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World Calibration Centre for Surface Ozone
Carbon Monoxide and Methane

Laboratory Air Pollution / Environmental Technology

WCC-Empa REPORT 07/1

Submitted to the

World Meteorological Organization

SYSTEM AND PERFORMANCE AUDIT

OF SURFACE OZONE AND CARBON MONOXIDE

AT THE

GLOBAL GAW STATION BUKIT KOTO TABANG

INDONESIA, FEBRUARY 2007

Submitted by

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Empa is accredited as a calibration laboratory for ozone measuring instruments in accordance with ISO/IEC 17025

CONTENTS

ASSESSMENT AND RECOMMENDATIONS

The fourth system and performance audit at the Global GAW station Bukit Koto Tabang (BKT) was conducted by WCC-Empa[1] from 30 January thru 6 February 2007 in agreement with the WMO/GAW quality assurance system [*WMO*, 2007]. The BKT observatory is operated by the Meteorological and Geophysical Agency (BMG).

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] and in March 2004 [*Zellweger, et al.*, 2004].

The following people contributed to the audit:

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Mr Rismoyo	BMG, Station Manager
Mr Herizal	BMG, Station Operator, Head of Data Management
Mr Armein	BMG, Station Operator, Head of Observations
Mr Asep Firman Ilahi	BMG, Station Operator
Mr Carles Siregar	BMG, Station Operator
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Mr Yasri	BMG, Station Operator
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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 (BMG, Ms Nurhayati), the station manager (BMG, Mr Rismoyo) 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. On the 300 m^2 flat roof, the air inlet and several radiation and meteorological instruments are mounted. It is an ideal platform for continuous atmospheric monitoring as well as measurement campaigns. However, more attention should be paid to the functionality of the laboratory installations.

Recommendation 1 (*, 2007)**
The air-conditioning systems need to be repaired (done after the audit). All functional AC units should be continuously running, and the laboratory door should be kept closed at all times.

Recommendation 2 (*, 2007)**
It is of utmost importance that the internet access for the station is re-established. An access independent from LAPAN should be set-up at the site.

Recommendation 3 (, ongoing)**
The facility organisation and maintenance needs to be improved. The station should be cleaned from instruments and installations which are no longer operational and which will not be repaired. Furthermore, all station staff should have access to e.g. tools, and spare parts should be labelled and stored in a central place.

Station Management and Operation

The station is managed by the Meteorological and Geophysical Agency (BMG). The station is visited daily by at least two operators. It was found during the audit that some of the responsibilities are not communicated clearly enough. The management of a Global GAW station requires clear leadership yet more flexibility than traditional meteorological stations. The operators of GAW-related instrumentation need different and additional expertise. They should be considered “experts” by the management and should be given full support.

Recommendation 4 (*, ongoing)**
The general organization of operations must be improved. Each staff member, including leading positions, should know their responsibilities and duties. Authorities need to be clearly defined. Communication among staff members needs to be improved, and knowledge should be shared.

Recommendation 5 (, ongoing)**
WCC-Empa and QA/SAC Switzerland recommend to have yearly internal inspection by BMG Jakarta by someone ‘with a sense of good laboratory practice’ and some technical expertise.

Air Inlet System

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. Two ozone analysers are currently used at the station for continuous parallel surface ozone measurements (TEI 49 and TEI 49C instruments). The instrumentation is adequate for its intended purpose. The new TEI 49C must be considered the main instrument. The old TEI49 could be used at a different location after completing one year of parallel measurements.

Recommendation 6 (*, immediately)**
Data of the TEI 49C instrument only should be considered for submission to WDCGG in future.

Recommendation 7 (*)
The TEI 49 instrument should be operated in parallel to the TEI 49C for a total period of at least one year. After this, the instrument might be used at another site.

Standards. The station is equipped with a TEI 49-PS ozone calibrator. This instrument has been shown to suffer from high noise, and in addition a defective temperature reading board was found. In its current condition it cannot be used as an ozone calibrator.

Recommendation 8 (*, 2007)**
Replacement of the ozone calibrator is urgent. Considering the situation in Indonesia with a potentially growing air quality monitoring network, it is advisable to purchase a calibrator to be located at BMG, and do six-monthly to yearly calibrations at the individual sites.

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 delivered to the station 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 (1a-b). [OA] represents surface ozone readings as delivered by the instrument.

Direct calibration excluding the water trap:

TEI49C #58547-318:	0 – 90 ppb good agreement	
Unbiased O_3 mixing ratio (ppb)	X_{O3} (ppb) = ([OA] + 0.29 ppb) / 1.007	(1a)

Calibration including the water trap:

TEI49C #58547-318:	0 – 90 ppb good agreement	
Unbiased O3 mixing ratio (ppb)	X_{O3} (ppb) = ([OA] + 0.57 ppb) / 0.996	(1b)

The results of these inter-comparisons are presented in Figure 1. An ozone loss of approximately 1 % was observed over the water trap.

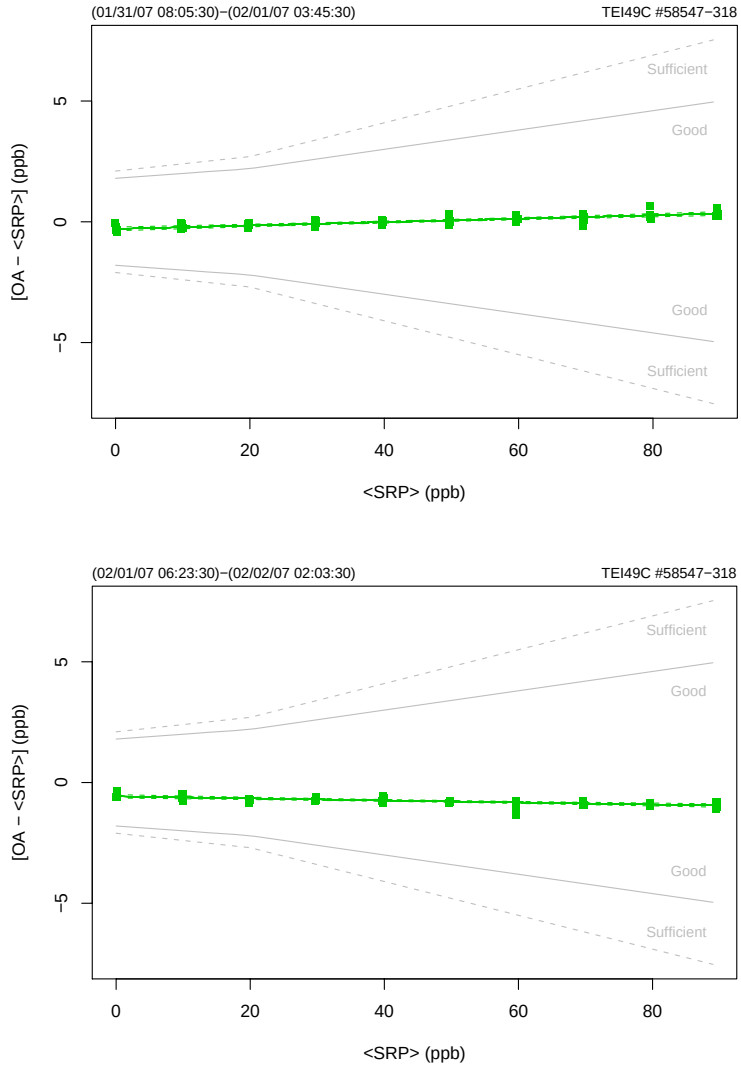

Figure 1. Bias of the new Bukit Koto Tabang ozone analyser (TEI 49C) with respect to the SRP as a function of concentration (upper panel: excluding water trap; lower panel: including water trap). Each point represents the average of the last 10 one-minute values at a given level. Areas defining 'good' 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 has been in operation at the site since 1996. The TEI 49 analyser was found to be in good calibration. However, the pressure sensor had to be adjusted during the audit. The results of the assessment is summarised below (1c-d). [OA] represents surface ozone readings obtained from the station data acquisition. Calibrations of this instrument were made without the water trap. An initial inter-comparison including the water trap (not shown) showed a result which was comparable to the inter-comparison without the trap (1c). Therefore an ozone loss smaller than 1 % is observed over the trap.

Initial calibration with unchanged pressure sensor (TEI 49 pressure sensor 2% above reference):

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

Unbiased O_3 mixing ratio (ppb) X_{O3} (ppb) = ([OA] + 0.64 ppb) / 0.986 (1c)

Calibration with adjusted pressure sensor:

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

Unbiased O_3 mixing ratio (ppb) X_{O3} (ppb) = ([OA] + 0.26 ppb) / 1.010 (1d)

The results of these inter-comparisons are presented in Figure 2.

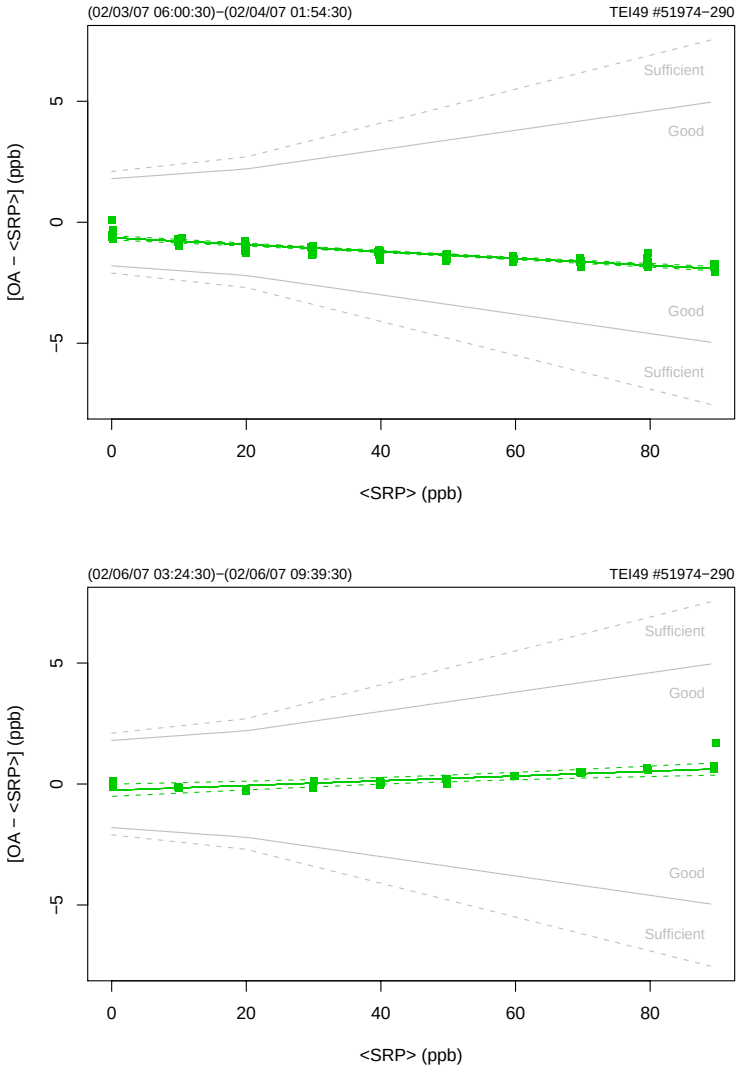

Figure 2. Bias of the Bukit Koto Tabang ozone analyser (TEI 49) with respect to the SRP as a function of concentration (upper panel: initial calibration with unchanged pressure sensor; lower panel: after pressure sensor adjustment). Each point represents the average of the last 10 one-minute values at 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 9 (*, 2007)**
It is important to adhere to standard operating procedures (SOPs). Adjustments of the pressure sensors need to be made with the sensor disconnected or the instrument pump switched off (cf. SOP and check list).

TEI 49PS:

This instrument has been used as a calibrator since 1996. It was already noticed during the audit in 2004 that the instrument is relatively unstable. The actual inter-comparison with the WCC-Empa TS showed a large deviation from the reference and excessive instrument noise. The instrument cannot be used as an ozone calibrator in its current condition. Most of the noise can be explained by incorrect temperature readings from a defective electronic board (CNTRS 49-007). The result of the assessment is summarised below (1e). [OC] represents surface ozone readings obtained from the station data acquisition.

TEI49PS #52307-291: 0 – 90 ppb excessive noise

Unbiased O_3 mixing ratio (ppb) XO3 (ppb) = ([OA] + 0.88 ppb) / 0.958 (1e)

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

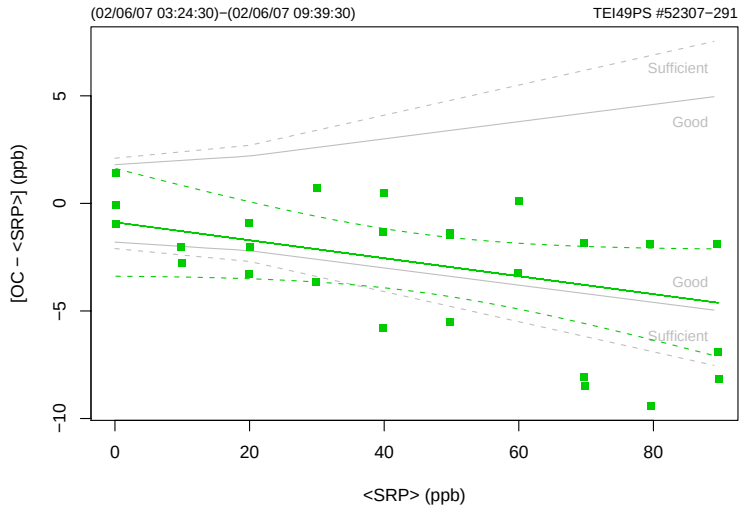

Figure 3. Bias of the Bukit Koto Tabang ozone calibrator (TEI 49PS) with respect to the SRP as a function of concentration. Each point represents the average of the last 10 one-minute values at a given level. Areas defining 'good' and 'sufficient' agreement according to GAW assessment criteria [Klausen,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

Recommendation 10 (*, 2007)**
The TEI 49PS must not be used for calibrations of ozone analysers. It should be explored if the temperature board CNTRS 49-007 can be replaced or repaired. A replacement with a new TEI49i-PS is needed (cf. Recommendation8).

Carbon Monoxide Measurements

Instrumentation. Bukit Koto Tabang is currently equipped with a TEI 48C-TL carbon monoxide analyser. The instrumentation is adequate for the intended purpose; however, significant and large zero drift adds to the overall uncertainty of the BKT carbon monoxide measurements.

> **Recommendation 11 (**, 2007-2010)**
> *Replacement of the current CO analyser by a model with less zero drift is recommended by WCC-Empa.*

Standards. The station is normally equipped with 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 12 (*, 2007-2010)**
> *For the long term operation of the BKT station, funds need to be made available for calibration gas supply.*

Intercomparison (Performance Audit). Two inter-comparisons were made during the audit. The first inter-comparison was made with unchanged instrument settings, and the second inter-comparison with adjusted calibration factors. Both inter-comparisons involved repeated challenges of the instruments with randomised carbon monoxide concentrations from travelling standards. The following equation (2a-b) characterises the instrument bias (cf. Figure 4):

TEI 48C-TL #66839-352 with unchanged settings (BKG -8.233 SPAN 1.042):

Unbiased CO mixing ratio (ppb): X_{CO} (ppb) = ([CO] - 13.3 ppb) / 0.948 (2a)

TEI 48C-TL #66839-352 with adjusted settings (BKG -8.900 SPAN 1.062):

Unbiased CO mixing ratio (ppb): X_{CO} (ppb) = ([CO] + 1.4 ppb) / 0.986 (2b)

The results show that the instrument is in relatively good calibration; however, individual data points are associated with large uncertainties. This is mainly because the instrument shows a significant temperature-dependent zero drift, which must be corrected to obtain final data. A better correction of the zero drift could only be achieved with more frequent zero checks.

> **Recommendation 13 (***, 2007)**
> *It should be considered to increase the frequency of zero checks to e.g. alternating between sample and zero in 15 minute intervals. This cannot be achieved with the current set-up, but may be implemented in a new data acquisition and instrument control software.*

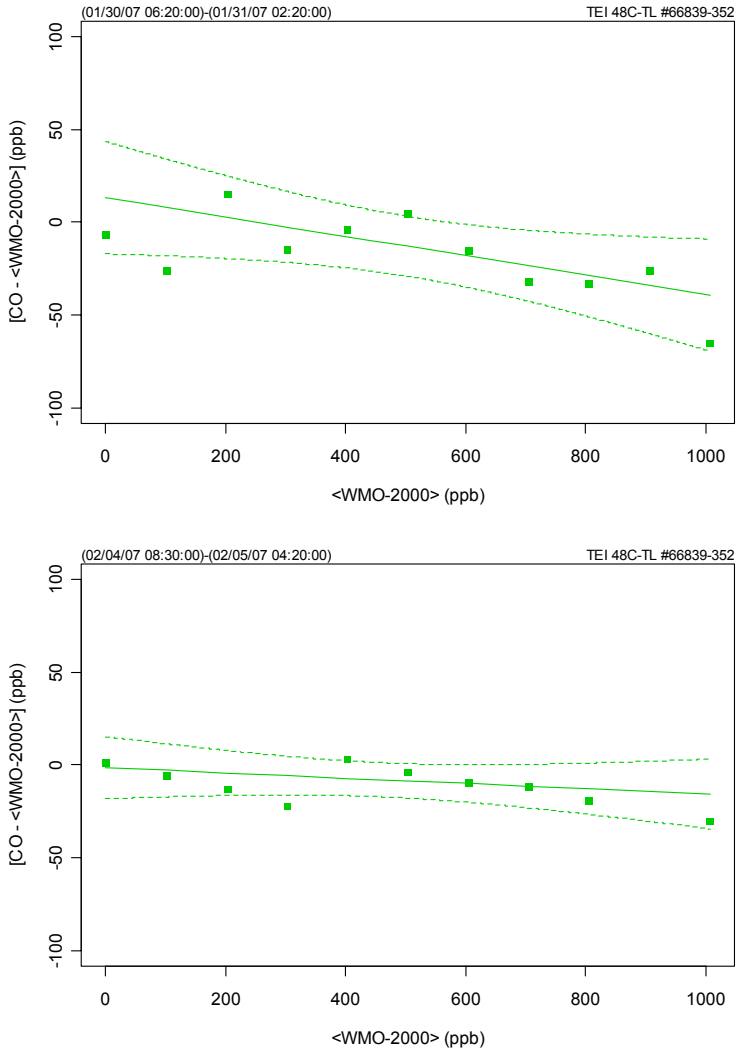

Figure 4. Bias of the Bukit Koto Tabang carbon monoxide analyser (TEI 48C-TL) with respect to the WMO-2000 reference scale as a function of concentration. Each point represents the average of data at a given level from a specific run. The dashed lines about the regression lines are the Working-Hotelling 95% confidence bands. Upper panel: with unchanged settings (BKG -8.233 SPAN 1.042); Lower panel: with adjusted settings (BKG -8.900 SPAN 1.062).

Data Acquisition and Management

At the time of the audit each system had its own data acquisition. QA/SAC Switzerland started to implement a Lab View based central data acquisition for the surface ozone, carbon monoxide, betameter and nephelometer instruments.

It was noticed during the audit that no coherent data management system was implemented. Data was spread on different computers of which most were infected by viruses.

Until now, data evaluation was mainly done by QA/SAC Switzerland, in collaboration with the station staff.

Recommendation14 (*, 2007)**
WCC-Empa supports a centralised data acquisition on a dedicated computer with automatic transmission of the data to the internet at regular intervals.

Recommendation15 (*, 2007)**
Data management and back-up policy need to be improved. Data should be stored on dedicated computers with up-to-date security patches and virus definitions.

Recommendation16 (*, 2007)**
The responsibility of data evaluations (e.g. flagging, QA/SAC Switzerland/QC) should be transferred from QA/SAC Switzerland to the station staff.

Data Submission

Data have been submitted to the World Data Centre for Greenhouse Gases (WDCGG). At the time of the audit data for surface ozone (January 04 – February 06), nitrogen dioxide and sulphur dioxide (January 04 – July 05) were available at the data centre. Some of the data however seems not sufficiently quality assured.

Recommendation 17 (, 2007)**
WCC-Empa supports the submission of GAW data to the corresponding data centres; however, all data should undergo thorough quality control before submission. Data which has been submitted needs to be revised, in collaboration with QA/SAC Switzerland and WCC-Empa.

Conclusions

The Global GAW station Bukit Koto Tabang comprises a growing suite of ongoing measurements; however, some operations were discontinued due to a lack of resources and expertise. Nevertheless, 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, though the carbon monoxide analyser suffers from significant zero drift.

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	(2)	Partly functional units
Power supply	(3)	Frequent failures, limited UPS
Internet access	(2)	Available, unreliable
General Management and Operation		
Organisation	(4)	Responsibilities unclear
Competence of staff	(2)	Insufficient science support
Air Inlet System	(4)	Direct lines to instruments
Instrumentation		
Ozone	(5)	TEI49C
Carbon monoxide	(3)	TEI48C
Aerosol PM10	(5)	BAM1020
Aerosol Scattering Coeff	(4)	Ecotech M9003 (single wavel.)
Flask sampling	(5)	NOAA/ESRL
CO2 flux at 40 m AGL	(0)	Available, not in operation
Meteo	(3)	Instrumentation coming of age
Radiation	(3)	Data acquisition problematic
Standards		
Ozone	(1)	TEI49PS unreliable
Carbon monoxide	(4)	Calibration of dilution unit
Aerosol Scattering Coeff	(5)	Automatic using CO2 gas
Carbon dioxide	(0)	Not available
Data Management		
Data acquisition	(3)	Centralised data acquisition
Data processing	(3)	Still reliant on twinning partner
Data submission	(2)	Not all data submitted yet

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

Dübendorf, May 2007

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

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.*, 2004], and the station is also registered in GAWSIS (www.empa.ch/gaw/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 February 2007 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	Data Coverage (%)		
		<12 m	<3 y	Overall
Aerosol				
Light absorption coefficient#	Aethalometer	0	0	
Light scattering coefficient	Nephelometer (Ecotech M9003)			
Mass concentration (PM10)	Betameter	54	72	73
Mass concentration (TSP)	Hivol sampler			
Ozone				
Surface ozone	UV absorption (TEI 49 and 49C)	88	95	76
Greenhouse Gas				
CO_2#	NDIR (LICOR 6262)			
CO_2, SF_6, N_2O	NOAA/ESRL flask sampling			
Reactive Gas				
CO	NDIR (TEI 48C-TL)	84	79	67
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)				

#: discontinued; Missing data availability: no data coverage information was available at the time of the audit.

Ozone, Carbon Monoxide and Methane Distribution at Bukit Koto Tabang

The monthly and yearly distributions of one hourly mean values for surface ozone and carbon monoxide for the year 2006 are shown in Figure 5.

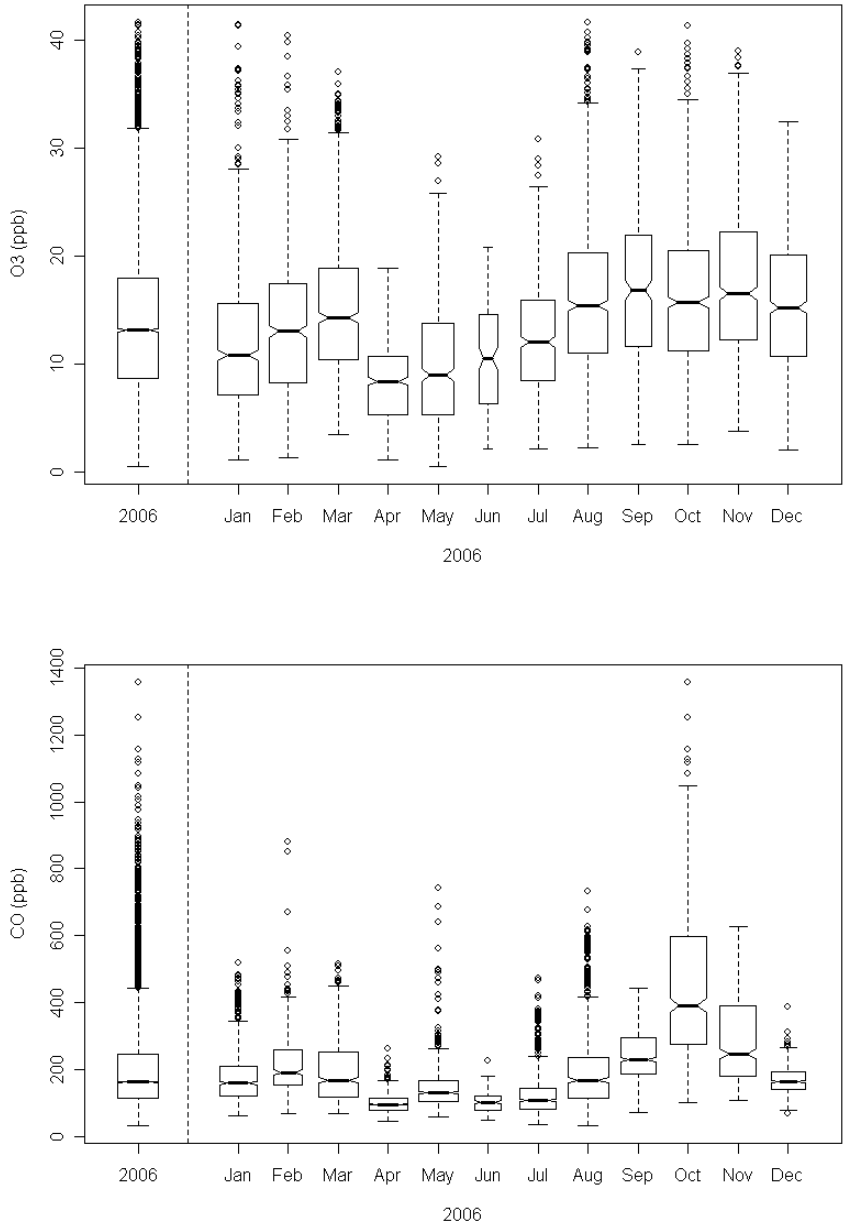

Figure 5. Yearly and monthly box plots of 1-hourly aggregates for the year for surface Ozone (upper panel) and carbon monoxide (lower panel). The boxes indicate the 25, 50, and 75 percentile, respectively. Whiskers mark data within 1.5 times the inter-quartile range, and open circles denote data outside this range. The width of the boxes is proportional to the number of data points available for each month.

Organisation and Contact Persons

The GAW activities of Indonesia are coordinated by Centre for Climate and Air Quality Analysis Division (Head Ms Nurhayati) of the Meteorological and Geophysical Agency (BMG). An organisational chart of the station is shown in Figure 6.

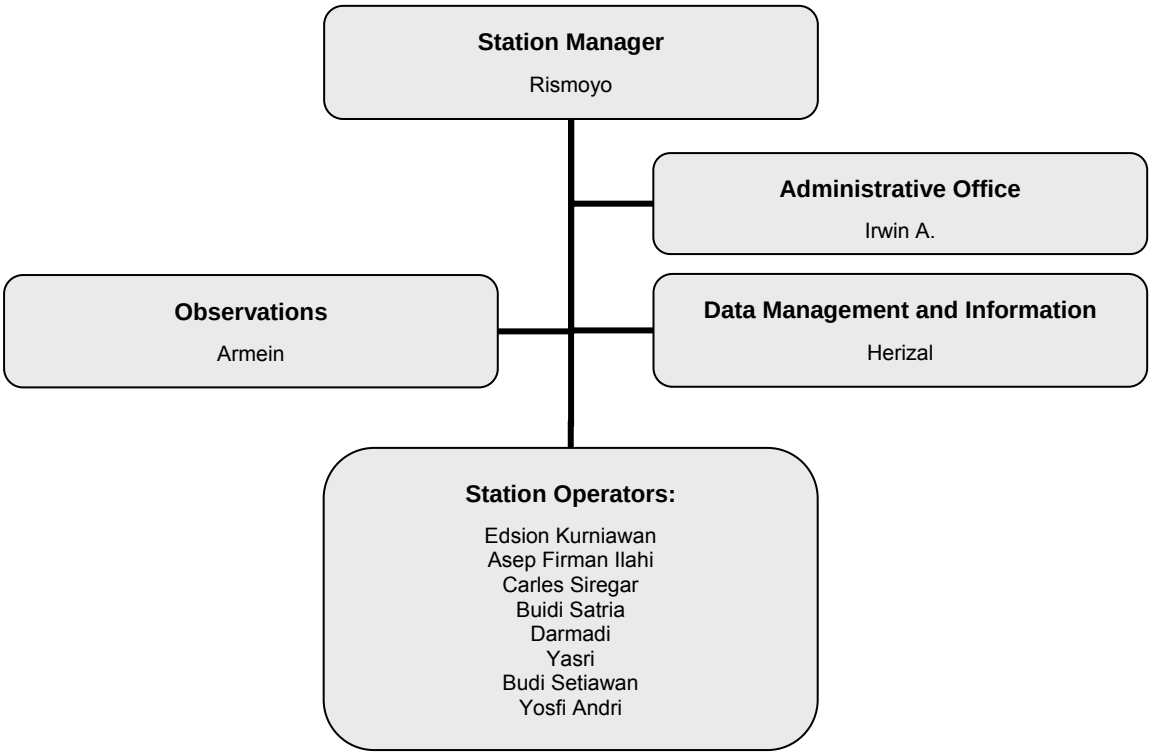

Figure 6. Organisation of the GAW station Bukit Koto Tabang as of February 2007.

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. Major changes since the last audit by WCC-Empa in 2004 include the installation of a new instrument (TEI 49C), which replaces the TEI 49 analyser. All inter-comparisons were done according to Standard Operating Procedures [*WMO*, in preparation-a].

Monitoring Set-up and Procedures

Air Conditioning

The laboratory is partly air conditioned. Some AC units were not functional at the time of the audit, and the laboratory door remained open during the daytime. The current air-conditioning system is not sufficient to reach a stable indoor temperature, and defect units need to be replaced (cf. recommendation 1). The defective units were repaired after the audit.

Air Inlet System

The air inlet system has been described in the previous audit report [*Zellweger, et al.*, 2004]. The new instrument was connected to the existing inlet line with a tee after the water trap. Residence time including the water trap is estimated to be approx. 25 seconds.

Instrumentation

The station is equipped with two ozone analysers (TEI 49 and 49C). Instrumental details for the ozone analysers (OA) are summarised in Table 2 below.

Standards

A TEI 49-PS ozone standard is available at the site. However, this instrument was found to be defective during the audit, and repair or replacement is needed. (cf. Recommendation 8).

Operation and Maintenance
See previous audit report [*Zellweger, et al.*, 2004].

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]). Data of the new analyser TEI49C was downloaded manually with the TEI software version 2.2.0. A new LabView based data acquisition system was implemented during the audit by QA/SAC Switzerland and is currently further optimised.

Data Treatment
Data treatment is still mainly done by external partners in collaboration with the station staff. The responsibility for data evaluation should be transferred to the station staff (cf. Recommendation 16).

Data Submission
Ozone data have been submitted to the World Data Centre for Surface Ozone at JMA (WDCGG). Some of these data however seems not sufficiently quality assured.

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-a] 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.

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

Travelling standard (TS)	Model, S/N	TEI 49C-PS #54509-300 (WCC-Empa)
	Settings	BKG = -0.1; COEFF = 1.010
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	920.8 (Station reference)
	TS	921.6, adjusted to 920.8
	TEI 49C	917.8, adjusted to 920.8
	TEI 49	939.8 (not adjusted for first inter-comparison, afterwards adjusted to ambient pressure (921) for second inter-comparison)
	TEI 49-PS	923.8 (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 49C: 6 runs without water trap (31 Jan thru 1 Feb 07) 6 runs with water trap (1-2 Feb 07) TEI 49: 6 runs with unchanged press. sensor (3-4 Feb 07) 3 runs with adjusted press. sensor (6 Feb 07) TEI 49-PS: 3 runs (6 Feb 07)

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 above. The readings of the travelling standard (TS) were compensated for bias with respect to the Standard Reference Photometer (SRP) prior to the evaluation of the ozone analyser (OA) values.

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. Two inter-comparisons were made during the audit. The result of the first assessment (direct comparison between TS and the analyser) is shown in Table 3. A further comparison was made including the water trap; these results are presented in Table 4.

Figure 7 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 3. Ten-minute aggregates (initial inter-comparison, direct TS-analyser) computed from the last 10 of a total of 20 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)
2007-01-31 08:10	1	0	0.03	-0.12	0	0.09	0.06
2007-01-31 08:30	1	30	29.86	29.78	0	0.06	0.03
2007-01-31 08:50	1	60	59.84	59.90	0	0.07	0.02
2007-01-31 09:10	1	40	39.89	39.79	0	0.09	0.04
2007-01-31 09:30	1	90	89.83	90.09	0	0.07	0.03
2007-01-31 09:50	1	50	49.88	50.01	0	0.10	0.05
2007-01-31 10:10	1	10	9.85	9.69	0	0.20	0.05
2007-01-31 10:30	1	20	19.84	19.64	0	0.06	0.04
2007-01-31 10:50	1	80	79.76	80.16	0	0.07	0.03
2007-01-31 11:10	1	70	69.82	69.85	0	0.04	0.04
2007-01-31 11:30	2	0	0.19	-0.12	0	0.12	0.02
2007-01-31 11:50	2	40	39.92	39.79	0	0.06	0.03
2007-01-31 12:10	2	70	69.89	69.97	0	0.08	0.02
2007-01-31 12:30	2	30	29.97	29.75	0	0.12	0.04
2007-01-31 12:50	2	90	89.90	89.88	0	0.03	0.06
2007-01-31 13:10	2	20	20.03	19.78	0	0.08	0.04
2007-01-31 13:30	2	10	9.96	9.76	0	0.10	0.03
2007-01-31 13:50	2	60	59.88	59.92	0	0.08	0.05
2007-01-31 14:10	2	50	49.88	49.72	0	0.06	0.04
2007-01-31 14:30	2	80	79.86	79.89	0	0.09	0.03
2007-01-31 14:50	3	0	0.21	-0.19	0	0.05	0.03
2007-01-31 15:10	3	90	89.86	89.79	0	0.06	0.03
2007-01-31 15:30	3	70	69.87	69.77	0	0.08	0.04
2007-01-31 15:50	3	40	39.89	39.67	0	0.08	0.03
2007-01-31 16:10	3	50	49.89	49.66	0	0.07	0.02
2007-01-31 16:30	3	20	19.95	19.75	0	0.08	0.03
2007-01-31 16:50	3	30	29.90	29.72	0	0.12	0.03
2007-01-31 17:10	3	60	59.86	59.64	0	0.14	0.13
2007-01-31 17:30	3	10	10.07	9.74	0	0.10	0.05
2007-01-31 17:50	3	80	79.85	79.77	0	0.06	0.05
2007-01-31 18:10	4	0	0.23	-0.19	0	0.07	0.03
2007-01-31 18:30	4	30	29.83	29.47	0	0.12	0.04
2007-01-31 18:50	4	60	59.83	59.69	0	0.05	0.05
2007-01-31 19:10	4	40	40.02	39.85	0	0.09	0.03
2007-01-31 19:30	4	90	89.98	89.91	0	0.07	0.05
2007-01-31 19:50	4	50	50.03	49.87	0	0.09	0.05
2007-01-31 20:10	4	10	10.06	9.74	0	0.09	0.03
2007-01-31 20:30	4	20	19.95	19.76	0	0.06	0.03
2007-01-31 20:50	4	80	79.89	79.87	0	0.05	0.04
2007-01-31 21:10	4	70	69.92	69.77	0	0.07	0.04
2007-01-31 21:30	5	0	0.23	-0.29	0	0.05	0.01
2007-01-31 21:50	5	40	39.90	39.70	0	0.06	0.05
2007-01-31 22:10	5	70	69.91	69.88	0	0.06	0.04
2007-01-31 22:30	5	30	29.92	29.59	0	0.08	0.04
2007-01-31 22:50	5	90	89.72	89.65	0	0.10	0.05
2007-01-31 23:10	5	20	19.88	19.50	0	0.09	0.06
2007-01-31 23:30	5	10	9.90	9.49	0	0.05	0.03
2007-01-31 23:50	5	60	59.79	59.66	0	0.05	0.04
2007-02-01 00:10	5	50	49.96	49.74	0	0.07	0.03
2007-02-01 00:30	5	80	80.00	79.87	0	0.07	0.04
2007-02-01 00:50	6	0	0.19	-0.25	0	0.10	0.03
2007-02-01 01:10	6	90	89.91	89.93	0	0.07	0.15
2007-02-01 01:30	6	70	69.78	69.36	0	0.48	0.17
2007-02-01 01:50	6	40	39.87	39.56	0	0.09	0.04
2007-02-01 02:10	6	50	49.87	49.54	0	0.09	0.04
2007-02-01 02:30	6	20	19.84	19.51	0	0.10	0.03
2007-02-01 02:50	6	30	30.04	29.92	0	0.09	0.02
2007-02-01 03:10	6	60	60.12	60.00	0	0.08	0.02
2007-02-01 03:30	6	10	10.20	9.84	0	0.12	0.04
2007-02-01 03:50	6	80	79.99	79.85	0	0.06	0.01

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

Table 4. Ten-minute aggregates (second inter-comparison, including water trap) computed from the last 10 of a total of 20 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)
2007-02-01 06:28	1	0	0.28	-0.21	0	0.19	0.05
2007-02-01 06:48	1	30	29.92	29.16	0	0.09	0.03
2007-02-01 07:08	1	60	59.90	58.68	0	0.08	0.06
2007-02-01 07:28	1	40	39.97	39.22	0	0.07	0.03
2007-02-01 07:48	1	90	89.91	88.76	0	0.11	0.04
2007-02-01 08:08	1	50	49.98	49.01	0	0.07	0.04
2007-02-01 08:28	1	10	10.07	9.48	0	0.09	0.04
2007-02-01 08:48	1	20	19.95	19.07	0	0.09	0.04
2007-02-01 09:08	1	80	79.82	78.70	0	0.11	0.05
2007-02-01 09:28	1	70	69.90	68.74	0	0.15	0.06
2007-02-01 09:48	2	0	0.18	-0.25	0	0.10	0.04
2007-02-01 10:08	2	40	39.88	38.93	0	0.09	0.02
2007-02-01 10:28	2	70	69.82	68.63	0	0.05	0.04
2007-02-01 10:48	2	30	29.86	28.93	0	0.06	0.03
2007-02-01 11:08	2	90	89.76	88.38	0	0.13	0.07
2007-02-01 11:28	2	20	19.96	19.16	0	0.09	0.03
2007-02-01 11:48	2	10	9.95	9.19	0	0.08	0.03
2007-02-01 12:08	2	60	59.85	58.67	0	0.05	0.18
2007-02-01 12:28	2	50	49.91	48.87	0	0.10	0.03
2007-02-01 12:48	2	80	79.86	78.71	0	0.05	0.05
2007-02-01 13:08	3	0	0.13	-0.54	0	0.12	0.02
2007-02-01 13:28	3	90	89.84	88.73	0	0.07	0.04
2007-02-01 13:48	3	70	69.90	68.78	0	0.12	0.06
2007-02-01 14:08	3	40	39.92	38.92	0	0.09	0.04
2007-02-01 14:28	3	50	49.92	48.89	0	0.06	0.05
2007-02-01 14:48	3	20	19.98	19.07	0	0.09	0.04
2007-02-01 15:08	3	30	29.89	29.12	0	0.46	0.18
2007-02-01 15:28	3	60	59.89	58.34	0	0.97	0.23
2007-02-01 15:48	3	10	10.06	9.20	0	0.11	0.05
2007-02-01 16:08	3	80	79.82	78.60	0	0.07	0.04
2007-02-01 16:28	4	0	0.16	-0.51	0	0.04	0.05
2007-02-01 16:48	4	30	29.96	29.12	0	0.12	0.03
2007-02-01 17:08	4	60	59.90	58.90	0	0.06	0.08
2007-02-01 17:28	4	40	39.94	39.02	0	0.06	0.07
2007-02-01 17:48	4	90	89.86	88.58	0	0.06	0.06
2007-02-01 18:08	4	50	49.97	48.97	0	0.09	0.03
2007-02-01 18:28	4	10	10.05	9.29	0	0.11	0.06
2007-02-01 18:48	4	20	19.98	19.01	0	0.10	0.04
2007-02-01 19:08	4	80	79.87	78.65	0	0.12	0.06
2007-02-01 19:28	4	70	69.94	68.92	0	0.08	0.05
2007-02-01 19:48	5	0	0.16	-0.39	0	0.07	0.04
2007-02-01 20:08	5	40	40.09	39.26	0	0.07	0.03
2007-02-01 20:28	5	70	69.98	68.82	0	0.09	0.03
2007-02-01 20:48	5	30	29.90	29.05	0	0.08	0.03
2007-02-01 21:08	5	90	89.77	88.67	0	0.09	0.04
2007-02-01 21:28	5	20	19.97	19.12	0	0.08	0.05
2007-02-01 21:48	5	10	10.01	9.39	0	0.08	0.05
2007-02-01 22:08	5	60	59.88	58.76	0	0.13	0.03
2007-02-01 22:28	5	50	49.96	48.96	0	0.12	0.02
2007-02-01 22:48	5	80	79.87	78.65	0	0.11	0.03
2007-02-01 23:08	6	0	0.19	-0.46	0	0.07	0.03
2007-02-01 23:28	6	90	89.87	88.62	0	0.10	0.07
2007-02-01 23:48	6	70	69.93	68.88	0	0.07	0.03
2007-02-02 00:08	6	40	39.99	38.96	0	0.09	0.04
2007-02-02 00:28	6	50	50.00	48.99	0	0.10	0.06
2007-02-02 00:48	6	20	20.05	19.18	0	0.09	0.03
2007-02-02 01:08	6	30	29.91	29.16	0	0.09	0.08
2007-02-02 01:28	6	60	59.87	58.81	0	0.05	0.05
2007-02-02 01:48	6	10	10.00	9.43	0	0.09	0.05
2007-02-02 02:08	6	80	79.82	78.72	0	0.09	0.04

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

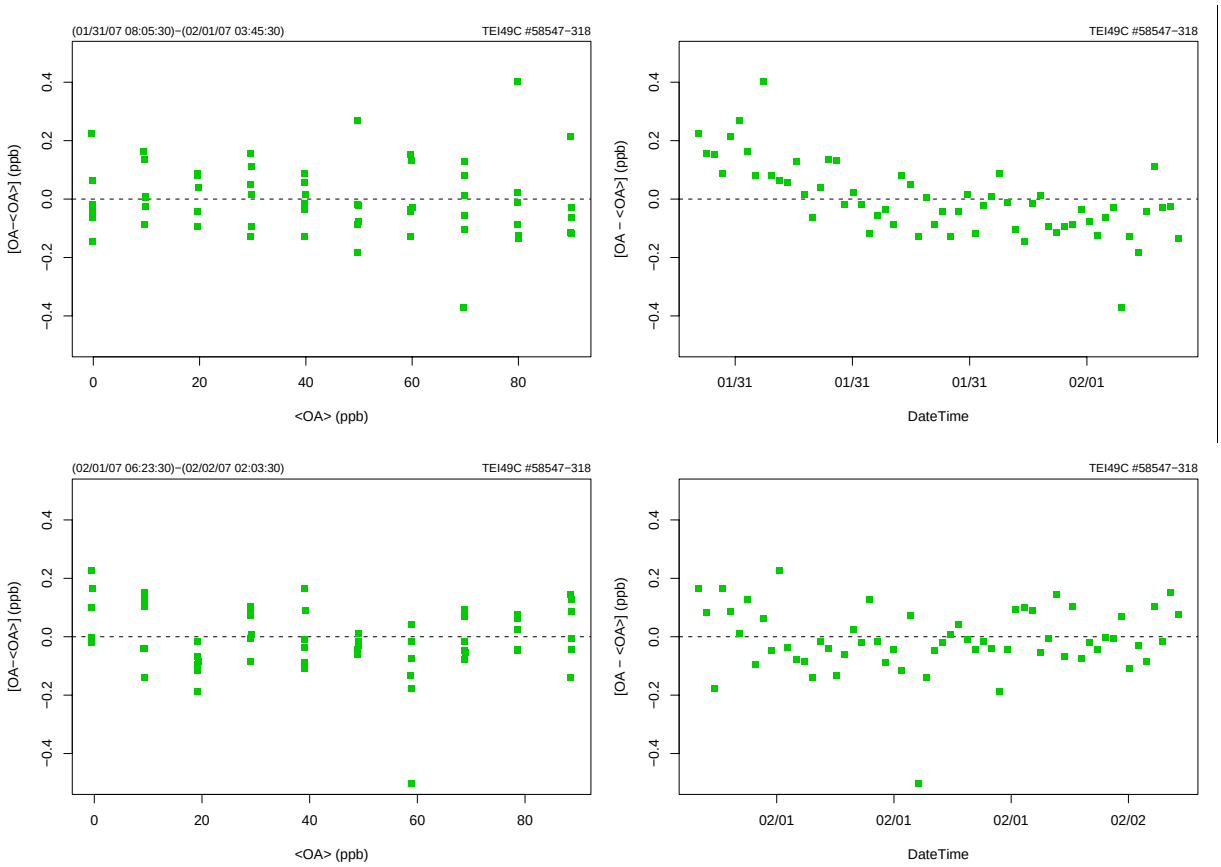

Figure 7. Regression residuals of the BKT ozone analyser (TEI 49C) as a function of concentration (left) and time (right). The upper panel shows the initial inter-comparison (direct TS-instrument), and the lower panel a second inter-comparison including the water trap.

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:

Direct calibration excluding water trap:

$$\mathbf{X_{O3}\ (ppb) = ([OA] + 0.29\ ppb) / 1.007}$$

$$\mathbf{u_{O3}\ (ppb) = sqrt(0.27\ ppb^2 + 2.57e\text{-}05 * X_{O3}^2)} \quad (1a)$$

Calibration including water trap:

$$\mathbf{X_{O3}\ (ppb) = ([OA] + 0.57\ ppb) / 0.996}$$

$$\mathbf{u_{O3}\ (ppb) = sqrt(0.27\ ppb^2 + 2.62e\text{-}05 * X_{O3}^2)} \quad (1b)$$

TEI 49 #51974-290:

This instrument was installed at BKT in 1996. Two inter-comparisons were made during the audit. The result of the first assessment (direct comparison between TS and the analyser with unchanged settings) is shown in Table 5. A further comparison was made after adjustment of the pressure sensor (-2%); these results are presented in Table 6.

Figure 8 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.

Table 5. 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)
2007-02-03 06:05	1	0	0.18	0.19	0	0.04	0.07
2007-02-03 06:20	1	30	29.82	28.64	0	0.05	0.10
2007-02-03 06:35	1	60	59.78	58.16	0	0.05	0.09
2007-02-03 06:50	1	40	39.79	38.37	0	0.10	0.07
2007-02-03 07:05	1	90	89.85	87.52	0	0.10	0.08
2007-02-03 07:20	1	50	50.07	48.43	0	0.06	0.09
2007-02-03 07:35	1	10	10.07	9.27	0	0.11	0.08
2007-02-03 07:50	1	20	19.91	18.99	0	0.06	0.19
2007-02-03 08:05	1	80	79.82	77.82	0	0.09	0.09
2007-02-03 08:20	1	70	69.88	68.03	0	0.07	0.08
2007-02-03 08:35	2	0	0.23	-0.17	0	0.08	0.06
2007-02-03 08:50	2	30	29.91	28.62	0	0.09	0.05
2007-02-03 09:05	2	60	59.90	58.21	0	0.05	0.09
2007-02-03 09:20	2	40	39.95	38.64	0	0.09	0.08
2007-02-03 09:35	2	90	89.89	87.71	0	0.09	0.07
2007-02-03 09:50	2	50	50.08	48.58	0	0.11	0.10
2007-02-03 10:05	2	10	10.10	9.16	0	0.12	0.05
2007-02-03 10:20	2	20	20.02	18.90	0	0.07	0.12
2007-02-03 10:35	2	80	79.94	78.03	0	0.08	0.09
2007-02-03 10:50	2	70	69.99	68.13	0	0.06	0.09
2007-02-03 11:05	3	0	0.17	-0.53	0	0.06	0.06
2007-02-03 11:20	3	40	39.97	38.48	0	0.06	0.08
2007-02-03 11:35	3	70	70.00	68.17	0	0.10	0.09
2007-02-03 11:50	3	30	29.99	28.88	0	0.07	0.10
2007-02-03 12:05	3	90	89.80	87.74	0	0.07	0.09
2007-02-03 12:20	3	20	19.93	18.75	0	0.10	0.08
2007-02-03 12:35	3	10	9.95	9.03	0	0.10	0.12
2007-02-03 12:50	3	60	59.88	58.16	0	0.09	0.08
2007-02-03 13:05	3	50	49.93	48.12	0	0.08	0.09
2007-02-03 13:20	3	80	79.90	78.36	0	0.17	0.17
2007-02-03 13:35	4	0	0.22	-0.26	0	0.10	0.16
2007-02-03 13:50	4	90	89.85	87.77	0	0.04	0.08
2007-02-03 14:05	4	70	69.85	68.14	0	0.06	0.04
2007-02-03 14:20	4	40	39.88	38.36	0	0.09	0.07
2007-02-03 14:35	4	50	49.88	48.26	0	0.11	0.08
2007-02-03 14:50	4	20	19.94	18.90	0	0.09	0.03
2007-02-03 15:05	4	30	29.89	28.54	0	0.11	0.08
2007-02-03 15:20	4	60	59.85	58.18	0	0.04	0.08
2007-02-03 15:35	4	10	9.99	9.19	0	0.06	0.09
2007-02-03 15:50	4	80	79.89	77.94	0	0.09	0.11
2007-02-03 16:05	5	0	0.17	-0.54	0	0.08	0.04
2007-02-03 16:20	5	30	30.08	28.65	0	0.06	0.09
2007-02-03 16:35	5	60	60.00	58.25	0	0.07	0.05
2007-02-03 16:50	5	40	40.09	38.49	0	0.09	0.06
2007-02-03 17:05	5	90	89.85	87.81	0	0.08	0.09
2007-02-03 17:20	5	50	49.88	48.32	0	0.07	0.06
2007-02-03 17:35	5	10	10.06	8.98	0	0.15	0.10
2007-02-03 17:50	5	20	20.00	18.69	0	0.10	0.10
2007-02-03 18:05	5	80	79.96	77.94	0	0.08	0.07
2007-02-03 18:20	5	70	70.01	68.01	0	0.06	0.09
2007-02-03 18:35	6	0	0.19	-0.42	0	0.07	0.06
2007-02-03 18:50	6	40	39.99	38.62	0	0.07	0.08
2007-02-03 19:05	6	70	69.93	68.02	0	0.06	0.08
2007-02-03 19:20	6	30	30.04	28.57	0	0.11	0.08
2007-02-03 19:35	6	90	89.88	87.64	0	0.07	0.07
2007-02-03 19:50	6	20	20.03	18.80	0	0.07	0.09
2007-02-03 20:05	6	10	10.07	9.16	0	0.10	0.06
2007-02-03 20:20	6	60	59.90	58.06	0	0.11	0.09
2007-02-03 20:35	6	50	49.95	48.25	0	0.09	0.04
2007-02-03 20:50	6	80	79.89	77.79	0	0.08	0.08
2007-02-03 21:05	7	0	0.23	-0.53	0	0.08	0.05
2007-02-03 21:20	7	90	89.89	87.85	0	0.07	0.05
2007-02-03 21:35	7	70	69.93	67.84	0	0.09	0.09
2007-02-03 21:50	7	40	39.99	38.26	0	0.09	0.06

DateTime (UTC)	Run	Level	TS (ppb)	OA (ppb)	Flag[#]	sdTS (ppb)	sdOA (ppb)
2007-02-03 22:05	7	50	49.94	48.30	0	0.05	0.07
2007-02-03 22:20	7	20	20.04	18.66	0	0.11	0.07
2007-02-03 22:35	7	30	29.97	28.62	0	0.07	0.11
2007-02-03 22:50	7	60	59.92	58.06	0	0.08	0.10
2007-02-03 23:05	7	10	10.49	9.73	0	0.48	0.22
2007-02-03 23:20	7	80	79.81	78.06	0	0.09	0.07
2007-02-03 23:35	8	0	0.24	-0.36	0	0.08	0.08
2007-02-03 23:50	8	30	29.89	28.37	0	0.09	0.06
2007-02-04 00:05	8	60	59.90	58.29	0	0.06	0.09
2007-02-04 00:20	8	40	39.88	38.34	0	0.07	0.06
2007-02-04 00:35	8	90	89.75	87.63	0	0.09	0.07
2007-02-04 00:50	8	50	49.87	48.27	0	0.10	0.05
2007-02-04 01:05	8	10	10.09	9.16	0	0.08	0.12
2007-02-04 01:20	8	20	19.93	18.79	0	0.08	0.07
2007-02-04 01:35	8	80	79.83	77.80	0	0.08	0.08
2007-02-04 01:50	8	70	69.88	67.99	0	0.05	0.07

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

Table 6. Ten-minute aggregates (adjusted 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)
2007-02-06 03:29	1	0	0.23	0.14	0	0.16	0.08
2007-02-06 03:44	1	30	30.24	30.21	0	0.12	0.08
2007-02-06 03:59	1	60	60.19	60.30	0	0.11	0.10
2007-02-06 04:14	1	40	40.20	40.05	0	0.15	0.05
2007-02-06 04:29	1	90	90.01	91.44	0	0.03	1.02
2007-02-06 04:44	1	50	50.03	49.82	0	0.06	0.09
2007-02-06 04:59	1	10	9.98	9.75	0	0.16	0.05
2007-02-06 05:14	1	20	20.01	19.58	0	0.10	0.20
2007-02-06 05:29	1	80	79.89	80.22	0	0.09	0.09
2007-02-06 05:44	1	70	70.08	70.32	0	0.09	0.07
2007-02-06 05:59	2	0	0.24	0.26	0	0.09	0.08
2007-02-06 06:14	2	40	40.03	39.97	0	0.14	0.07
2007-02-06 06:29	2	70	69.86	70.12	0	0.08	0.10
2007-02-06 06:44	2	30	30.00	29.68	0	0.10	0.09
2007-02-06 06:59	2	90	89.84	90.28	0	0.10	0.03
2007-02-06 07:14	2	20	20.13	19.77	0	0.09	0.08
2007-02-06 07:29	2	10	10.11	9.83	0	0.13	0.07
2007-02-06 07:44	2	60	60.04	60.15	0	0.10	0.07
2007-02-06 07:59	2	50	49.94	49.97	0	0.06	0.05
2007-02-06 08:14	2	80	79.81	80.19	0	0.08	0.09
2007-02-06 08:29	3	0	0.24	0.04	0	0.07	0.08
2007-02-06 08:44	3	90	89.76	90.11	0	0.08	0.07
2007-02-06 08:59	3	70	70.00	70.20	0	0.09	0.11
2007-02-06 09:14	3	40	40.06	39.85	0	0.09	0.08
2007-02-06 09:29	3	50	49.95	49.94	0	0.07	0.06
2007-02-06 09:44	3	20	20.01	19.62	0	0.08	0.08

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

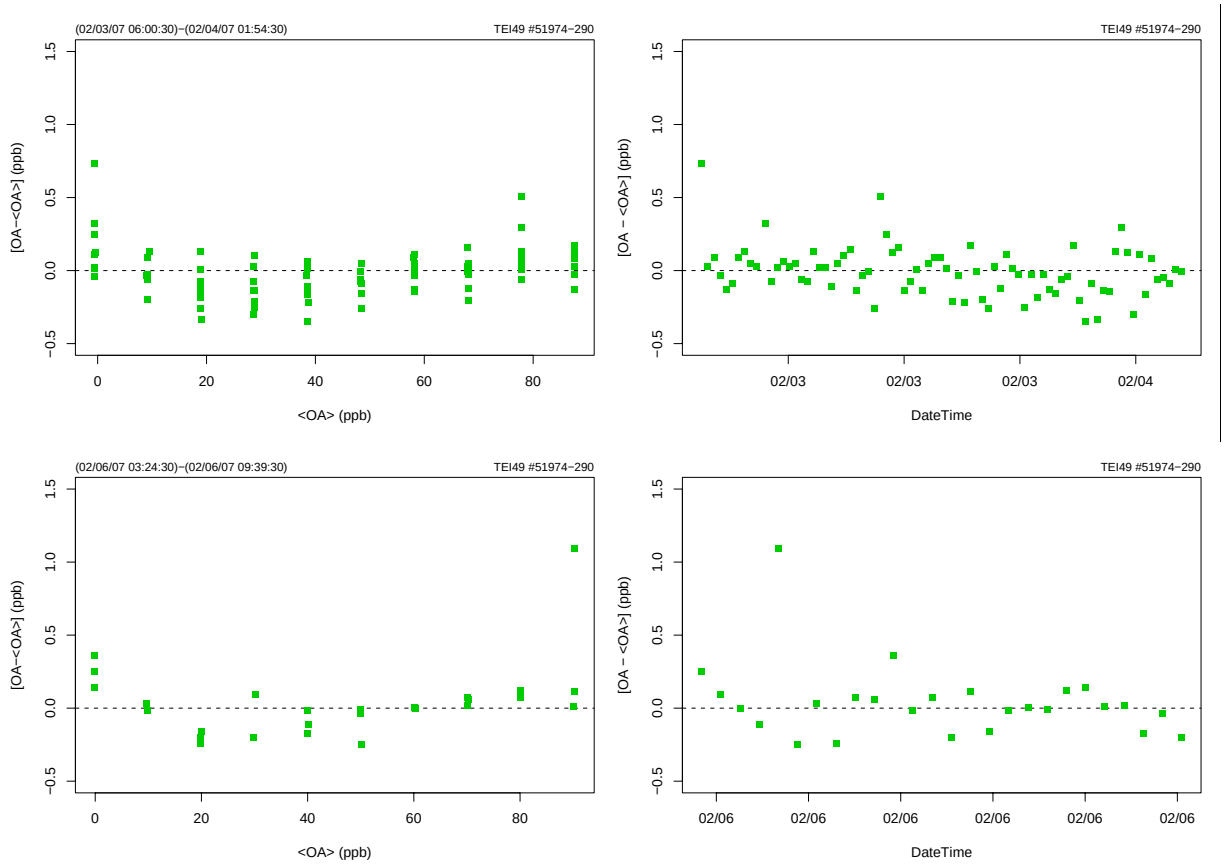

Figure 8. Regression residuals of the BKT ozone analyser (TEI 49) s a function of concentration (left) and time (right). Upper panel: Initial inter-comparison with unchanged pressure sensor settings. Lower panel: Adjusted pressure sensor settings.

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:

Initial calibration with unchanged pressure sensor (TEI 49 pressure sensor reading 2% higher compared to reference pressure):

$$\mathbf{X_{O3}\ (ppb) = ([OA] + 0.64\ ppb) / 0.986}$$

$$\mathbf{u_{O3}\ (ppb) = sqrt(0.30\ ppb^2 + 2.67e\text{-}05 * X_{O3}^2)} \quad (1c)$$

Calibration with adjusted pressure sensor:

$$\mathbf{X_{O3}\ (ppb) = ([OA] + 0.26\ ppb) / 1.010}$$

$$\mathbf{u_{O3}\ (ppb) = sqrt(0.32\ ppb^2 + 2.65e\text{-}05 * X_{O3}^2)} \quad (1d)$$

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. During the current audit the instrument was extremely unstable due to partly wrong temperature readings. The temperature control board CNTRS 49-007 was identified to be defective. The result of the assessment (direct comparison between TS and the calibrator) is shown in Table 7. Figure 9 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 7. 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)
2007-02-06 03:29	1	0	0.23	1.58	0	0.16	0.06
2007-02-06 03:44	1	30	30.24	30.79	0	0.12	0.10
2007-02-06 03:59	1	60	60.19	60.1	0	0.11	0.09
2007-02-06 04:14	1	40	40.21	40.51	0	0.17	0.09
2007-02-06 04:29	1	90	90.01	81.58	0	0.03	0.25
2007-02-06 04:44	1	50	50.03	44.34	0	0.06	0.07
2007-02-06 04:59	1	10	9.98	7.87	0	0.16	0.07
2007-02-06 05:14	1	20	20.01	16.63	0	0.10	0.07
2007-02-06 05:29	1	80	79.89	70.22	0	0.09	0.16
2007-02-06 05:44	1	70	70.08	61.35	0	0.09	0.12
2007-02-06 05:59	2	0	0.24	-0.81	0	0.09	0.10
2007-02-06 06:14	2	40	40.03	34.07	0	0.14	0.09
2007-02-06 06:29	2	70	69.86	61.53	0	0.08	0.14
2007-02-06 06:44	2	30	30	26.18	0	0.10	0.13
2007-02-06 06:59	2	90	89.84	82.65	0	0.10	0.89
2007-02-06 07:14	2	20	20.13	17.98	0	0.09	0.13
2007-02-06 07:29	2	10	10.11	7.24	0	0.13	0.13
2007-02-06 07:44	2	60	60.04	56.6	0	0.10	0.11
2007-02-06 07:59	2	50	49.94	48.27	0	0.06	0.09
2007-02-06 08:14	2	80	79.81	77.64	0	0.08	0.10
2007-02-06 08:29	3	0	0.24	0.06	0	0.07	0.10
2007-02-06 08:44	3	90	89.76	87.59	0	0.08	0.10
2007-02-06 08:59	3	70	70	67.92	0	0.09	0.14
2007-02-06 09:14	3	40	40.06	38.55	0	0.09	0.13
2007-02-06 09:29	3	50	49.95	48.37	0	0.07	0.11
2007-02-06 09:44	3	20	20.01	18.96	0	0.08	0.11

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

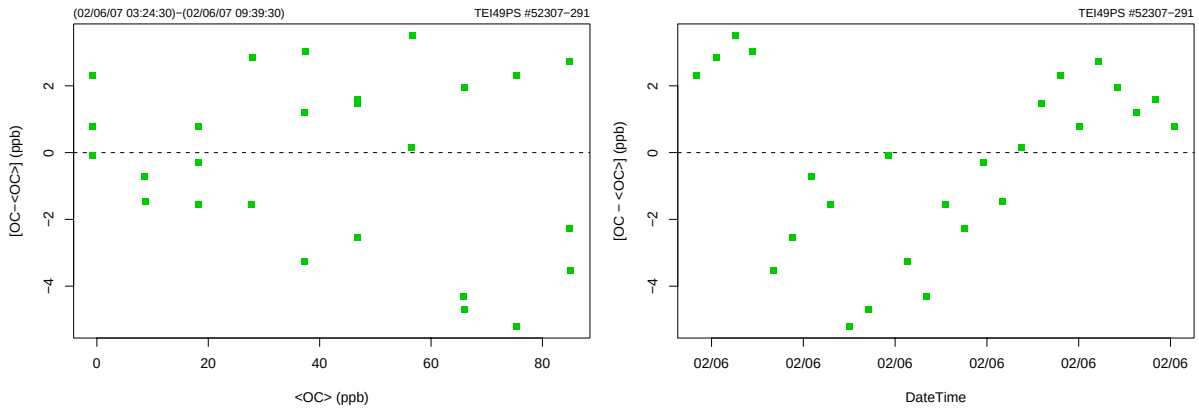

Figure 9. Regression residuals of the BKT ozone calibrator (TEI 49-PS) as a function of concentration (left) and time (right).

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:

$$X_{O3}\ (ppb) = ([OA] + 0.88\ ppb) / 0.958$$

$$u_{O3}\ (ppb) = sqrt(7.55\ ppb^2 + 2.92e\text{-}05 * X_{O3}^2) \quad (1e)$$

Conclusions

The BKT ozone analysers were found to agree well with the WCC-Empa ozone standard. However, it was noticed that the pressure sensor of the TEI 49 instrument was not correctly adjusted to the station reference, which caused a deviation of approx. 2% compared to WCC-Empa.

The BKT ozone calibrator was found to be defective, and repair or replacement is needed (cf. Recommendation 8).

Carbon Monoxide Measurements

The current set-up of carbon monoxide measurements remained unchanged since the last audit by WCC-Empa [*Zellweger, et al.*, 2004]. All inter-comparisons were done according to Standard Operating Procedures [*WMO*, in preparation-b].

Monitoring Set-up and Procedures

Air Conditioning

The air-conditioning is identical to the one for surface ozone as described above. However, it is more critical for carbon monoxide measurements to maintain a stable room temperature (cf. Recommendation 1).

Air Inlet System

See previous audit report [*Zellweger, et al.*, 2004].

Instrumentation

See previous audit reports [*Zellweger, et al.*, 2004; *Zellweger, et al.*, 2001]. Instrumental details are also listed in Table 9.

Standards and Calibration

The station has been provided with calibration gases by WCC-Empa. Table 8 gives details of the cylinders currently available at the station. Two types of calibration standards are available: Low concentrations (approx. 1 ppm) for direct calibrations of the instrument, and higher concentrations (15 or 50 ppm) for automatic span checks. The standards with serial number starting with D94 were delivered to the site in 2006.

Table 8. 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	cont.
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	cont.
Messer, D94 4280, dilution	49781 ± 500 ppb synth. air 5.0	10/06	WCC-Empa	stock	
Messer, D94 4278, dilution	49806 ± 500 ppb synth. air 5.0	10/06	WCC-Empa	stock	
Messer, D94 4289, direct calibration	1016.6 ± 10.2 ppb synth. air 5.0	10/06	WCC-Empa	stock	

* WMO-2000 carbon monoxide scale

Operation and Maintenance

See previous audit report [*Zellweger, et al.*, 2004].

Data Acquisition and Data Transfer

At the time of the audit data of the TEI 48C-TL analyser was still downloaded manually with the TEI software version 2.2.0. A new LabView based data acquisition system was implemented during the audit by QA/SAC Switzerland and is currently further optimised.

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 need to be re-analysed to clarify if a correction for span drift is necessary.

Data Submission

Carbon monoxide data have not yet been submitted to the GAW World Data Centre for Carbon Monoxide at JMA (World Data Centre for Greenhouse Gases, WDCGG). This is mainly because the existing data has not yet been fully quality controlled. However, QA/SAC Switzerland re-analysed the data series, and a final version which can be submitted to WDCGG should soon become available.

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. For example, no information is found in the log file when the CO cylinder for the automatic span checks was exchanged in December 2004. Such information must be entered in the log files. The instrument manuals are available at the site.

Inter-Comparison of Carbon Monoxide Analysers

All procedures were conducted according to the Standard Operating Procedure [*WMO*, in preparation-b] 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 13 below.

Setup and Connections

Table 9 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 both WCC-Empa and BKT data acquisition systems as indicated, and no corrections were applied.

Table 9. Experimental details of the carbon monoxide inter-comparison.

Travelling standard (TS)		One cylinder (Messer Schweiz, D94 4280, 49780±100 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 / 0.1 2 / 102.6 / 0.2 3 / 202.5 / 0.4 4 / 302.7 / 0.6 5 / 403.4 / 0.9 6 / 504.1 / 1.1 7 / 604.8 / 1.3 8 / 705.4 / 1.5 9 / 806.0 / 1.7 10 / 907.0 / 1.9 11 / 1007.3 / 2.1
Field instrument	Model, S/N	TEI 48C Trace Level #66839-352
	Principle	NDIR, gas filter correlation technique
	Modification	Nafion drier PERMAPURE PD-50-24'' reflux mode using critical orifice and pump of instrument
	Range	1 ppm
	Settings	First inter-comparison:: BKG -8.233 SPAN 1.042 After adjustment of calibration factors: BKG -8.900 SPAN 1.062
Connection of TS to field instrument		Sample inlet
Data Acquisition		5-minute aggregates from instrument internal data logger (TEI C Series communications software version 2.2.0)
Duration per level (min)		120, inclusive of interspersed automatic zero (20') and span (10') checks every second hour
Sequence of levels		Repeated runs of randomised fixed sequence
Runs		2 runs (30 January thru 5 February, 2007)

Results

Each carbon monoxide level was effectively applied for 120 minutes, which resulted in a maximum of 17 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 10). No span correction was applied to the data for the evaluation of the result.

Table 10. CO aggregates computed from single injections for each level and repetition during the inter-comparison of the BKT TEI 48C-TL CO analyser with WCC-Empa travelling standards (TS).

Date Time (UTC)	TS (ppb)	sdTS (ppb)	CO (ppb)	sdCO(ppb)	No. 5' av.
Initial inter-comparison					
(01/30/07 06:20:00)	0.00	0.08	-7.12	17.26	17
(01/30/07 08:20:00)	102.60	0.23	76.61	17.35	17
(01/30/07 10:20:00)	202.46	0.43	217.47	5.76	17
(01/30/07 12:20:00)	302.73	0.64	287.90	5.74	17
(01/30/07 14:20:00)	403.37	0.85	399.37	5.36	17
(01/30/07 16:20:00)	504.09	1.07	508.79	8.94	17
(01/30/07 18:20:00)	604.79	1.28	589.29	2.71	17
(01/30/07 20:20:00)	705.44	1.49	673.71	3.04	17
(01/30/07 22:20:00)	806.03	1.71	773.01	4.70	17
(01/31/07 00:20:00)	906.97	1.92	880.94	6.78	17
(01/31/07 02:20:00)	1007.26	2.13	942.08	31.71	17
New calibration factors					
(02/04/07 08:30:00)	0.00	0.08	1.37	8.36	11
(02/04/07 10:20:00)	102.60	0.23	96.69	20.65	17
(02/04/07 12:20:00)	202.46	0.43	189.16	7.71	17
(02/04/07 14:20:00)	302.73	0.64	280.65	11.19	17
(02/04/07 16:20:00)	403.37	0.85	406.64	6.01	17
(02/04/07 18:20:00)	504.09	1.07	500.21	4.91	17
(02/04/07 20:20:00)	604.79	1.28	595.48	3.84	17
(02/04/07 22:20:00)	705.44	1.49	693.70	8.82	17
(02/05/07 00:20:00)	806.03	1.71	786.65	14.48	17
(02/05/07 02:20:00)	906.97	1.92	834.80	6.36	17
(02/05/07 04:20:00)	1007.26	2.13	976.91	13.35	17

Figure 10 shows the regression residuals of the analyser over the course of the initial inter-comparison runs, before adjustment of the calibration factors of the instrument. The absence of a temporal trend (left panel) indicates stable instrument conditions, even though the data are noisy. The absence of a concentration dependence (right panel) in the residuals indicates linearity of the instrument.

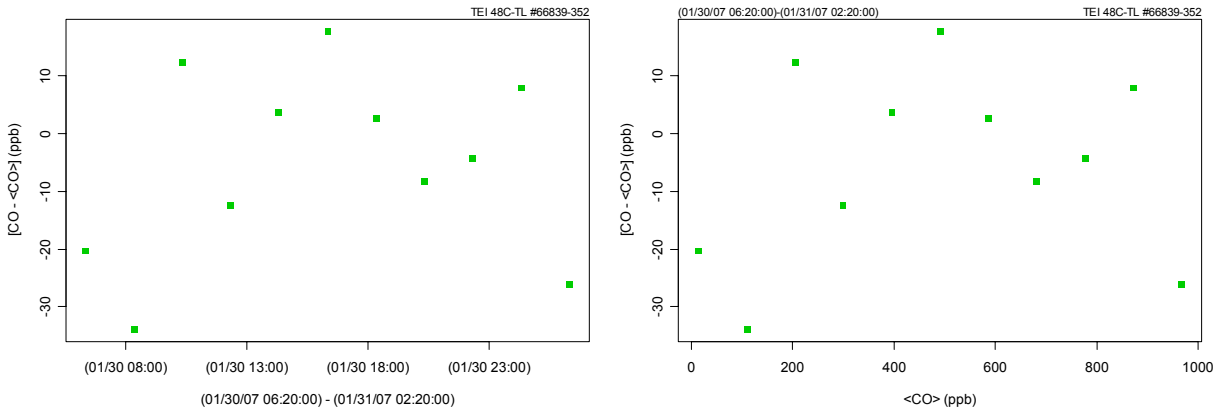

Figure 10. Regression residuals of the BKT carbon monoxide analyser based on the initial inter-comparison with the dilution unit. Points represent averages of valid 5 minute values. Left panel: time dependence; Right panel: concentration dependence.

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).

$$\mathbf{X_{CO}\ (ppb) = ([CO] - 13.3\ ppb) / 0.948}$$

$$\mathbf{u_{CO}\ (ppb) = sqrt(312.2\ ppb^2 + 3.18e\text{-}05 * X_{CO}^2)} \quad (2a)$$

Figure 11 shows the regression residuals of the analyser after adjustment of the calibration factors of the instrument. An outlier at 900 ppb was excluded for the inter-comparison. 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.

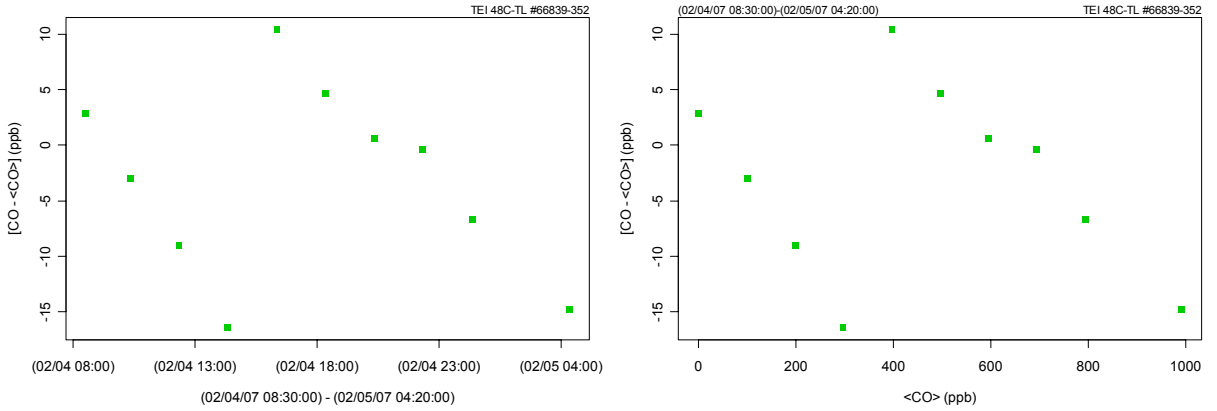

Figure 11. Regression residuals of the BKT carbon monoxide analyser (new calibration settings) based on the inter-comparison with the dilution unit. Points represent averages of valid 5 minute values. Left panel: time dependence; Right panel: concentration dependence.

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 (2b).

$$\mathbf{X_{CO}\ (ppb) = ([CO] + 1.4\ ppb) / 0.986}$$

$$\mathbf{u_{CO}\ (ppb) = sqrt(87.0\ ppb^2 + 3.57e\text{-}05 * X_{CO}^2)} \quad (2b)$$

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.

Discussion

The inter-comparison between WCC-Empa and Bukit Koto Tabang showed relatively large deviations from the reference value and relatively large uncertainties. The bias and the remaining uncertainty were reduced after adjustment of the calibration factors of the instrument.

The combined uncertainty of the instrument is composed of various elements, namely

a) Instrument drift: The TEI 48C shows a significant zero drift that appears to be correlated with the laboratory temperature. All raw data has to be zero corrected before further use.

b) Instrument noise and linearity are within the instrument specification.

Changes made to the instrument

The SPAN calibration factor was changed from 1.042 to 1.062.

Conclusions

The TEI 48C was found to operate well within the limits of the instrument specifications. It is important to consider the uncertainties of the estimated CO concentration in any further analysis of the data.

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 11, the inter-comparison data is given in Table 12.

Table 11. 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 #54509-300 (WCC-Empa)
	Settings	BKG = -0.1; COEFF = 1.010
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 November, 2006) 3 runs after return of TS (6 March, 2007)

Table 12. 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)
2006-11-27	1	0	-0.21	0.47	-0.05	0.07
2006-11-27	1	90	90.37	0.31	90.1	0.12
2006-11-27	1	190	185.38	0.36	185.71	0.08
2006-11-27	1	30	30.87	0.35	30.99	0.13
2006-11-27	1	140	137.53	0.26	137.81	0.11
2006-11-27	1	60	60.23	0.27	60.22	0.16
2006-11-27	1	0	-0.02	0.45	0.09	0.07
2006-11-27	2	0	-0.07	0.4	0.03	0.08
2006-11-27	2	30	30.94	0.39	30.8	0.06
2006-11-27	2	140	137.55	0.34	137.87	0.11
2006-11-27	2	60	60.13	0.31	60.17	0.11
2006-11-27	2	90	89.98	0.26	90.05	0.12
2006-11-27	2	190	185.08	0.2	185.77	0.1
2006-11-27	2	0	0.00	0.29	0.09	0.05
2006-11-27	3	0	-0.08	0.44	0.02	0.05
2006-11-27	3	90	90.16	0.32	90.21	0.08
2006-11-27	3	190	185.4	0.28	185.89	0.1
2006-11-27	3	140	137.8	0.47	138.11	0.07
2006-11-27	3	30	30.92	0.24	30.96	0.1
2006-11-27	3	60	59.74	0.4	60.23	0.12
2006-11-27	3	0	0.05	0.42	0.06	0.04
2007-03-06	4	0	0.09	0.24	0.13	0.11
2007-03-06	4	90	90.4	0.42	90.92	0.11
2007-03-06	4	190	188.23	0.28	188.85	0.19
2007-03-06	4	30	32.2	0.4	32.28	0.08
2007-03-06	4	140	141.26	0.34	141.69	0.14
2007-03-06	4	60	60.98	0.39	61.2	0.08
2007-03-06	4	0	-0.14	0.41	0.15	0.12
2007-03-06	5	0	0.07	0.41	0.21	0.11
2007-03-06	5	90	90.82	0.2	91.24	0.07
2007-03-06	5	190	188.81	0.32	189.56	0.14
2007-03-06	5	30	32.17	0.32	32.47	0.07
2007-03-06	5	140	141.38	0.24	142.05	0.08
2007-03-06	5	60	61.25	0.34	61.27	0.1
2007-03-06	5	0	0.06	0.42	0.12	0.1
2007-03-06	6	0	-0.21	0.34	0.06	0.07
2007-03-06	6	30	31.99	0.31	32.27	0.07
2007-03-06	6	140	141.34	0.26	141.85	0.11
2007-03-06	6	60	60.75	0.25	61.22	0.07
2007-03-06	6	90	91.06	0.57	91.47	0.13
2007-03-06	6	190	188.95	0.34	189.64	0.13
2007-03-06	6	0	-0.03	0.33	0.08	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 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 3). The uncertainty of the TS was estimated previously (cf. equation 19 in [*Klausen, et al.*, 2003]).

$$\mathbf{X_{TS}\ (ppb) = ([TS] - 0.08\ ppb) / 1.0024}$$

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

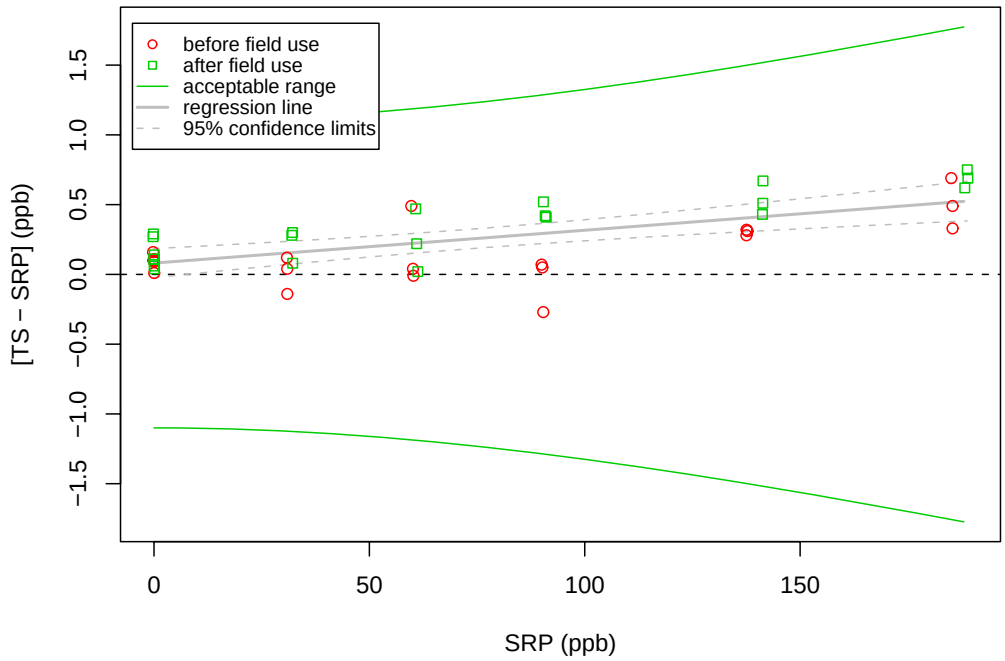

Figure 12. Deviations between travelling standard (TS) and Standard Reference Photometer (SRP) before and after use of the TS at the field site.

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. Details are given in Table 13 - Table 14.

Table 13. 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 is 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 4280, 49780±100 ppb CO (α=0.05). Cylinder remained at the station.
(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
Levels (ppb)		0 to 1000, in steps of 100
Duration per level (min)		Three 4-minute averages alternating with calibrations
Sequence of Levels		Repeated runs of randomised sequence
Runs		1 run before shipment of TS (03 October, 2006) 1 run after return of TS (05 March, 2007)

Table 14. Calibration of Breitfuss dilution system and carbon monoxide mixing ratios.

	Mass Flow Controller MFC 1 (mL min^{-1})		Mass Flow Controller MFC 2 (mL min^{-1})		Carbon Monoxide Mixing Ratio (ppb)	
Date	**Setpoint**	**Measured**[#]	**Setpoint**	**Measured**	**Expected**	**Measured**[#]
2006-10-03	3000	3001.6±2.0	0	0.00±0.00	0.0	0.2±0.1
2006-10-03	2994	3004.0±1.5	6	6.22±0.02	102.8	102.2±0.5
2006-10-03	2988	3000.7±0.5	12	12.25±0.01	202.4	202.3±0.5
2006-10-03	2982	2995.3±0.3	18	18.30±0.01	302.3	302.5±0.5
2006-10-03	2976	2989.4±0.2	24	24.38±0.01	402.7	403.2±0.5
2006-10-03	2970	2983.5±0.2	30	30.45±0.01	503.0	504.1±0.9
2006-10-03	2964	2977.4±0.2	36	36.53±0.01	603.4	603.1±0.6
2006-10-03	2958	2972.0±0.4	42	42.60±0.01	703.5	703.8±1.0
2006-10-03	2952	2965.8±0.2	48	48.65±0.01	803.5	803.1±0.9
2006-10-03	2946	2959.4±0.2	54	54.74±0.01	904.1	904.3±0.8
2006-10-03	2940	2953.7±0.2	60	60.79±0.01	1003.9	1003.2±1.1
2007-03-05	3000	2998.2±0.9	0	0.00±0.00	0.0	NA
2007-03-05	2994	2994.8±0.9	6	6.17±0.02	102.4	NA
2007-03-05	2988	2991.4±0.3	12	12.22±0.01	202.5	NA
2007-03-05	2982	2985.0±0.4	18	18.29±0.01	303.2	NA
2007-03-05	2976	2979.4±0.2	24	24.38±0.01	404.1	NA
2007-03-05	2970	2973.5±0.3	30	30.49±0.01	505.2	NA
2007-03-05	2964	2967.2±0.3	36	36.58±0.01	606.3	NA
2007-03-05	2958	2961.4±0.3	42	42.69±0.01	707.4	NA
2007-03-05	2952	2955.3±0.2	48	48.80±0.01	808.7	NA
2007-03-05	2946	2950.4±0.3	54	54.93±0.01	909.8	NA
2007-03-05	2940	2944.6±0.5	60	61.02±0.01	1010.7	NA

[#]Average±sd (n =10); NA: data not available because cylinder was not shipped back to WCC-Empa

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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:	29 January – 6 February, 2007
1.2	Auditor:	Dr. C. Zellweger, Dr. J. Klausen
1.2.1	Station staff involved in audit:	Rismoyo, Herizal, Asep Firman Ilahi, Carles Siregar, Darmadi, Budi Satria, Budi Setiawan
1.3	Ozone Reference [SRP]:	NIST SRP#15
1.4	Ozone Transfer Standard [TS]	
1.4.1	Model and serial number:	TEI 49C PS #54509-300
1.4.2	Range of calibration:	0 – 200 ppb
1.4.3	Mean calibration (ppb):	$(1.0024\pm0.0010) \times [SRP] + (0.08\pm0.09)$
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):	$[OA] = (0.996\pm0.000) \times [SRP] - (0.57\pm0.05)$
1.5.5	Unbiased ozone mixing ratio (ppb) at start of audit:	$X = ([OA] + 0.57) / 0.996$
1.5.6	Standard uncertainty remaining after compensation of calibration bias (ppb):	$u_X \approx (0.27\ ppb^2 + 2.62e\text{-}5 \times X^2)^{1/2}$
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 -comparison including the water trap
1.7	Reference:	WCC-Empa Report 07/1

[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:	29 January – 6 February, 2007
1.2	Auditor:	Dr. C. Zellweger, Dr. J. Klausen
1.2.1	Station staff involved in audit:	Rismoyo, Herizal, Asep Firman Ilahi, Carles Siregar, Darmadi, Budi Satria, Budi Setiawan
1.3	Ozone Reference [SRP]:	NIST SRP#15
1.4	Ozone Transfer Standard [TS]	
1.4.1	Model and serial number:	TEI 49C PS #54509-300
1.4.2	Range of calibration:	0 – 200 ppb
1.4.3	Mean calibration (ppb):	$(1.0024\pm0.0010) \times [SRP] + (0.08\pm0.09)$
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):	$[OA] = (0.986\pm0.000) \times [SRP] - (0.64\pm0.05)$
1.5.5	Unbiased ozone mixing ratio (ppb) at start of audit:	$X = ([OA] + 0.64) / 0.986$
1.5.6	Standard uncertainty remaining after compensation of calibration bias (ppb):	$u_X \approx (0.30\ ppb^2 + 2.67e\text{-}5 \times X^2)^{1/2}$
1.5.7	Coefficients after audit	unchanged
1.5.8	Calibration after audit (ppb):	$[OA] = (1.010\pm0.001) \times [SRP] - (0.26\pm0.05)$
1.5.9	Unbiased ozone mixing ratio (ppb) after audit:	$X = ([OA] + 0.26) / 1.010$
1.5.10	Standard uncertainty remaining after compensation of calibration bias (ppb):	$u_X \approx (0.32\ ppb^2 + 2.65e\text{-}5 \times X^2)^{1/2}$
1.6	Comments:	-main station instrument until September 2006 -pressure sensor was adjusted during the audit -inter-comparison without water trap
1.7	Reference:	WCC-Empa Report 07/1

[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:	29 January – 6 February, 2007
1.2	Auditor:	Dr. C. Zellweger, Dr. J. Klausen
1.2.1	Station staff involved in audit:	Rismoyo, Herizal, Asep Firman Ilahi, Carles Siregar, Darmadi, Budi Satria, Budi Setiawan
1.3	CO Reference:	WMO-2000
1.4	CO Transfer Standard [TS]	
1.4.1	CO Cylinder:	Messer D94 4280, 49780±100 (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:	TEI 48C-TL #66839-352
1.5.2	Range of calibration:	0 – 1000 ppb
1.5.3	Coefficients at start of audit	BKG -8.233 ppm SPAN 1.042
1.5.4	Calibration at start of audit (ppb):	$CO = (0.948 \pm 0.002) \times X + (13.3 \pm 1.6)$
1.5.5	Unbiased CO mixing ratio (ppb) at start of audit:	$X = (CO - 13.3) / 0.948$
1.5.6	Standard uncertainty after compensation of calibration bias at start of audit(ppb):	$u_X \approx (312.2\ ppb^2 + 3.18e\text{-}05 \times X^2)^{1/2}$
1.5.7	Coefficients after audit	BKG -8.900 SPAN 1.062
1.5.8	Calibration after audit (ppb):	$CO = (0.986 \pm 0.003) \times X - (1.4 \pm 1.6)$
1.5.9	Unbiased CO mixing ratio (ppb) after audit:	$X = (CO + 1.4) / 0.986$
1.5.10	Standard uncertainty after compensation of calibration bias after audit(ppb):	$u_X \approx (87.0\ ppb^2 + 3.57e\text{-}05 \times X^2)^{1/2}$
1.6	Comments:	
1.7	Reference:	WCC-Empa Report 07/1

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

REFERENCES

Herzog, A., et al. (1999), System and Performance Audit for Surface Ozone, Global GAW Station Bukit Koto Tabang, Indonesia, WCC-Empa Report 99/7, 25 pp, Empa Dübendorf, Switzerland.

Hofer, P., et al. (2000), Traceability, Uncertainty and Assessment Criteria of Surface Ozone Measurements, 19 pp, Swiss Federal Laboratories for Materials Testing and Research (EMPA), Dübendorf, Switzerland.

Klausen, J., et al. (2003), Uncertainty and bias of surface ozone measurements at selected Global Atmosphere Watch sites, *J. Geophys. Res.-Atmos.*, *108*, 4622, doi:4610.1029/2003JD003710.

Novelli, P. C., et al. (2003), Re-analysis of tropospheric CO trends: Effects of the 1997-1998 wild fires, *J. Geophys. Res.-Atmos.*, *108*, 4464, doi:4410.1029/2002JD003031.

WMO (2007), WMO Global Atmosphere Watch (GAW) Strategic Plan: 2008 – 2015, GAW Report No. 172, World Meteorological Organization, Geneva, Switzerland.

WMO (in preparation-a), Standard Operating Procedure (SOP) for Performance Audits of Surface Ozone Measurements at WMO/GAW Sites, Draft Version 1.0, World Meteorological Organization, Scientific Advisory Group Reactive Gases, Geneva, Switzerland.

WMO (in preparation-b), Standard Operating Procedure (SOP) for System and Performance Audits of Trace Gas Measurements at WMO/GAW Sites, Draft Version 1.4, World Meteorological Organization, Scientific Advisory Group Reactive Gases, Geneva, Switzerland.

Zellweger, C., et al. (2004), System and Performance Audit for Surface Ozone and Carbon Monoxide, Global GAW Station Bukit Koto Tabang, Indonesia, WCC-Empa Report 04/1, 45 pp, Empa Dübendorf, Switzerland.

Zellweger, C., et al. (2001), System and Performance Audit for Surface Ozone, Global GAW Station Bukit Koto Tabang, Indonesia, WCC-Empa Report 01/2, 44 pp, Empa Dübendorf, Switzerland.