the assessment is summarised below (2). [OA] represents surface ozone readings obtained from the station data acquisition.

TEI49 #51974-290: 0 – 90 ppb: good agreement

Unbiased O_3 mixing ratio (ppb) X_{O3} (ppb) = ([OA] + 0.19 ppb) / 0.987 (2)

The result of the inter-comparison is presented in Figure 2. No significant differences were found between the present and the previous audit.

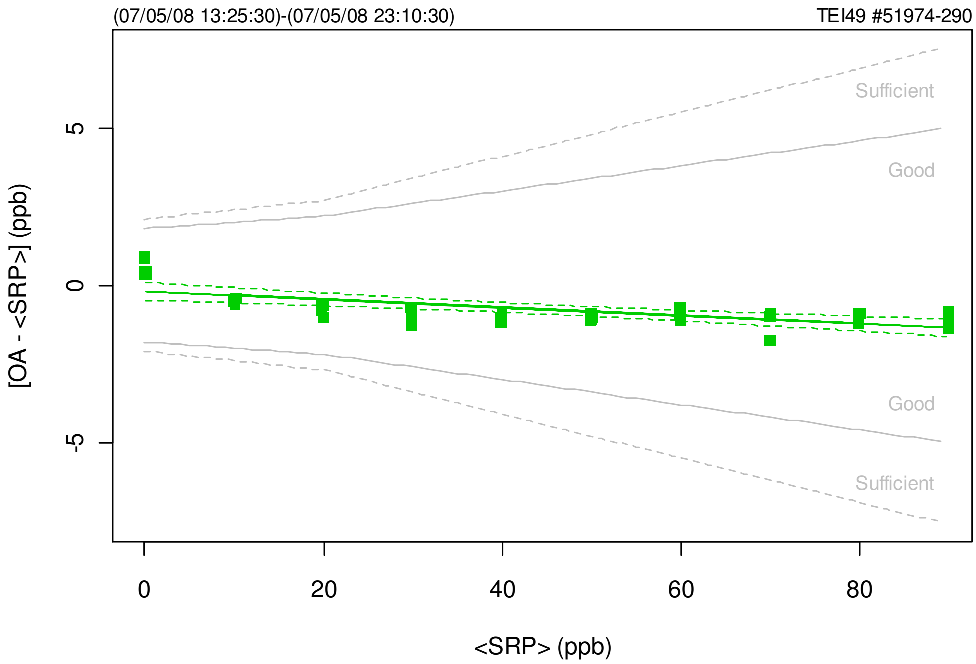

Figure 2. Bias of the Bukit Koto Tabang ozone analyser (TEI 49) with respect to the SRP as a function of concentration. Each point represents the average of the last 10 one-minute values at a given level. Areas defining 'good' and 'sufficient' agreement according to GAW assessment criteria [Klausen, et al., 2003] are delimited by gray lines. The dashed lines about the regression lines are the Working-Hotelling 95% confidence bands.

TEI 49PS:

This instrument has been used as a calibrator since 1996. It was unstable during the assessment of the WCC-Empa audit in 2004 and was not working in 2007 because of a defective board, which was replaced after the last audit. The actual inter-comparison with the WCC-Empa TS showed that the instrument is working again, but the instrument noise remains larger compared to the current station analyzer. Furthermore the calibrator seems to be not linear at low ozone mole fractions. The result of the assessment is summarised below (3). [OC] represents surface ozone readings obtained from the station data acquisition.

TEI49PS #52307-291: 0 – 90 ppb, good agreement, but non-linearity issues

Unbiased O_3 mixing ratio (ppb) X_{O3} (ppb) = ([OA] + 1.18 ppb) / 0.981 (3)

The results of these inter-comparisons are presented in Figure 3.

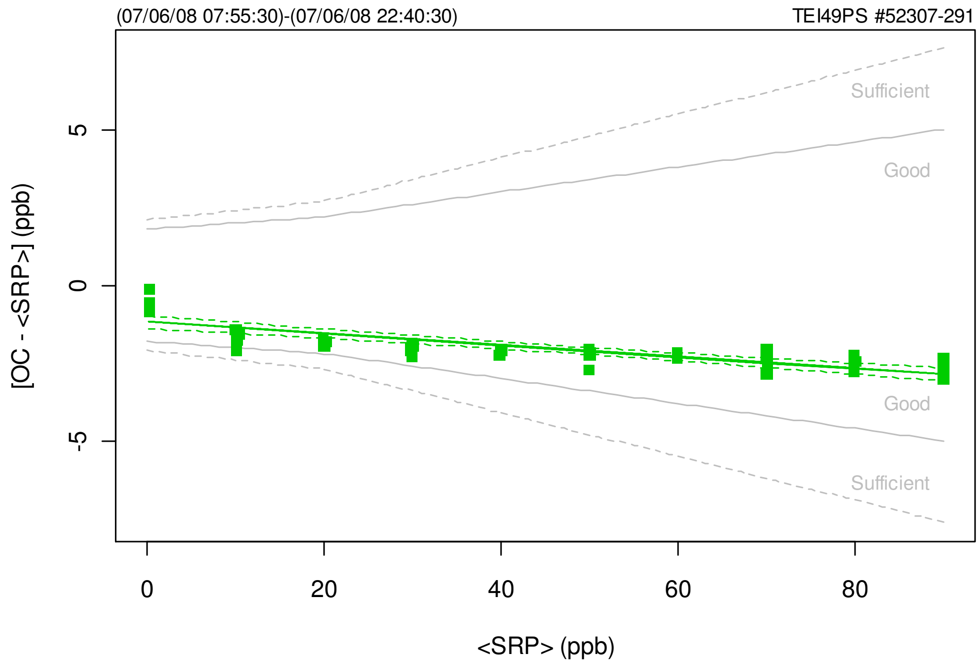

Figure 3. Bias of the Bukit Koto Tabang ozone calibrator (TEI 49PS) with respect to the SRP as a function of concentration. Each point represents the average of the last 10 one-minute values at a given level. Areas defining 'good' and 'sufficient' agreement according to GAW assessment criteria [Klausen, et al., 2003] are delimited by gray lines. The dashed lines about the regression lines are the Working-Hotelling 95% confidence bands.

Recommendation 5 (, 2007)**
The TEI 49PS can be used for quality control purposes and instrument checks, but must never be used for calibrations of ozone analysers. A replacement with a new TEI49i-PS is recommended.

Carbon Monoxide Measurements

Instrumentation. A refurbished Horiba APMA 360 was installed after the audit in 2007. The original TEI 48C-TL was still at the site but was not running at the time of the audit. It could be repaired by extensive cleaning of the gas filter wheel, but the instrument should no longer be used for CO measurements at BKT. The new instrumentation is adequate for the intended purpose.

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

> **Recommendation 6 (***, 2009-2011)**
> *For the long term operation of the BKT station, funds are needed for the purchase of calibration gases. BMKG should not rely on delivery of calibration gases by WCC-Empa.*

Intercomparison (Performance Audit). The inter-comparisons involved repeated challenges of the instruments with randomised carbon monoxide concentrations from travelling standards. The following equation (2) characterises the instrument bias (cf. Figure 4):

HORIBA APMA360 #890617034 (Zero -1, SPAN 1.0338):

Unbiased CO mixing ratio (ppb): X_{CO} (ppb) = ([CO] – 0.1 ppb) / 0.934 (2)

The results show that the analyzer is in functioning well concerning instrument noise and linearity; however, CO readings were lower by approximately 7% compared to WCC-Empa. The reason for this could not be found during the audit.

> **Recommendation 7 (**, 2009)**
> *The reason for the lower readings during the audit need to be identified. WCC-Empa recommends to continue measurements with the current instrument settings; in addition, the checks with the 1 ppm CO standard should carefully be made in regular (monthly) intervals. If the lower readings should be confirmed by a future audit, data should be corrected accordingly.*

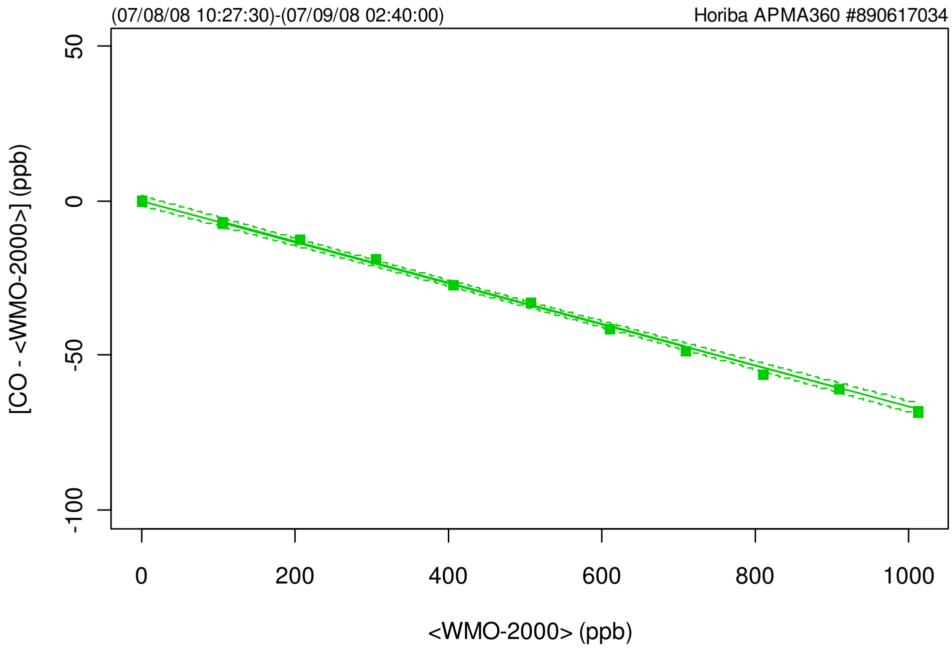

Figure 4. Bias of the Bukit Koto Tabang carbon monoxide analyser (HORIBA APMA360) with respect to the WMO-2000 reference scale as a function of concentration. Each point represents the average of data at a given level from a specific run. The dashed lines about the regression lines are the Working-Hotelling 95% confidence bands.

Data Acquisition and Management

The station is now equipped with a centralised data acquisition system as recommended in the previous audit report. The system was programmed by QA/SAC-Switzerland using LabView and currently includes the CO, surface ozone and aerosol programme of BKT. Data is automatically transferred to an FTP server in near-real time for further processing.

Recommendation 8 (, ongoing)**
Other measurement parameters should be incorporated into the centralised data acquisition system.

Operation and Maintenance

The station is daily visited by station operators. Each operator has a specific measurement as the main responsibility, but is doing checks on the other systems as well during station visits. It was noticed during the audit that information available in log books and check lists was not always comprehensive and complete. Furthermore, some technical skills such as gas cylinder handling need to be improved.

Recommendation 9 (*, ongoing)**
Documentation is a key aspect for a successful operation of the measurements and needs more attention by the station staff. Log files and check lists need to be carefully filled in.

Recommendation 10 (*, ongoing)**
BMKG should explore all possibilities for operator training. Participation in GAWTEC courses and other means of continuing education is strongly encouraged, and the knowledge needs to be shared between all station staff.

Data Submission

Data have been submitted to the World Data Centre for Greenhouse Gases (WDCGG). Currently data for surface ozone (September 96 – December 07), carbon monoxide (July 01 – June 07), nitrogen dioxide and sulphur dioxide (January 96 – July 05) were available at the data centre.

Recommendation 11 (*, 2009)**
A review of the available SO_2 and NO_2 data showed that some of the submitted data is of questionable quality. These data series need to be quality controlled and re-submitted if possible. Meanwhile WCC-Empa recommends that the SO_2 and NO_2 data series are withdrawn from WDCGG

Conclusions

The Global GAW station Bukit Koto Tabang comprises a still growing suite of ongoing measurements. The existing data sets are a valuable contribution to the GAW programme, especially because they cover a geographical region where only spares in-situ information about atmospheric composition is available. The continuation of existing measurements on a long term basis and the addition of new parameters are therefore strongly encouraged. All assessed measurements were of sufficiently high quality, but an issue concerning the calibration of the new CO instrument needs further attention.

Summary Ranking of Bukit Koto Tabang Station

System Audit Aspect	Adequacy#	Comment
Access	(5)	Paved access road
Facilities		
Laboratory and office space	(5)	Spacious concrete building
Air Conditioning	(4)	Mostly functional units
Power supply	(3)	Frequent failures, limited
Internet access	(3)	Available, unreliable
General Management and Operation		
Organisation	(4)	Improved since 2007
Competence of staff	(3)	Continuous training needed
Air Inlet System	(4)	Direct lines to instruments
Instrumentation		
Ozone	(5)	TEI49C
Carbon monoxide	(4)	Horiba APMA360
Aerosol PM10	(5)	BAM1020
Aerosol Scattering Coeff	(4)	Ecotech M9003
Flask sampling	(5)	NOAA/ESRL
CO_2, CH_4, NO_x, SO_2	(0)	Purchased, not yet
Meteo	(3)	Instrumentation coming of
Radiation	(3)	Data acquisition problematic
Standards		
Ozone	(1)	TEI49PS unreliable
Carbon monoxide	(4)	Dilution unit
Aerosol Scattering Coeff	(5)	Automatic using CO_2 gas
Other gases	(0)	Not yet available
Data Management		
Data acquisition	(4)	Centralised data acquisition
Data processing	(3)	Still reliant on twinning
Data submission	(3)	Review of some data needed

#0: inadequate thru 5: adequate; *refer to GAWSIS (www.empa.ch/gaw/gawsis) for a complete overview of measured parameters.

Dübendorf, July 2010

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APPENDIX

Global GAW Station Bukit Koto Tabang

Site description

Information about the Bukit Koto Tabang GAW station can be found in previous audit reports [*Zellweger, et al.*, 2007], and the station is also registered in GAWSIS (http://gaw.empa.ch/gawsis).

Measurement Programme

The observatory Bukit Koto Tabang started its operation in 1995. A short overview of the measurement programme and its status as of July 2008 is shown in Table 1. Refer to GAWSIS for more details. In addition to this, other facilities (e.g. equatorial atmosphere radar, lidar, GPS) are run by mainly Japanese institutions.

Table 1. 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 49 and 49C)
Greenhouse Gas	
CO_2[#]	NDIR (LICOR 6262)
CO_2, SF_6, N_2O	NOAA/ESRL flask sampling
Reactive Gas	
CO	NDIR (HORIBA APMA360)
CO, H_2	NOAA/ESRL flask sampling
NO_2	Passive sampler
SO_2	Passive sampler
Solar radiation	
Global irradiance	Pyranometer (Kipp & Zonen)
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 (PTU, wind speed + direction)	

Ozone and Carbon Monoxide Distribution at Bukit Koto Tabang

See previous audit report [Zellweger, et al., 2007].

Organisation and Contact Persons

The GAW activities of Indonesia are coordinated by Centre for Climate and Air Quality Analysis Division (Head Ms Nurhayati) of the Meteorological and Geophysical Agency (BMKG). The organisational structure remained unchanged since the last audit, but all leading positions were changed. An organisational chart is shown in Figure 5.

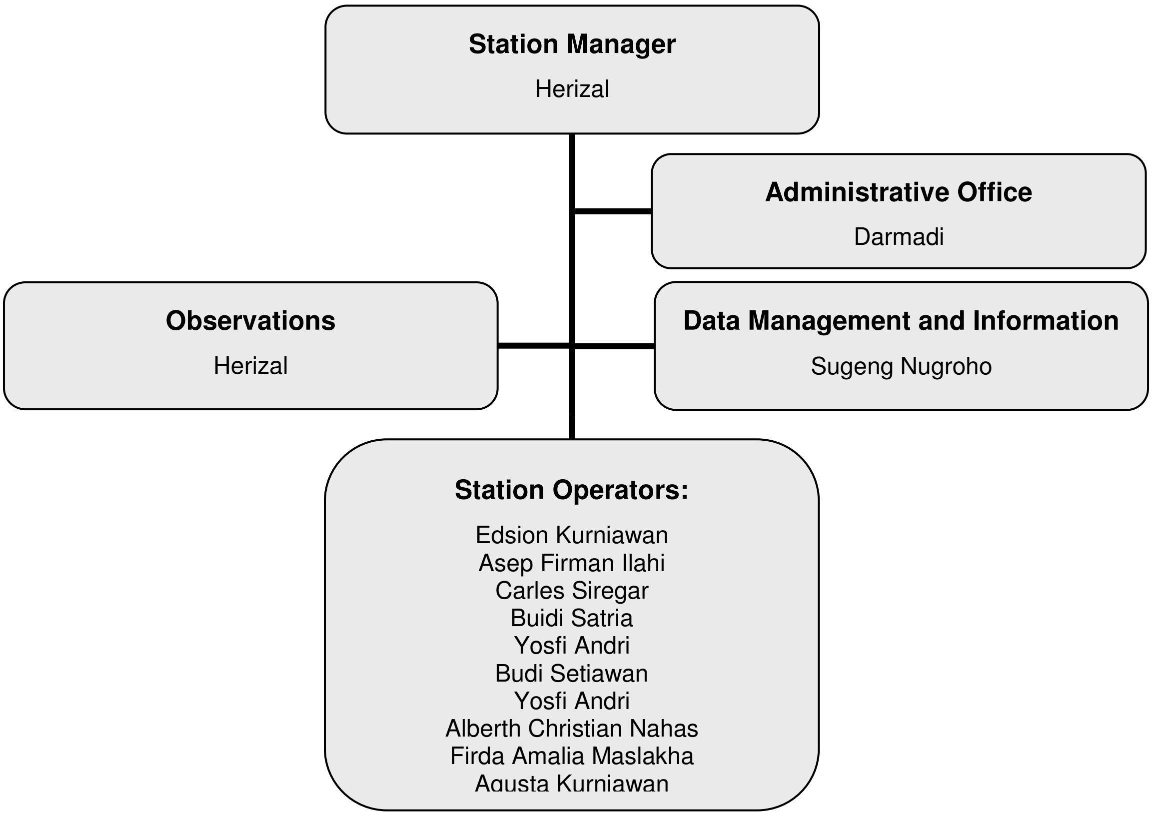


Figure 5. Organisation of the GAW station Bukit Koto Tabang as of July 2008.

Surface Ozone Measurements

Surface ozone measurements started in 1996 at the Bukit Koto Tabang site, and time series are available since then except for a period between 1999 and 2001. The instrumental set-up remained unchanged since the last audit. All inter-comparisons were done according to Standard Operating Procedures [*WMO*, in preparation].

Monitoring Set-up and Procedures

Air Conditioning

The laboratory is air conditioned. Some AC units were not functional at the time of the last audit, but the defective units were repaired after the audit in 2007.

Air Inlet System

Unchanged since last audit [*Zellweger, et al.*, 2007].

Instrumentation

Unchanged since last audit [*Zellweger, et al.*, 2007]. Instrumental details for the ozone analysers (OA) are summarised in Table 2.

Standards

A TEI 49-PS ozone standard is available at the site. This instrument was repaired during the last audit in 2007, but should not be used for ozone calibrations. In the meantime, a new ozone calibrator was purchased.

Operation and Maintenance
See previous audit report [*Zellweger, et al.*, 2007].

Data Acquisition and Data Transfer
At the time of the audit data of the TEI 49 and TEI 49-PS was still acquired using the DT50 data logger (see [*Zellweger, et al.*, 2004]). The data of the TEI49C analyser was acquired on a LabView based data acquisition system that was implemented during the audit in 2007 by QA/SAC Switzerland.

Data Treatment
See previous audit report [*Zellweger, et al.*, 2007].

Data Submission
Ozone data have been submitted to the World Data Centre for Surface Ozone at JMA (WDCGG).

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

Inter-Comparison of Ozone Analyzers and Calibrator

All procedures were conducted according to the Standard Operating Procedure [*WMO*, in preparation] and included inter-comparisons of the travelling standard with the Standard Reference Photometer at Empa before and after the inter-comparison of the analyser.

Setup and Connections
Table 2 details the experimental setup during the inter-comparison of the travelling standard with the station analysers and the calibrator. The data used for the evaluation was recorded by both WCC-Empa and Bukit Koto Tabang data acquisition systems as indicated. Data of the BKT data acquisition system (BKT analysers) was used for the evaluation of the results.

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 inter-comparison as described elsewhere *[Klausen, et al., 2003]*. All results are valid for the calibration factors as given in Table 2 below. 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.

TEI 49C #58547-318
This instrument was installed at BKT in September 2006. The initial calibration was done against SRP#15 at the laboratory of WCC-Empa in May 2006 and confirmed to be valid during the audit in 2007. The result of the current assessment (direct comparison between TS and the analyser) is shown in Table 3.

Figure 6 shows the regression residuals of the TEI 49C ozone analyser for the inter-comparisons described above with respect to the SRP as a function of ozone concentration for the range 0 – 90 ppb and as a function of time.

Table 2. Experimental details of the ozone inter-comparison.

Travelling standard (TS)	Model, S/N	TEI 49C-PS #56891-310 (WCC-Empa)
	Settings	BKG = -0.2; COEFF = 1.007
Main analyzer (OA) This instrument is the main ozone analyser since the current audit.	Model, S/N	TEI 49C #58547-318
	Principle	UV absorption
	Range	1 ppm
	Settings	BKG = 0.1; COEFF = 1.014
Backup analyzer (OA) This instrument was the main ozone analyser before the current audit.	Model, S/N	TEI 49 #51974-290
	Principle	UV absorption
	Range	1 ppm
	Settings	Offset 50, Slope 521
Calibrator (OC)	Model, S/N	TEI 49-PS #52307-291
	Principle	UV absorption
	Range	1 ppm
	Settings	NA
Ozone source		Internal generator of TS
Zero air supply		Custom built, consisting of: silica gel - inlet filter 5 µm - metal bellow pump - Purafil (potassium permanganate) - activated charcoal - outlet filter 5 µm (WCC-Empa)
Connection between instruments		Ca. 1.5 meter of 1/4" PFA tubing between TS manifold and inlet filter of OA
Data acquisition	TS	One minute aggregates from digital output of WCC-Empa data acquisition (custom designed LabView programme)
	Analyser OA	Station Data Acquisition
Pressure readings at beginning of inter-comparison (hPa)	Ambient	918.1 (Station reference)
	TS	917.9, not adjusted
	TEI 49C	913.4, not adjusted
	TEI 49	937.1 (large offset; not adjusted because data of this instrument should not be used)
	TEI 49-PS	920.3 (not adjusted)
Levels (ppb)		0, 10, 20, 30, 40, 50, 60, 70, 80, 90
Duration per level (min)		15
Sequence of levels		Repeated runs of randomised fixed sequence
Runs		TEI 49: 4 runs (5 July 08) TEI 49C: 5 runs (5 thru 6 July 08) TEI 49-PS: 6 runs (6 July 08)

Table 3. Ten-minute aggregates (initial inter-comparison, direct TS-analyser) computed from the last 10 of a total of 15 one-minute values for the inter-comparison of the BKT ozone analyser (OA) TEI 49C #58547-318 with the WCC-Empa travelling standard (TS).

DateTime (UTC)	Run	Level	TS (ppb)	OA (ppb)	Flag[#]	sdTS (ppb)	sdOA (ppb)
2008-07-05 13:30	1	0	0.12	0.09	0	0.12	0.04
2008-07-05 13:45	1	30	29.79	29.90	0	0.09	0.05
2008-07-05 14:00	1	60	59.79	60.03	0	0.16	0.11
2008-07-05 14:15	1	40	39.88	39.99	0	0.13	0.05
2008-07-05 14:30	1	90	89.89	90.27	0	0.11	0.04
2008-07-05 14:45	1	50	49.86	50.08	0	0.12	0.08
2008-07-05 15:00	1	10	10.24	10.15	0	0.28	0.13
2008-07-05 15:15	1	20	19.80	19.82	0	0.16	0.06
2008-07-05 15:30	1	80	79.76	80.00	0	0.13	0.04
2008-07-05 15:45	1	70	69.83	70.11	0	0.12	0.06
2008-07-05 16:00	2	0	0.20	0.12	0	0.07	0.04
2008-07-05 16:15	2	40	39.87	39.98	0	0.12	0.04
2008-07-05 16:30	2	70	69.84	70.13	0	0.20	0.07
2008-07-05 16:45	2	30	29.93	29.91	0	0.11	0.06
2008-07-05 17:00	2	90	89.81	90.27	0	0.15	0.05
2008-07-05 17:15	2	20	20.01	20.11	0	0.14	0.03
2008-07-05 17:30	2	10	10.06	10.16	0	0.06	0.03
2008-07-05 17:45	2	60	59.73	59.92	0	0.12	0.04
2008-07-05 18:00	2	50	49.92	50.17	0	0.09	0.04
2008-07-05 18:15	2	80	79.90	80.28	0	0.10	0.04
2008-07-05 18:30	3	0	0.16	0.04	0	0.10	0.04
2008-07-05 18:45	3	90	89.88	90.16	0	0.13	0.06
2008-07-05 19:00	3	70	69.83	70.02	0	0.11	0.05
2008-07-05 19:15	3	40	39.93	40.00	0	0.09	0.04
2008-07-05 19:30	3	50	49.93	50.04	0	0.08	0.04
2008-07-05 19:45	3	20	20.00	19.96	0	0.12	0.05
2008-07-05 20:00	3	30	29.90	29.93	0	0.07	0.03
2008-07-05 20:15	3	60	59.92	60.14	0	0.09	0.06
2008-07-05 20:30	3	10	10.16	10.13	0	0.16	0.04
2008-07-05 20:45	3	80	79.80	80.13	0	0.09	0.04
2008-07-05 21:00	4	0	0.19	0.09	0	0.10	0.04
2008-07-05 21:15	4	30	29.85	29.87	0	0.08	0.04
2008-07-05 21:30	4	60	59.84	60.04	0	0.13	0.05
2008-07-05 21:45	4	40	39.95	40.04	0	0.10	0.04
2008-07-05 22:00	4	90	89.85	90.14	0	0.08	0.05
2008-07-05 22:15	4	50	49.94	50.17	0	0.09	0.06
2008-07-05 22:30	4	10	10.20	10.15	0	0.13	0.05
2008-07-05 22:45	4	20	19.84	19.75	0	0.10	0.05
2008-07-05 23:00	4	80	79.81	80.12	0	0.12	0.06
2008-07-05 23:15	4	70	69.90	70.13	0	0.06	0.05
2008-07-05 23:30	5	0	0.17	0.05	0	0.13	0.05
2008-07-05 23:45	5	40	39.86	39.88	0	0.12	0.06
2008-07-06 00:00	5	70	69.84	69.98	0	0.19	0.09
2008-07-06 00:15	5	30	29.97	30.09	0	0.13	0.04
2008-07-06 00:30	5	90	89.90	90.19	0	0.09	0.06
2008-07-06 00:45	5	20	20.07	20.02	0	0.13	0.07
2008-07-06 01:00	5	10	10.06	10.00	0	0.12	0.06
2008-07-06 01:15	5	60	59.81	60.10	0	0.10	0.05
2008-07-06 01:30	5	50	49.97	50.05	0	0.09	0.03
2008-07-06 01:45	5	80	79.91	80.12	0	0.08	0.05

[#]0: valid data; 1: invalid data.

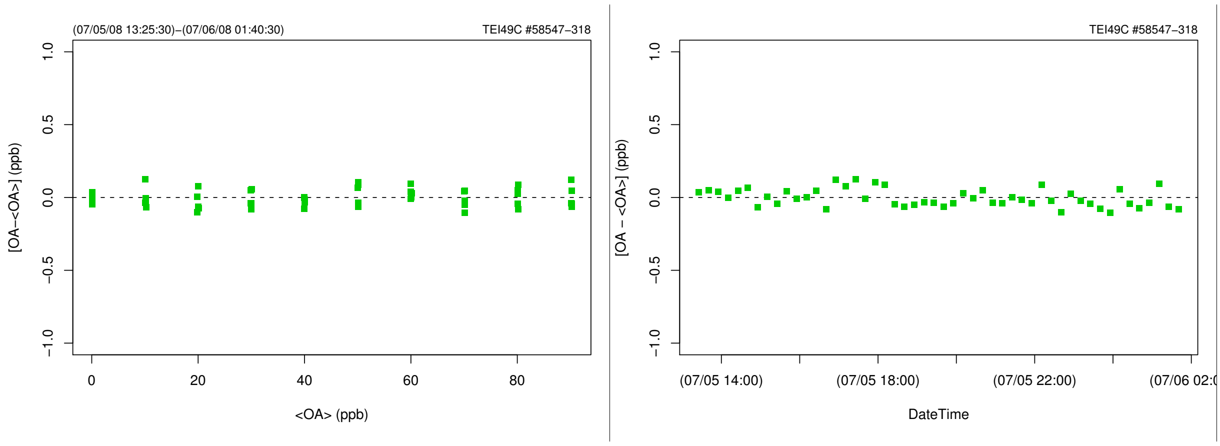


Figure 6. Regression residuals of the BKT ozone analyser (TEI 49C) as a function of concentration (left) and time (right).

Based on these inter-comparison results, unbiased ozone volume mixing ratios X_{O3} and an estimate for the remaining combined standard uncertainty u_{O3} can be computed from the one-minute data [OA] using equation (1) [*Klausen, et al.*, 2003].

TEI 49C #58547-318:

$$X_{O3} \text{ (ppb)} = ([OA] - 0.03 \text{ ppb}) / 1.003$$

$$u_{O3} \text{ (ppb)} = \text{sqrt}(0.27 \text{ ppb}^2 + 2.59\text{e-}05 * X_{O3}^2) \quad (1)$$

TEI 49 #51974-290:

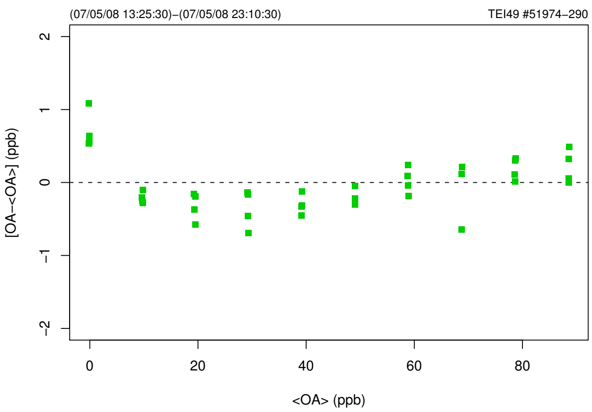
The instrument was installed at BKT in 1996, and should no longer be used for ozone measurement at BKT. Figure 7 shows the regression residuals of the TEI 49 ozone analyser for the inter-comparisons described above with respect to the SRP as a function of ozone concentration for the range 0 - 90 ppb and as a function of time. The result of the assessment (direct comparison between TS and the analyser) is shown in Table 4.

Table 4. Ten-minute aggregates (unadjusted pressure sensor) computed from the last 10 of a total of 15 one-minute values for the inter-comparison of the BKT ozone analyser (OA) TEI 49 #51974-290 with the WCC-Empa travelling standard (TS).

DateTime (UTC)	Run	Level	TS (ppb)	OA (ppb)	Flag[#]	sdTS (ppb)	sdOA (ppb)
2008-07-05 13:30	1	0	0.12	0.91	0	0.12	0.07
2008-07-05 13:45	1	30	29.79	29.03	0	0.09	0.08
2008-07-05 14:00	1	60	59.79	59.08	0	0.16	0.15
2008-07-05 14:15	1	40	39.88	38.82	0	0.13	0.10
2008-07-05 14:30	1	90	89.89	89.10	0	0.11	0.11
2008-07-05 14:45	1	50	49.86	48.71	0	0.12	0.12
2008-07-05 15:00	1	10	10.24	9.73	0	0.28	0.14
2008-07-05 15:15	1	20	19.80	19.13	0	0.16	0.08
2008-07-05 15:30	1	80	79.76	78.70	0	0.13	0.08
2008-07-05 15:45	1	70	69.83	68.12	0	0.12	0.12
2008-07-05 16:00	2	0	0.20	0.55	0	0.07	0.08
2008-07-05 16:15	2	40	39.87	38.69	0	0.12	0.09
2008-07-05 16:30	2	70	69.84	68.89	0	0.20	0.10
2008-07-05 16:45	2	30	29.93	28.61	0	0.11	0.10
2008-07-05 17:00	2	90	89.81	88.58	0	0.15	0.04
2008-07-05 17:15	2	20	20.01	19.30	0	0.14	0.09
2008-07-05 17:30	2	10	10.06	9.45	0	0.06	0.09
2008-07-05 17:45	2	60	59.73	58.87	0	0.12	0.10
2008-07-05 18:00	2	50	49.92	48.82	0	0.09	0.11
2008-07-05 18:15	2	80	79.90	79.06	0	0.10	0.07
2008-07-05 18:30	3	0	0.16	0.40	0	0.10	0.11
2008-07-05 18:45	3	90	89.88	88.60	0	0.13	0.08
2008-07-05 19:00	3	70	69.83	68.88	0	0.11	0.13

DateTime (UTC)	Run	Level	TS (ppb)	OA (ppb)	Flag#	sdTS (ppb)	sdOA (ppb)
2008-07-05 19:15	3	40	39.93	38.88	0	0.09	0.08
2008-07-05 19:30	3	50	49.93	49.04	0	0.08	0.09
2008-07-05 19:45	3	20	20.00	18.91	0	0.12	0.10
2008-07-05 20:00	3	30	29.90	29.12	0	0.07	0.10
2008-07-05 20:15	3	60	59.92	58.78	0	0.09	0.11
2008-07-05 20:30	3	10	10.16	9.50	0	0.16	0.08
2008-07-05 20:45	3	80	79.80	78.64	0	0.09	0.08
2008-07-05 21:00	4	0	0.19	0.45	0	0.10	0.08
2008-07-05 21:15	4	30	29.85	28.76	0	0.08	0.10
2008-07-05 21:30	4	60	59.84	58.85	0	0.13	0.10
2008-07-05 21:45	4	40	39.95	39.09	0	0.10	0.07
2008-07-05 22:00	4	90	89.85	88.89	0	0.08	0.11
2008-07-05 22:15	4	50	49.94	48.87	0	0.09	0.09
2008-07-05 22:30	4	10	10.20	9.51	0	0.13	0.09
2008-07-05 22:45	4	20	19.84	18.95	0	0.10	0.10
2008-07-05 23:00	4	80	79.81	78.93	0	0.12	0.08
2008-07-05 23:15	4	70	69.90	69.05	0	0.06	0.06

#0: valid data; 1: invalid data.



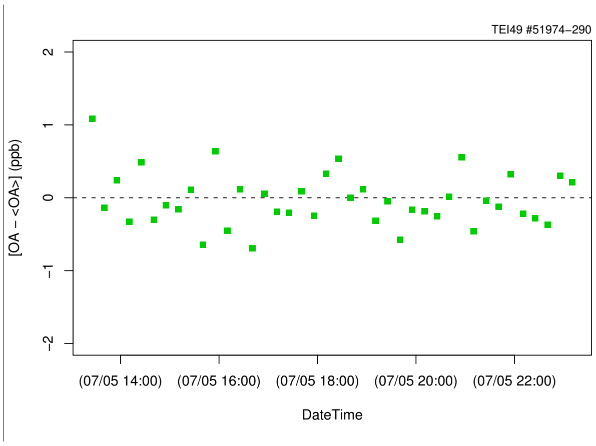


Figure 7. Regression residuals of the BKT ozone analyser (TEI 49) s a function of concentration (left) and time (right).

Based on these inter-comparison results, unbiased ozone volume mixing ratios X_{O3} and an estimate for the remaining combined standard uncertainty u_{O3} can be computed from the one-minute data [OA] using equation (1) [*Klausen, et al.*, 2003].

TEI 49 #51974-290:

$$X_{O3} \text{ (ppb)} = ([OA] + 0.19 \text{ ppb}) / 0.987$$

$$u_{O3} \text{ (ppb)} = \text{sqrt}(0.42 \text{ ppb}^2 + 2.72\text{e-}05 * X_{O3}^2) \quad (2)$$

TEI 49-PS #52307-291:

The ozone calibrator was installed at BKT in 1996. It was noticed during the WCC-Empa audit in 2004 [*Zellweger, et al.*, 2004] that this instrument has a poor stability compared to the station analyser. A problem was identified during the audit in 2007 with the temperature control board CNTRS 49-007. The board was replaced after the last audit, and the result of the assessment (direct comparison between TS and the calibrator) is shown in Table 5. Figure 8 shows the regression residuals of the TEI 49-PS ozone calibrator for the inter-comparison described above with respect to the SRP as a function of ozone concentration for the range 0 – 90 ppb and as a function of time.

Table 5. Ten-minute aggregates computed from the last 10 of a total of 15 one-minute values for the inter-comparison of the BKT ozone calibrator (OC) TEI 49-PS #52307-291 with the WCC-Empa travelling standard (TS).

DateTime (UTC)	Run	Level	TS (ppb)	OC (ppb)	Flag[#]	sdTS (ppb)	sdOC (ppb)
2008-07-06 08:00	1	0	0.24	-0.59	0	0.04	0.07
2008-07-06 08:15	1	40	39.85	37.72	0	0.07	0.11
2008-07-06 08:30	1	70	69.92	67.10	0	0.16	0.12
2008-07-06 08:45	1	30	30.05	28.09	0	0.11	0.09
2008-07-06 09:00	1	90	89.96	87.23	0	0.41	0.19
2008-07-06 09:15	1	20	20.16	18.30	0	0.14	0.09
2008-07-06 09:30	1	10	10.07	7.91	0	0.14	0.08
2008-07-06 09:45	1	60	59.83	57.50	0	0.06	0.15
2008-07-06 10:00	1	50	49.90	47.80	0	0.06	0.11
2008-07-06 10:15	1	80	79.90	77.68	0	0.05	0.20
2008-07-06 10:30	2	0	0.26	-0.48	0	0.09	0.13
2008-07-06 10:45	2	90	89.90	87.52	0	0.07	0.12
2008-07-06 11:00	2	70	69.96	67.39	0	0.06	0.09
2008-07-06 11:15	2	40	40.00	37.86	0	0.11	0.22
2008-07-06 11:30	2	50	49.95	47.70	0	0.06	0.12
2008-07-06 11:45	2	20	20.07	18.05	0	0.06	0.13
2008-07-06 12:00	2	30	29.91	27.58	0	0.11	0.07
2008-07-06 12:15	2	60	59.92	57.80	0	0.08	0.09
2008-07-06 12:30	2	10	10.13	7.93	0	0.07	0.06
2008-07-06 12:45	2	80	79.83	77.10	0	0.10	0.13
2008-07-06 13:00	3	0	0.25	-0.45	0	0.10	0.07
2008-07-06 13:15	3	30	29.77	27.73	0	0.13	0.15
2008-07-06 13:30	3	60	59.86	57.54	0	0.13	0.11
2008-07-06 13:45	3	40	39.94	37.88	0	0.06	0.17
2008-07-06 14:00	3	90	89.93	87.29	0	0.08	0.11
2008-07-06 14:15	3	50	49.96	47.77	0	0.07	0.19
2008-07-06 14:30	3	10	10.24	8.40	0	0.20	0.16
2008-07-06 14:45	3	20	19.92	18.15	0	0.07	0.15
2008-07-06 15:00	3	80	79.79	77.18	0	0.12	0.13
2008-07-06 15:15	3	70	69.95	67.90	0	0.09	0.23
2008-07-06 15:30	4	0	0.26	0.03	0	0.10	0.12
2008-07-06 15:45	4	40	39.81	37.54	0	0.06	0.19
2008-07-06 16:00	4	70	69.88	67.62	0	0.16	0.15
2008-07-06 16:15	4	30	30.03	28.05	0	0.09	0.16
2008-07-06 16:30	4	90	89.90	87.29	0	0.16	0.19
2008-07-06 16:45	4	20	20.13	18.25	0	0.09	0.12
2008-07-06 17:00	4	10	10.03	8.50	0	0.07	0.13
2008-07-06 17:15	4	60	59.82	57.53	0	0.11	0.26
2008-07-06 17:30	4	50	49.93	47.86	0	0.06	0.19
2008-07-06 17:45	4	80	79.96	77.57	0	0.04	0.15
2008-07-06 18:00	5	0	0.30	-0.66	0	0.12	0.18
2008-07-06 18:15	5	90	89.91	87.64	0	0.08	0.18
2008-07-06 18:30	5	70	69.93	67.83	0	0.09	0.11
2008-07-06 18:45	5	40	39.98	37.84	0	0.07	0.13
2008-07-06 19:00	5	50	49.94	47.20	0	0.07	0.20
2008-07-06 19:15	5	20	20.13	18.13	0	0.11	0.19
2008-07-06 19:30	5	30	29.93	28.01	0	0.12	0.26
2008-07-06 19:45	5	60	59.89	57.62	0	0.14	0.14
2008-07-06 20:00	5	10	10.14	8.33	0	0.18	0.11
2008-07-06 20:15	5	80	79.83	77.48	0	0.10	0.11
2008-07-06 20:30	6	0	0.24	-0.43	0	0.08	0.05
2008-07-06 20:45	6	30	29.80	27.66	0	0.07	0.08
2008-07-06 21:00	6	60	59.85	57.53	0	0.12	0.12
2008-07-06 21:15	6	40	39.99	37.91	0	0.08	0.12
2008-07-06 21:30	6	90	89.92	86.99	0	0.10	0.12
2008-07-06 21:45	6	50	49.97	47.71	0	0.09	0.17
2008-07-06 22:00	6	10	10.37	8.70	0	0.52	0.16
2008-07-06 22:15	6	20	19.97	17.94	0	0.07	0.20
2008-07-06 22:30	6	80	79.81	77.17	0	0.13	0.18
2008-07-06 22:45	6	70	69.97	67.74	0	0.05	0.18

[#]0: valid data; 1: invalid data.

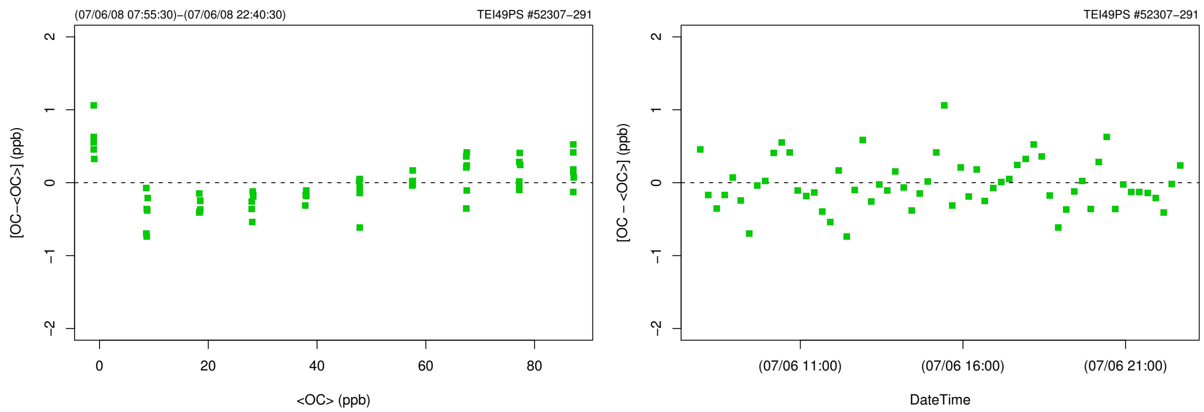


Figure 8. Regression residuals of the BKT ozone calibrator (TEI 49-PS) as a function of concentration (left) and time (right).

Based on these inter-comparison results, unbiased ozone volume mixing ratios X_{O3} and an estimate for the remaining combined standard uncertainty u_{O3} can be computed from the one-minute data [OA] using equation (1) [*Klausen, et al.*, 2003].

TEI 49PS #52307-291:

$$\mathbf{X_{O3}\ (ppb) = ([OA] + 1.18\ ppb)\ /\ 0.981}$$

$$\mathbf{u_{O3}\ (ppb) = sqrt(0.40\ ppb^2 + 2.75e\text{-}05 * X_{O3}^2)} \quad \mathbf{(3)}$$

Conclusions

The main BKT ozone analyser (TEI 49C) was found to agree well with the WCC-Empa ozone standard. The other analyser (TEI 49) and the station calibrator (TEI 49PS) were still working, but should not be used for ozone measurements and calibrations at BKT.

Carbon Monoxide Measurements

After the audit in 2007 the TEI 48C instrument was replaced by a Horiba APMA-360 analyzer. The two instruments were running in parallel for several months; however, the TEI 48C was no longer functional at the beginning of the present audit. The TEI 48C was extensively cleaned and reassembled, and showed afterwards acceptable results. However, a full assessment could not be made. The TEI 48C instrument should no longer be used for CO measurements at BKT. All inter-comparisons were done according to Standard Operating Procedures [*WMO*, 2007a].

Monitoring Set-up and Procedures

Air Conditioning

See ozone.

Air Inlet System

The Horiba instrument is connected to the existing inlet line [*Zellweger, et al.*, 2004]. The residence time in the inlet line is less than 5 seconds.

Instrumentation

A Horiba APMA-360 analyser was installed in August 2007 by QA/SAC-Switzerland. The instrument was initially calibrated by WCC-Empa before shipment to Indonesia. A Permapure Nafion dryer in split flow mode is used for sample air drying. Instrumental details are listed in Table 7. The TEI 48C instrument [*Zellweger, et al.*, 2004] was still available at the site. However, the instrument was not working probably due to a heavily polluted gas filter correlation wheel. It could not be assessed during the present audit and should no longer be used for CO measurements at BKT.

Standards and Calibration

The station has been provided with calibration gases by WCC-Empa. Table 6 gives details of the cylinders currently available at the station. Two types of calibration standards are available: Low levels (approx. 1 ppm) for direct calibrations of the instrument, and higher levels (15 to 50 ppm) for automatic span checks using the dilution system.

Table 6. Carbon monoxide standards available at the BKT station

Manufacturer, S/N, Use	CO Content (ppb) * and matrix	Calibration		In service	
		Date	By	From	To
Messer, SL76529, direct calibration	1015.4 ± 20.3 ppb synth. air 5.5	05/01	WCC-Empa	07/01	07/08.
Messer, SL76527, dilution	15000 ± 300 ppb synth. air 5.5	05/01	WCC-Empa	07/01	12/04
Messer, 168878, dilution	51100 ± 1022 ppb synth. air 5.0	08/04	WCC-Empa	12/04	?
Messer, D94 4280, dilution	49781 ± 500 ppb synth. air 5.0	10/06	WCC-Empa	?	09/08
Messer, D94 4278, dilution	49806 ± 500 ppb synth. air 5.0	10/06	WCC-Empa	09/08	04/09
Messer, D94 4289, direct calibration	1016.6 ± 10.2 ppb synth. air 5.0	10/06	WCC-Empa	07/08	04/09
SMI, CC111787, direct calibration	1029.5 ± 10.3 ppb natural air	04/09	WCC-Empa	04/09	09/09
SMI, CA06490, dilution	44860 ± 450 ppb natural air	04/09	WCC-Empa	04/09	cont.

* *WMO-2000 carbon monoxide scale*

Operation and Maintenance
The system is running fully automated. Zero and span checks using the dilution system [*Zellweger, et al.*, 2004] are made every four hours. The system is daily checked for general operation. A weekly check list should be filled in recording parameters that are not available through the data acquisition (calibration factors, other instrument parameters, pressures of the calibration gases etc.). The inlet filter is changed every two weeks.

Data Acquisition and Data Transfer
The data of the Horiba CO analyser is acquired on a LabView based data acquisition system that was implemented during the audit in 2007 by QA/SAC Switzerland. Data of the TEI 48C instrument was manually downloaded using the TEI iPort software.

Data Treatment
The first five minute average value after a switch of the zero/span valve is discarded. The remaining five minute average values are used for further data evaluation. Zero values are used to correct for instrument zero drift using a lowess fit. Span values from the automatic span checks are used for quality control purposes and have also been used for the correction of a span drift. Data validation and flagging is done by a R based script but is still dependent on the collaboration with QA/SAC-Switzerland. Responsibility for data validation should be transferred to the station staff.

Data Submission
Carbon monoxide data have been jointly submitted by Empa and BMGK to the WDCGG. Currently data series until June 2007 are available at the WDCGG.

Documentation
All information is entered in an electronic log book and check list. The information in these files is only partly comprehensive and up-to-date. Log book and check lists should be filled in more carefully. This was already noticed during the audit in 2007 and clearly needs more attention by the station staff (cf. Recommendation 9).

Inter-Comparison of Carbon Monoxide Analysers

All procedures were conducted according to the Standard Operating Procedure [*WMO*, 2007a] and included inter-comparisons of the travelling standards at Empa before and after the inter-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 11 below.

Setup and Connections
Table 7 shows details of the experimental setup during the inter-comparison of transfer standard and station analyser. The data used for the evaluation was recorded by the BKT data acquisition systems as indicated, and corrected for zero drift according to the usual data treatment procedure.

Table 7. Experimental details of the carbon monoxide inter-comparison.

Travelling standard (TS)		One cylinder (Messer Schweiz, D94 4278, 49806±500 ppb CO in synthetic air) and a zero-air generator (silica gel - inlet filter 5 µm - metal bellow pump - Sofnocat - outlet filter 5 µm) custom-built by WCC-Empa, in combination with a dilution system (Breitfuss, MGM)
Levels (ppb)		Level / Reference / St.Uncertainty: 1 / 0.0 / 0.0 2 / 104.7 / 1.5 3 / 205.7 / 2.9 4 / 305.5 / 4.3 5 / 406.8 / 5.7 6 / 507.9 / 7.1 7 / 609.8 / 8.5 8 / 709.4 / 9.9 9 / 810.9 / 11.4 10 / 910.4 / 12.7 11 / 1012.4 / 14.2
Field instrument	Model, S/N	Horiba APMA-360 #890617034
	Principle	NDIR
	Modification	Nafion drier PERMAPURE PD-50-24'' split flow mode using critical orifice and external pump
	Range	10 ppm
	Settings	Zero -1, Span 1.0338
Connection of TS to field instrument		Sample inlet
Data Acquisition		1-min aggregates from GAWDAQ; further aggregated to 5-min averages for data analysis
Duration per level (min)		90, inclusive of interspersed automatic zero (15) and span (10') checks every four hours
Sequence of levels		Repeated runs of randomised fixed sequence
Runs		1 run (2008-07-08/09)

Results

Each carbon monoxide level was effectively applied for 90 minutes, which resulted in a maximum of 18 useable 5' averages per level and run. These were corrected for zero-drift (using loess regression) and further aggregated by level before use in the assessment (cf. Table 8). No span correction was applied to the data for the evaluation of the result.

Table 8. CO aggregates computed for each level during the inter-comparison of the BKT HORIBA APMA360 CO analyser with WCC-Empa travelling standards (TS).

Date Time (UTC)	TS (ppb)	sdTS (ppb)	CO (ppb)	sdCO(ppb)	No. 5' av.
(07/08/08 10:27:30)	205.7	2.9	193.2	3.7	18
(07/08/08 12:05:00)	0	1	-0.1	3.3	12
(07/08/08 13:27:30)	810.9	11.4	754.8	2.7	16
(07/08/08 14:45:00)	507.9	7.1	474.8	3.5	13
(07/08/08 16:27:30)	1012.4	14.1	944.1	4.2	16
(07/08/08 17:55:00)	406.8	5.7	379.4	4.4	17
(07/08/08 19:20:55)	609.8	8.5	568.4	4.7	11
(07/08/08 20:55:00)	709.4	9.9	660.7	4.5	17
(07/08/08 22:25:00)	104.7	1.5	97.6	2.9	17
(07/09/08 00:07:16)	910.4	12.7	849.3	2.3	11
(07/09/08 01:27:30)	305.5	4.3	286.7	3.7	16
(07/09/08 02:40:00)	0	1	0.2	3.8	9

Figure 9 shows the regression residuals of the analyser over the course of the inter-comparison runs. The absence of a temporal trend (left panel) indicates stable instrument conditions. The absence of a concentration dependence (right panel) in the residuals indicates linearity of the instrument.

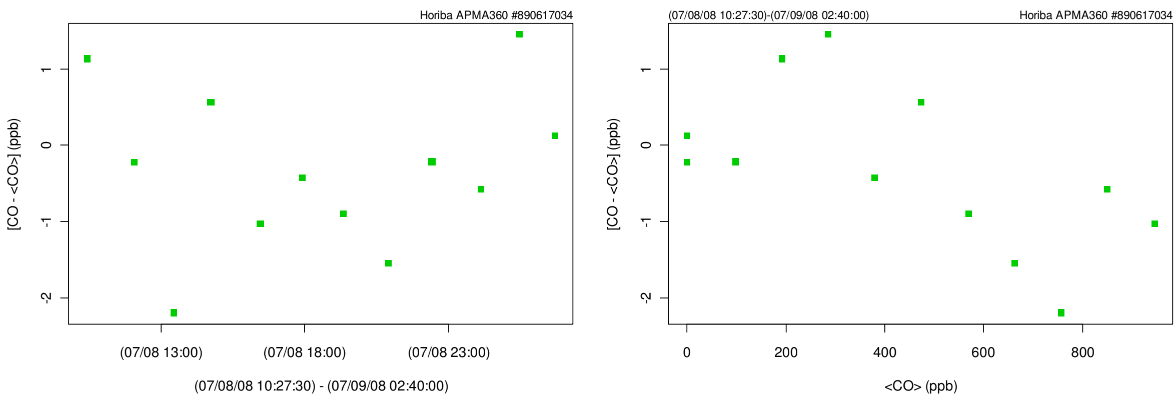


Figure 9. Regression residuals of the Horiba APMA-360 carbon monoxide analyser based on the initial inter-comparison with the dilution unit. Points represent averages of valid 5 minute values. Left panel: time dependence; Right panel: concentration dependence.

Based on these inter-comparison results, unbiased carbon monoxide volume mixing ratios X_{CO} and an estimate for the remaining combined standard uncertainty u_{CO} of 5 min averages can be computed from the zero corrected five-minute data CO that was taken initially of the analyser using equation (2a).

$$\mathbf{X_{CO}\ (ppb) = ([CO] - 0.1\ ppb) / 0.934}$$

$$\mathbf{u_{CO}\ (ppb) = sqrt(6.8\ ppb^2 + 1.45e\text{-}04 * X_{CO}^2)} \quad \mathbf{(2)}$$

The estimate of the remaining standard uncertainty u_{CO} based on instrument noise, a linear concentration dependent contribution of 0.5% and an uncertainty of the zero correction of 3 ppb.

Changes made to the instrument

None.

Conclusions

The APMA-360 CO instrument was running fine concerning linearity and analytical noise. However, a significant bias of approximately 6.6% was observed during the audit. The reason for the bias could not be identified. WCC-Empa recommends waiting with data correction based on the inter-comparison results until the audit results are confirmed by other observations such as manual span checks etc.

WCC-Empa Travelling Standards

Ozone

The WCC-Empa travelling standard (TS) was compared with the Standard Reference Photometer before and after use during the field audit. Details of these inter-comparisons at the Empa calibration laboratory are summarised in Table 9, the inter-comparison data is given in Table 10.

Table 9. Experimental details of the inter-comparison of travelling standard (TS) and Standard Reference Photometer (SRP).

Standard Reference Photometer		NIST SRP#15 (WCC-Empa)
Travelling standard (TS)	Model, S/N	TEI 49C-PS #56891-310 (WCC-Empa)
	Settings	BKG = -0.2; COEFF = 1.007
Ozone source		Internal generator of SRP
Zero air supply		Pressurized air - zero air generator (Purafil, charcoal, filter) (WCC-Empa)
Connection between instruments		Ca. 1 meter of 1/4" PFA tubing between SRP manifold and TS inlet
Data acquisition		SRP data acquisition system, 1-minute averages with standard deviations
Levels (ppb)		0, 30, 60, 90, 140, 190
Duration per level (min)		Variable based on standard deviation criterion, the last 10 30-second readings are aggregated
Sequence of Levels		Repeated runs of randomised sequence
Runs		3 runs before shipment of TS (27 May, 2008) 3 runs after return of TS (6 August, 2008)

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

Date	Run	Level#	SRP (ppb)	sdSRP (ppb)	TS (ppb)	sdTS (ppb)
2008-05-27	1	0	0.17	0.19	0.20	0.09
2008-05-27	1	90	85.80	0.21	85.91	0.08
2008-05-27	1	60	57.93	0.29	58.08	0.09
2008-05-27	1	140	129.39	0.33	129.56	0.26
2008-05-27	1	190	173.14	0.55	173.44	0.58
2008-05-27	1	30	27.45	0.15	27.60	0.17
2008-05-27	1	0	-0.01	0.28	0.08	0.12
2008-05-27	2	0	0.07	0.24	0.11	0.07
2008-05-27	2	140	131.30	0.23	131.75	0.39
2008-05-27	2	30	27.86	0.16	27.97	0.14
2008-05-27	2	90	86.42	0.27	86.69	0.28
2008-05-27	2	190	172.71	0.88	173.38	0.83
2008-05-27	2	60	55.80	0.24	55.94	0.18
2008-05-27	2	0	0.05	0.33	0.16	0.10
2008-05-27	3	0	0.12	0.24	0.11	0.08
2008-05-27	3	60	58.23	0.22	58.44	0.06
2008-05-27	3	140	130.09	0.61	130.31	0.47
2008-05-27	3	90	84.65	0.28	84.97	0.15
2008-05-27	3	190	171.42	0.56	171.83	0.65
2008-05-27	3	30	27.12	0.16	27.32	0.13
2008-05-27	3	0	-0.02	0.29	0.16	0.08
2008-08-06	4	0	-0.28	0.34	-0.10	0.12
2008-08-06	4	90	192.89	0.13	192.42	0.14
2008-08-06	4	60	142.25	0.34	141.66	0.11
2008-08-06	4	140	61.53	0.29	61.34	0.10
2008-08-06	4	190	91.82	0.30	91.63	0.14
2008-08-06	4	30	31.82	0.34	31.81	0.11
2008-08-06	4	0	-0.10	0.30	-0.09	0.06
2008-08-06	5	0	-0.21	0.39	-0.09	0.14
2008-08-06	5	140	61.34	0.36	61.38	0.07
2008-08-06	5	30	192.95	0.45	192.41	0.10
2008-08-06	5	90	142.27	0.48	141.73	0.10
2008-08-06	5	190	31.90	0.31	31.87	0.09
2008-08-06	5	60	91.79	0.27	91.46	0.15
2008-08-06	5	0	-0.09	0.30	-0.01	0.13
2008-08-06	6	0	-0.22	0.19	-0.05	0.05
2008-08-06	6	60	91.70	0.19	91.46	0.09
2008-08-06	6	140	61.79	0.39	61.38	0.13
2008-08-06	6	90	31.91	0.28	31.96	0.13
2008-08-06	6	190	192.95	0.28	192.59	0.12
2008-08-06	6	30	142.18	0.23	141.91	0.16
2008-08-06	6	0	-0.02	0.23	-0.13	0.11

#The level is only indicative.

The travelling standard passed the assessment criteria defined for maximum acceptable bias before and after the audit [*Klausen, et al.*, 2003] (cf. Figure 10). 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 3). The uncertainty of the TS was estimated previously (cf. equation 19 in [*Klausen, et al.*, 2003]).

X_{TS} (ppb) = ([TS] - 0.10 ppb) / 0.9981

u_{TS} (ppb) = sqrt((0.43 ppb)^2 + (0.0034 * X)^2) (3)

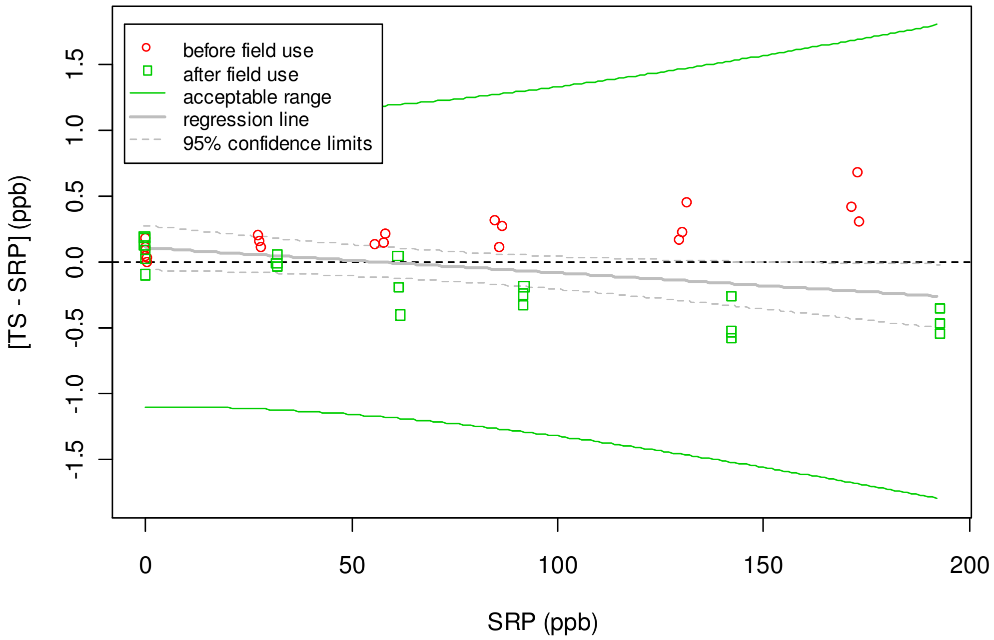


Figure 10. Deviations between travelling standard (TS) and Standard Reference Photometer (SRP) before and after use of the TS at the field site.

Carbon Monoxide

WCC-Empa refers to the revised WMO/GAW carbon monoxide scale (hereafter: WMO-2000 scale) [*Novelli, et al.*, 2003] hosted and maintained by the National Oceanic and Atmospheric Administration/Earth System Research Laboratory-Global Monitoring Division (NOAA/ESRL-GMD; formerly: NOAA/CMDL) who act as the GAW Central Calibration Laboratory (CCL). WCC-Empa maintains a set of laboratory standards obtained from the CCL that are regularly inter-compared with the CCL by way of travelling standards. The scale was transferred to the travelling standard using an Aerolaser AL5001 vacuum-fluorescence analyzer, an instrument with high precision and proven linearity. The inter-comparison was made using a CO cylinder that was shipped to BKT in 2006, and the dilution system was calibrated against the WCC-Empa flow reference before and after the audit. Details are given in Table 11 - Table 12.

Table 11. Experimental details of the transfer of the WMO-2000 carbon monoxide scale to the travelling standard (TS) used during the field inter-comparison.

Reference scale		Laboratory standards (30L aluminium cylinders) obtained directly from the Central Calibration Laboratory. Due to remaining minor inconsistencies in the WMO-2000 scale below 150 ppb, the transfer of the scale was based on two specific cylinders, CA02859 (194.7±1.9 ppb) CA02854 (295.5±3.0 ppb)
Transfer instrument	Model, S/N	Aerolaser AL5001, S/N 117 (WCC-Empa)
Travelling standard (TS)		zero air (1) and a high concentration carbon monoxide cylinder (2), in combination with a dilution unit (3)
(1) Zero air supply		Ambient air – Silicagel PS drying cartridge – zero air generator (Purafil, Sofnocat, filter) (WCC-Empa)
(2) Carbon monoxide cylinder		Messer Schweiz, D94 4278, 49806±500 ppb CO (α=0.05). Cylinder was shipped to BKT in 2006 and remained at the site.
(3) Dilution unit		Breitfuss MGM #2262/91/1. The levels used were calibrated before and after the field inter-comparison against a flow reference (DH Instruments, Inc., MOLBOX #396 and #643, MOLBLOC #850 and #851).
Connection between instruments		Ca. 2.5 meter 1/4" PFA tubing
Data acquisition		Aerolaser 1-min averages
Sequence of Levels		Repeated runs of randomised sequence
Runs		1 run before shipment of TS (2008-06-13) 1 run after return of TS (2008-08-21)

Table 12. Calibration of the Breitfuss dilution system.

Mass Flow Controller Setpoint [ml/min]		Mass Flow Controller Actual value before audit [ml/min]		Expected CO level before audit	Mass Flow Controller Actual value after audit [ml/min]		Expected CO level after audit	Average expected CO level	Standard Uncertainty
MFC1	MFC2	MFC1	MFC2	[ppb]	MFC1	MFC2	[ppb]	[ppb]	[ppb]
3000.0	0.0	2991.3	0.0	0.0	3004.5	0.0	0.0	0.0	0.0
2988.0	12.0	2988.1	12.3	203.7	2982.2	12.5	207.6	205.7	2.9
2952.0	48.0	2955.0	48.7	808.2	2961.3	49.2	813.7	810.9	11.4
2970.0	30.0	2974.6	30.5	505.7	2981.9	30.9	510.1	507.9	7.1
2940.0	60.0	2944.7	60.9	1009.2	2951.7	61.4	1015.6	1012.4	14.2
2976.0	24.0	2981.2	24.4	404.8	2989.0	24.7	408.7	406.8	5.7
2964.0	36.0	2969.4	36.7	608.7	2977.5	37.0	610.9	609.8	8.5
2958.0	42.0	2963.6	42.7	707.0	2971.6	43.1	711.8	709.4	9.9
2994.0	6.0	2999.7	6.2	103.2	3008.4	6.4	106.2	104.7	1.5
2946.0	54.0	2951.2	54.7	906.7	2959.8	55.3	914.0	910.4	12.7
2982.0	18.0	2987.6	18.3	303.7	2996.7	18.6	307.2	305.5	4.3

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Ozone Audit Executive Summary (BKT)

0.1	Station Name:	Bukit Koto Tabang
0.2	GAW ID:	BKT
0.3	Coordinates/Elevation:	0.202°S, 100.318°E (864 m a.s.l)
Parameter:		Surface Ozone

1.1	Date of Audit:	4 – 6 July, 2008
1.2	Auditor:	Dr. C. Zellweger, Dr. J. Klausen
1.2.1	Station staff involved in audit:	Herizal, Asep Firman Ilahi, Carles Siregar, Agusta Kurniawan
1.3	Ozone Reference [SRP]:	NIST SRP#15
1.4	Ozone Transfer Standard [TS]	
1.4.1	Model and serial number:	TEI 49C PS #56891-310
1.4.2	Range of calibration:	0 – 200 ppb
1.4.3	Mean calibration (ppb):	(0.9981±0.0010) × [SRP] + (0.10±0.12)
1.5	Ozone Analyser [OA]	
1.5.1	Model:	TEI 49C #58547-318
1.5.2	Range of calibration:	0 – 100 ppb
1.5.3	Coefficients at start of audit	BKG 0.1 ppb, SPAN 1.014
1.5.4	Calibration at start of audit (ppb):	[OA] = (1.003±0.000) × [SRP] + (0.03±0.05)
1.5.5	Unbiased ozone mixing ratio (ppb) at start of audit:	X = ([OA] - 0.03) / 1.003
1.5.6	Standard uncertainty remaining after compensation of calibration bias (ppb):	$u_X \approx (0.27\ ppb^2 + 2.59e\text{-}5 \times X^2)^{1/2}$
1.5.7	Coefficients after audit	unchanged
1.5.8	Calibration after audit (ppb):	unchanged
1.5.9	Unbiased ozone mixing ratio (ppb) after audit:	unchanged
1.5.10	Standard uncertainty remaining after compensation of calibration bias (ppb):	unchanged
1.6	Comments:	-main station instrument since September 2006 -direct inter-comparison with instrument
1.7	Reference:	WCC-Empa Report 08/3

[OA]: Instrument readings; [SRP]: SRP readings; X: mixing ratios on SRP scale

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1.3	Ozone Reference [SRP]:	NIST SRP#15
1.4	Ozone Transfer Standard [TS]	
1.4.1	Model and serial number:	TEI 49C PS #56891-310
1.4.2	Range of calibration:	0 – 200 ppb
1.4.3	Mean calibration (ppb):	(0.9981±0.0010) × [SRP] + (0.10±0.12)
1.5	Ozone Analyser [OA]	
1.5.1	Model:	TEI 49 #51974-290
1.5.2	Range of calibration:	0 – 100 ppb
1.5.3	Coefficients at start of audit	OFFSET: 50 SPAN: 521
1.5.4	Calibration at start of audit (ppb):	[OA] = (0.987±0.001) × [SRP] - (0.19±0.05)
1.5.5	Unbiased ozone mixing ratio (ppb) at start of audit:	X = ([OA] + 0.19) / 0.987
1.5.6	Standard uncertainty remaining after compensation of calibration bias (ppb):	$u_X \approx (0.42 \text{ ppb}^2 + 2.72\text{e-}5 \times X^2)^{1/2}$
1.5.7	Coefficients after audit	unchanged
1.5.8	Calibration after audit (ppb):	unchanged
1.5.9	Unbiased ozone mixing ratio (ppb) after audit:	unchanged
1.5.10	Standard uncertainty remaining after compensation of calibration bias (ppb):	unchanged
1.6	Comments:	-main station instrument until September 2006
1.7	Reference:	WCC-Empa Report 08/3

[OA]: Instrument readings; [SRP]: SRP readings; X: mixing ratios on SRP scale

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Ozone Audit Executive Summary (BKT)

0.1	Station Name:	Bukit Koto Tabang
0.2	GAW ID:	BKT
0.3	Coordinates/Elevation:	0.202°S, 100.318°E (864 m a.s.l)
Parameter:		Surface Ozone

1.1	Date of Audit:	4 – 6 July, 2008
1.2	Auditor:	Dr. C. Zellweger, Dr. J. Klausen
1.2.1	Station staff involved in audit:	Herizal, Asep Firman Ilahi, Carles Siregar, Agusta Kurniawan
1.3	Ozone Reference [SRP]:	NIST SRP#15
1.4	Ozone Transfer Standard [TS]	
1.4.1	Model and serial number:	TEI 49C PS #56891-310
1.4.2	Range of calibration:	0 – 200 ppb
1.4.3	Mean calibration (ppb):	(0.9981±0.0010) × [SRP] + (0.10±0.12)
1.5	Ozone Calibrator [OC]	
1.5.1	Model:	TEI 49PS #52307-291
1.5.2	Range of calibration:	0 – 100 ppb
1.5.3	Coefficients at start of audit	NA
1.5.4	Calibration at start of audit (ppb):	[OA] = (0.981±0.001) × [SRP] - (1.18±0.04)
1.5.5	Unbiased ozone mixing ratio (ppb) at start of audit:	X = ([OA] + 1.18) / 0.981
1.5.6	Standard uncertainty remaining after compensation of calibration bias (ppb):	$u_X \approx (0.40\ \text{ppb}^2 + 2.75\text{e-}5 \times X^2)^{1/2}$
1.5.7	Coefficients after audit	unchanged
1.5.8	Calibration after audit (ppb):	unchanged
1.5.9	Unbiased ozone mixing ratio (ppb) after audit:	unchanged
1.5.10	Standard uncertainty remaining after compensation of calibration bias (ppb):	unchanged
1.6	Comments:	
1.7	Reference:	WCC-Empa Report 08/3

[OA]: Instrument readings; [SRP]: SRP readings; X: mixing ratios on SRP scale

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Carbon Monoxide Audit Executive Summary (BKT)

0.1	Station Name:	Bukit Koto Tabang
0.2	GAW ID:	BKT
0.3	Coordinates/Elevation:	0.202°S, 100.318°E (864 m a.s.l)
Parameter:		Carbon Monoxide

1.1	Date of Audit:	4 – 6 July, 2008
1.2	Auditor:	Dr. C. Zellweger, Dr. J. Klausen
1.2.1	Station staff involved in audit:	Herizal, Asep Firman Ilahi, Carles Siregar, Agusta Kurniawan
1.3	CO Reference:	WMO-2000
1.4	CO Transfer Standard [TS]	
1.4.1	CO Cylinder:	Messer D94 4278, 49806±500 (ppb) (α=0.05)
1.4.2	Zero Air:	Ambient Air, Sofnocat, Purafil, filter (WCC-Empa)
1.4.3	Dilution unit:	Breitfuss MGM #2262/91
1.4.4	Range of calibration:	0 – 1000 ppb
1.5	CO analyzer [CA]	
1.5.1	Model:	HORIBA APMA360 #890617034
1.5.2	Range of calibration:	0 – 1000 ppb
1.5.3	Coefficients at start of audit	Zero -1 SPAN 1.0338
1.5.4	Calibration at start of audit (ppb):	$CO = (0.933 \pm 0.005) \times X + (0.1 \pm 0.9)$
1.5.5	Unbiased CO mixing ratio (ppb) at start of audit:	$X = (CO - 0.1) / 0.933$
1.5.6	Standard uncertainty after compensation of calibration bias at start of audit(ppb):	$u_X \approx (6.8\ ppb^2 + 1.46e\text{-}04 \times X^2)^{1/2}$
1.5.7	Coefficients after audit	unchanged
1.5.8	Calibration after audit (ppb):	unchanged
1.5.9	Unbiased CO mixing ratio (ppb) after audit:	unchanged
1.5.10	Standard uncertainty after compensation of calibration bias after audit(ppb):	unchanged
1.6	Comments:	Audit result should be considered preliminary till confirmed by other measurements
1.7	Reference:	WCC-Empa Report 08/3

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

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