Global Atmosphere Watch
World Calibration Centre for Surface Ozone
and Carbon Monoxide

Swiss Federal Laboratories for Materials Testing
and Research (EMPA)

EMPA-WCC REPORT 01/2

Submitted to the

World Meteorological Organization

SYSTEM AND PERFORMANCE AUDIT
OF SURFACE OZONE MEASUREMENTS
GLOBAL GAW STATION BUKIT KOTOTABANG
INDONESIA, JULY 2001

Submitted by

C. Zellweger, J. Klausen, B. Buchmann and P. Hofer

WMO World Calibration Centre for Surface Ozone and Carbon Monoxide

EMPA Dübendorf, Switzerland

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1. Abstract

A system and performance audit was conducted at the Global Atmosphere Watch station Bukit Kototabang from July 16 to 26, 2001 by the World Calibration Centre (EMPA-WCC) for Surface Ozone, Carbon Monoxide and Methane. The results can be summarised as follows:

System Audit of the Observatory

The Bukit Kototabang station offers suitable infrastructure concerning accessibility and laboratory facilities. However, land use change in the vicinity of the station should be carefully watched as the station may be influenced by local and regional pollution sources with further development of the area.

Audit of the Surface Ozone Measurement

Ozone measurements were not operational at the time of the audit. A failure in August 1999 of the fully automated system stopped measurements, and the station staff was unable to solve the problems without the help of external experts. A communication problem (e-mails were not answered by the station manager) made external support difficult. This problem was intensively discussed during the audit, and ozone measurements became again operational with a simpler instrument set-up designed by EMPA-WCC. The new data acquisition was delivered by the twinning partner from CSIRO Aspendale, and installed by EMPA-WCC during the audit.

The inter-comparison, consisting of three multipoint runs, between the WCC transfer standard and the ozone instruments of the station (analyser and calibrator) demonstrated good agreement between both instruments and the transfer standard. The recorded differences fulfilled the defined assessment criteria as "good" over the tested range up to 100 ppb (Figure 1).

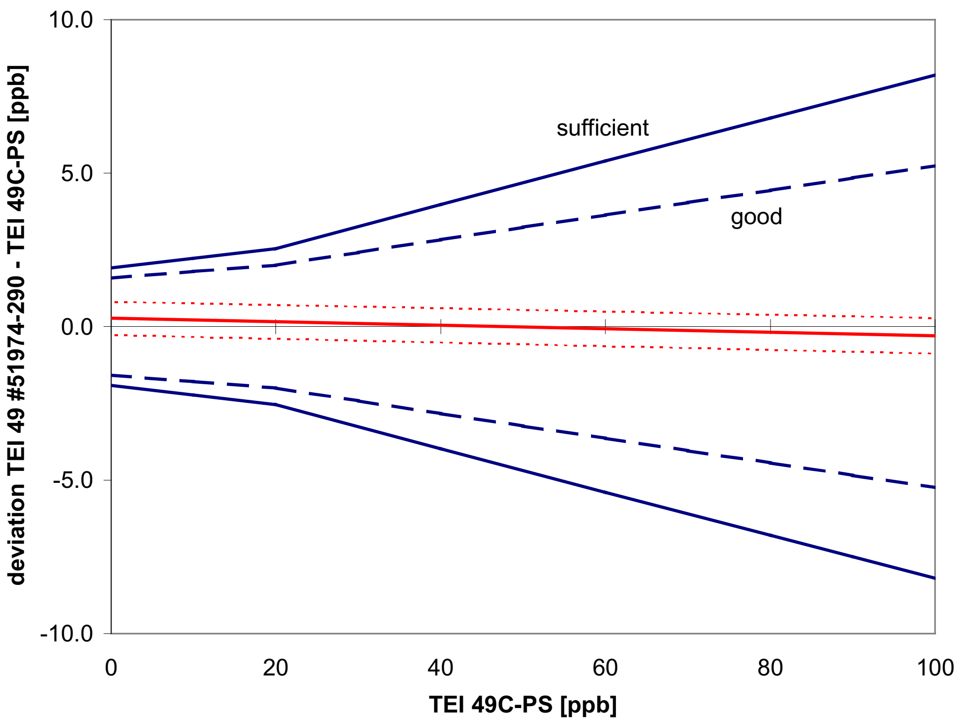

Figure 1: Inter-comparison of the TEI 49 #51974-290 field instrument with the WCC transfer standard

Implementation of Carbon Monoxide Measurements

A carbon monoxide instrument (TEI 48C) including calibration facilities was installed by EMPA-WCC during the audit as part of WMO/GEF project No. 340-99 (GLO/91/G32) 1115-99. The operators were intensively trained on the new instrument, and first CO data is available from the Bukit Kototabang GAW station.

Conclusions and Recommendations

After the audit of EMPA-WCC the global GAW station Bukit Kototabang was again fully operational for the parameter ozone. Repair work on the ozone instrumentation was done by EMPA-WCC, and the operators were trained on the new instrument set-up.

In addition, carbon monoxide measurements became operational at the site after installation of the instrumentation by EMPA-WCC.

Several recommendations were made by EMPA-WCC concerning not only ozone measurements but the general operation of the station. The main recommendations are summarised below:

- Persistent problems with any of the measurements at Bukit Kototabang should be communicated to external partners and WMO. Communication should be re-established where necessary and maintained to ensure continuing support by external partners. E-mail and internet access should be re-established for all persons involved in the GAW activities at Bukit Kototabang.
- It is recommended to nominate a second person for each parameter with the same background as the primary responsible person to ensure long-term continuity of technical knowledge.
- A budget, derived for example from the GAW measurement guide, should be available for the long-term operation and maintenance of the station. Part of the budget should be at the immediate disposal of the station manager.
- Land use in the vicinity of the station should be closely watched. Anthropogenic activities should be limited wherever possible.

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Dübendorf, 26. November 2001	EMPA Dübendorf, WCC
Project scientist	Project manager
Dr. C. Zellweger	Dr. B. Buchmann

2. Introduction

The **Global GAW Station Bukit Kototabang** is part of Indonesia's contribution to the World Meteorological Organization's (WMO) Global Atmosphere Watch (GAW) programme. The observatory was established within the framework of UNDP's Global Environment Facility (GEF) and is designated for long-term measurements of several chemical compounds and physical and meteorological parameters in the lower troposphere. The station has started its operation in autumn 1995 with a reduced measurement programme and was officially opened on December 7, 1996. The leading office is the Meteorological and Geophysical Agency (BMG) of the Department of Communication in Jakarta.

The air pollution and environmental technology section of the Swiss Federal Laboratories for Materials Testing and Research (EMPA) was assigned by the WMO to operate the GAW **World Calibration Center** (EMPA-WCC) for Surface Ozone, Carbon Monoxide and Methane, thereby establishing a co-ordinated quality assurance programme for this part of GAW. The detailed goals and tasks of the WCC concerning surface ozone are described in the GAW report No. 104. System and performance audits at global GAW stations are conducted regularly based on mutual agreement about every two years.

In agreement with the GAW country contacts, Mr Hery Harjanto and Ms Nurhayati of the Meteorological and Geophysical Agency (BMG) and the station manager, Mr Budi Suhardi, a system and performance audit at the global GAW station Bukit Kototabang, Indonesia, was conducted between July 16 to 27, 2001.

The scope of the audit was the whole measurement system in general and surface ozone measurements in particular. The entire system from the inlet to the data processing and the quality assurance was reviewed during the audit procedure. The ozone audit was performed according to the "Standard Operating Procedure (SOP) for performance auditing ozone analysers at global and regional WMO-GAW sites", WMO-GAW Report No. 97. The assessment criteria for the ozone inter-comparison have been developed by EMPA based on WMO-GAW Report No. 97 (EMPA-WCC Report 98/5, "Traceability, Uncertainty and Assessment Criteria of ground based Ozone Measurements", July 2000, available on request from EMPA or downloadable from www.empa.ch/gaw).

Furthermore, EMPA-WCC installed a carbon monoxide instrumentation based on a TEI 48C analyser as part of the GEF project No 340-99 (GLO/91/G32) 1115-99. The operators were trained on the new instrument during the audit.
The present audit report is distributed to the station manager, the GAW country contact in Jakarta, the twinning partner at CSRIO Aspendale, Australia, QA/SAC Japan and the World Meteorological Organization in Geneva.

Staff involved in the audit

Jakarta (BMG)	Mr Hery Harjanto	contacts, general program
	Ms Nurhayati	contacts, general program, organisation
Bukit Kototabang	Mr Budi Suhardi	contacts, general program, organisation
	Mr Imam Prawoto	technical assistance on the observatory
	Mr Nasrullah	technical assistance on the observatory
	Mr Herizal	technical assistance on the observatory
	Mr Kaharudin	technical assistance on the observatory
	Mr Charles Siregar	technical assistance on the observatory
	Mr Darmadi	technical assistance on the observatory
EMPA-WCC	Dr. Christoph Zellweger	lead auditor
EMPA-QA/SAC	Dr. Jörg Klausen	assistant auditor

Previous audits at the GAW station Bukit Kototabang:

- July 1999 by EMPA-WCC for surface ozone.

3. Global GAW Site Bukit Kototabang

3.1. Description of the Site

The global GAW station Bukit Kototabang is located in West Sumatra, Indonesia (0° 12' 07" S – 100° 19' 05" E) (Figure 2). The station is roughly 17 km north of the town Bukittinggi (population: 85'000) and approximately 120 km north of West Sumatra’s capital Padang.

The remote station Bukit Kototabang (which means hill flying town) 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 prevailing wind directions are either south-south-easterly (December to May) or north-north-westerly (May to October). The temperature varies from 16 to 25 °C with only slight annual variation, and the relative humidity is usually above 80%.

The facilities at the site consist of a large one-story building (Figure 3), which provides space for offices, laboratories (Figure 4) and a meeting room. On the 300 m^3 flat roof, the air inlet and several radiation and meteorological equipment are mounted.

The station is reached over a small access road which is closed to the public and is a few kilometres off the main road (moderate traffic) between Padang and Medan.

The vegetation of the surrounding area (30 km) consists mainly of tropical forest. However, as already noticed during the 1999 audit, the small access road to the station enabled deforestation and cultivation of the land by farmers. Within the two years since the last audit, the area has been further developed, and a small warung (restaurant) with wood fire cooking opened recently only in 200 m distance from the station. All these activities compromise the remoteness of the site and are potential pollution sources.

Figure 2: Map of Indonesia with the location of Bukit Kototabang (from http://www.lib.utexas.edu/maps)

Figure 3: Bukit Kototabang Global GAW station

Figure 4: Laboratory at Bukit Kototabang

Ozone- and Carbon Monoxide Levels at Bukit Kototabang

The distribution of the hourly mean values of O_3 from 1998 is shown in Figure 5.

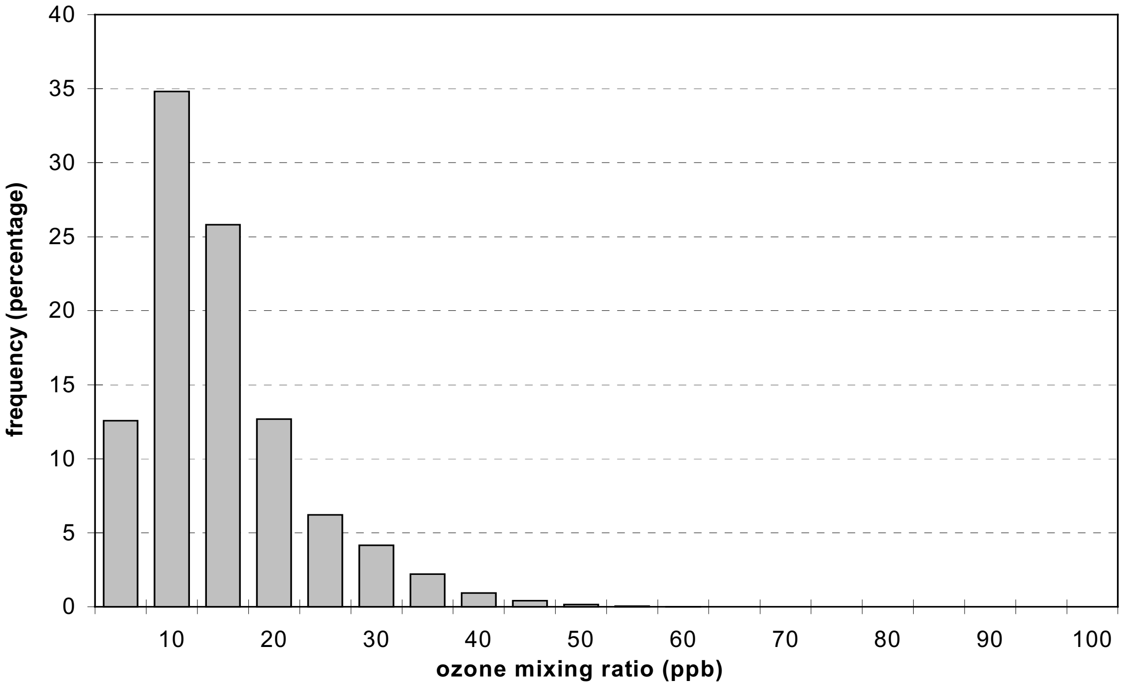

Figure 5: Frequency distribution of the hourly values of the ozone mixing ratio (ppb) at Bukit Kototabang of the year 1998.

Measurements of carbon monoxide started at Bukit Kototabang with the installation of the NDIR CO monitor TEI 48C by EMPA-WCC during this visit. First CO data is presented in section 5.1.5.

3.2. Staff / Operators

The staff responsible for the GAW station Bukit Kototabang is shown in Table 1.

Table 1: GAW Staff Bukit Kototabang (by July 2001)

Name	Position and duty
Mr Hery Harjanto	Meteorological and Geophysical Agency (BMG), Jakarta GAW Country contact
Ms Nurhayati	Head of climatological analysis division of BMG, Jakarta Primary station contact
Mr Budi Suhardi	Station manager, Officer-in-charge, responsible for ozone monitoring
Mr Imam Prawoto	Station operator (black carbon, PAH and automatic weather station)
Mr Nasrullah	Station operator (ozone, SO_2 and NO_x passive sampling)
Mr Herizal	Station operator (solar radiation)
Mr Kaharudin	Station operator (technician)
Mr Agus T. Damar	Station operator (aerosol and PAH) presently not at the station
Mr Charles Siregar	Station operator (carbon monoxide, meteorological parameters)
Mr Darmadi	Station operator (carbon dioxide)
Mr Yasri	Administration

4. System- and Performance Audit of Surface Ozone

Ozone measurements started at Bukit Kototabang in late 1996. Shortly after the last audit by EMPA-WCC in July 1999, the data acquisition and the zero / span interface unit (OMCS) installed by the twinning partner (CSIRO, Australia) failed. The station manager contacted Dr. Mick Meyer from CSIRO and received detailed instructions for diagnosis and repair. In addition CSIRO shipped an alternative data acquisition system (data logger) to Bukit Kototabang, along with spare parts, PFA tubing, and a dehumidifier. However, shortly after that, communication between the Bukit Kototabang station and CSIRO stopped. The problems remained unsolved, and no ozone data were acquired since August 1999.

During the audit EMPA re-installed the drivers for the OMCS and checked the whole system, but the OMCS could not be repaired. As a consequence a new data acquisition based on the data logger was installed. Furthermore, as recommended by the previous audit, the location of the air inlet was moved and the tubing was replaced and shortened. The dehumidifier shipped by CSIRO was installed to avoid condensation of water vapour inside the instruments. Details of the new set-up are described below.

Recommendations concerning ozone measurements are summarised in section 4.3. General, parameter independent recommendations can be found in section 6.

4.1. Monitoring Set-up and Procedures

4.1.1. Air Inlet System

Sampling-location:

on the north-western edge of the flat roof of the one-story building, approx. 7.5 m above ground, opposite the tower.

Sample inlet:

Rain protection:	The Inlet is protected against rain by a small, upside-down teflon bucket.
Dehumidifier:	Engel Portable Refrigerator with 1 liter glass bottle
Inlet-filter:	Teflon inlet filter up-stream of dehumidifier, exchange interval 2 weeks.

Sampling-line:

Dimensions:	inlet to dehumidifier:	length = ca. 10 m, inner diameter = 4 mm
	dehumidifier to TEI 49C:	length = 1.5 m, inner diameter = 4 mm
Material:	inlet: PFA	
	dehumidifier: glass	
Flow rate:	2 ℓ/min	

Residence time in the sampling line: ca. 35 s

Comment

The inlet was moved to the north-western edge of the flat roof and the tubing was completely replaced during the audit. This shortened the PFA tubing by approx. 15 m. Additionally, the dehumidifier shipped by CSIRO was installed by EMPA-WCC. The residence time of air between the intake and the analyser is rather long, mainly because of the large volume of the dehumidifier. The potential for ozone loss was previously tested by CSIRO, but also our own preliminary tests suggest non-detectable losses. However, it is important to keep the dehumidifier clean to avoid potential ozone losses.

Even though the new inlet location is somewhat closer to the slightly taller roof and the 30 m tower, air masses are not expected to be influenced by either construction.

4.1.2. Instrumentation

The monitoring system at the global GAW station Bukit Kototabang consists of an ozone analyser and an ozone calibrator as detailed in Table 2. Both instruments are installed in an environmentally controlled room with an average temperature of approx. 20°C. The instruments are not exposed to direct sunlight.

The zero air unit of the calibrator consists of the following:
pre-dehumidified air (Engel refrigerator) - pump – rubin gel - activated charcoal – filter

Table 2: Ozone instruments at Bukit Kototabang

	ozone instrument	station ozone calibrator
type	TEI 49 #51974-290	TEI 49PS #52307-291
method	UV absorption	UV absorption
at Bukit Kototabang	since September 1996	since September 1996
range	0-1000 ppb	0-1000 ppb
settings	prior to audit : Span: 500; Offset: 50 after audit: Span: 536; Offset: 47	Gain: 0; Ozone level: 000
analog output	0-10 V	0-10 V
digital output	GPIB/IEEE connection (not used with new set-up)	GPIB/IEEE connection (not used with new set-up)

Comment

The ozone measurement system installed by CSIRO which frequently logged auxiliary parameters (i.e. zero point and span values, multi-point calibration values, status and pressure) was not working at the beginning of the audit and could not be repaired by EMPA-WCC. We therefore re-designed the whole system, and it runs now in a completely manual mode using the analog output of the instruments. The advantage of the new set-up is its simplicity. However, all operations (zero and span checks) have to be done manually. They were included in the revised check lists (weekly instrument checks, 3-monthly calibrations).

Operation and Maintenance

Operation and maintenance were identified as points where significant improvements could be made at the GAW station Bukit Kototabang. The measures taken by the station operators since the failure of the data acquisition / OMCS unit in August 1999 were not sufficient to solve the problem. The ozone analyser was still running, but no data was acquired, and the weekly check lists were not filled in. The inlet filter has not been changed. The problems were intensively discussed with the station manager and operators, and recommendations of EMPA-WCC are summarised in section 4.3 (for ozone measurements) and in section 6 (general, parameter independent recommendations).

The station manager and operators were aware of the problems and agreed with the maintenance schedule for the new instrument set-up as described below.

- On a regular working day, the person in charge inspects the instruments for general operation.
- Station specific check lists (Appendix 2) have to be filled in weekly for the ozone analyser. They include inlet filter exchange, dehumidifier maintenance, basic instrument checks as well as download and save of the ozone data. It was agreed with the station manager that he regularly informs EMPA-WCC about the instrument status.
- Every three months, the station analyser should be inter-compared with the station calibrator. For this purpose, a specific check list / SOP was developed (Appendix 2).
- Every six months the inlet line should be checked for ozone losses. The cells of the analyser should also be checked and cleaned if necessary.

4.1.3. Data Handling

Data Acquisition and –transfer

The data acquisition is now based on the data logger DT50 and the software DeTerminal (both Data Electronics Inc., Australia). The DT50 is operated as a data logger in overflow mode with a stack size of 13650 data points. Communication between the DT50 and the HP 486 PC is provided through COM1: (RS232, serial port, 4800 baud). The analog output of both the TEI49 analyser and the TEI49PS calibrator are connected to the unit as single-ended voltage inputs. The data logger is configured to sample at the maximum possible sampling rate. During normal operation (=monitoring of ambient surface ozone concentration), 10 minute averages are recorded and stored in the data logger's internal memory. During inter-comparison of TEI49 and TEI49PS, 1 minute averages are recorded. In both cases, standard deviation, and minimum and maximum values are stored as well. The data logger is controlled by the terminal emulation software DeTerminal using macros. Data can be output as comma-separated text with a simple header. The PC needs only be turned on to download data and to change between normal and inter-comparison mode.

Data Treatment

Data should be checked weekly for plausibility after downloading from the data logger. This should be done by visual check of time series and by comparison with the station log book. It was also agreed with the station manager that data and checklists should be submitted to EMPA-WCC.

Data Submission

At present surface ozone data is not reported to the database of the GAW World Data Centre for Surface Ozone (WDCSO) at NILU.

4.1.4. Documentation

The Station was supplied by the twinning partner CSIRO with all the distribution disks for the operating system, drivers and application programs and all instrumentation manuals including those for the PC cards. Also as part of the two training programs the station was supplied with a comprehensive set of references.
It was noted during the audit that part of the documentation (drivers, programs, PC card manuals) was not available at the site. During the audit period, it was not possible to find the documents and programs.
Since the failure of the data acquisition, only insufficient documentation was made by the station operators concerning the ozone measurements. The break-down of the system on August 2, 1999 was not well documented.
It was agreed with the station manager that the audit should be a new start. Specific checklists and SOPs were developed by EMPA-WCC and QA-SAC in collaboration with the station operators.

Logbooks

New checklists are available for the ozone instruments. They should be filled in weekly (analyser) and 3-monthly (calibrator) along with additional information concerning instrument operation and maintenance.

Standard Operating Procedures (SOPs)

The manuals for the ozone instruments are available. A SOP for the new data acquisition was written by EMPA-QA/SAC and is available at the site. Furthermore, a SOP for the manual inter-comparison of the station analyser with the calibrator was written by EMPA-WCC and is available at the site.

Comment

It was agreed with the station operators that the whole documentation needs to be significantly improved from now on.

4.2. Inter-comparison of Ozone Instruments

4.2.1 Experimental Set-up

The WCC transfer standard TEI 49C PS (details see Appendix I-III) was operated in stand-by mode for warming up for 46 hours (inter-comparison with analyser) and 20 hours (inter-comparison with calibrator). During this stabilisation time the transfer standard and the PFA tubing connections to the instruments were conditioned with 500 ppb ozone for 150 minutes. Afterwards, three comparison runs between the field instruments and the WCC transfer standard were performed. Table 3 shows the experimental details and Figure 6 the experimental set up during the audit.

The audit procedure included a direct inter-comparison of the TEI 49C-PS WCC transfer standard with the Standard Reference Photometer SRP#15 (NIST UV photometer) before and after the audit in the calibration laboratory at EMPA. The results are shown in Appendix 1.

Table 3: Experimental details of the ozone inter-comparison

reference	EMPA: TEI 49C-PS #54509-300 transfer standard
field instruments	TEI 49 #51974-290 (analyser) TEI 49PS #52307-291 (calibrator)
ozone source	WCC: TEI 49C-PS, internal generator
zero air supply	EMPA: silica gel - inlet filter 5 µm - metal bellow pump - Purafil (potassium permanganate) - activated charcoal - outlet filter 5 µm
data acquisition system	16-channel ADC circuit board with acquisition software (Hunter & Caprez)
pressure transducer readings	TEI 49C-PS (WCC): 917.9 hPa TEI 49 #51974-290: 917 hPa TEI 49PS #52307-291: 917 hPa
concentration rang	0 - 100 ppb
number of concentrations	5 + zero air at start and end
approx. concentration levels	10 / 20 / 30 / 50 / 80 ppb
sequence of concentration	random
averaging interval per concentration	5 minutes
number of runs	3 x on July. 18, 2001 (calibrator) 3 x on July. 25, 2001 (analyser)
connection between instruments	about 1.5 meter of 1/4" PFA tubing

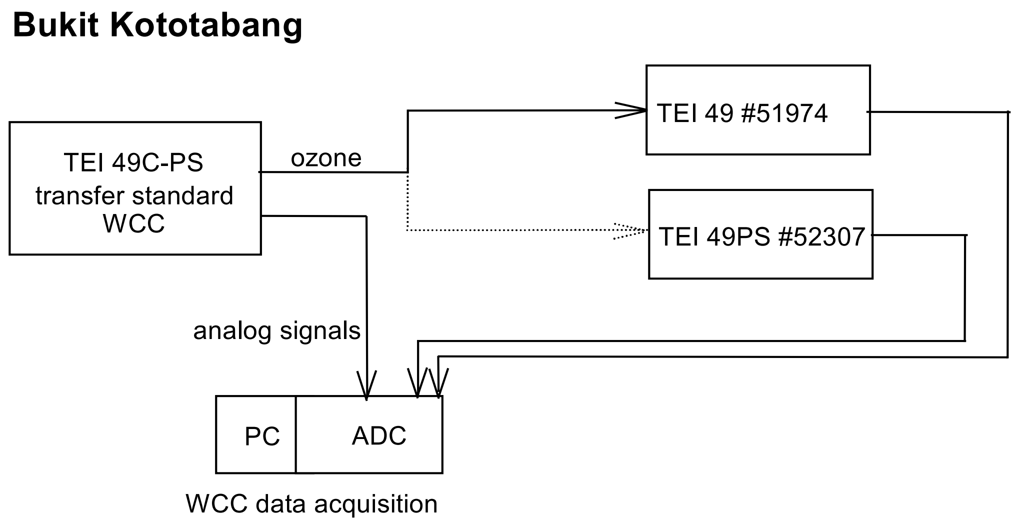

Figure 6: Experimental set up for the ozone inter-comparison at Bukit Kototabang 2001

4.2.2. Results

Ozone Analyser

The results comprise the inter-comparison between the TEI 49 field instrument and the WCC transfer standard TEI 49C-PS, carried out on July 25, 2001.

The resulting mean values of each ozone concentration and the standard deviations (s_d) of ten 30-second-means are presented in Table 4. For each mean value the differences between the tested instrument and the transfer standard are calculated in ppb and in %.

Examination of the residuals for each concentration as shown in Figure 7 revealed no systematic time-dependence, indicating that all runs can be treated as a single data set. Residuals as a function of ozone concentration delivered by the WCC transfer standard are shown in Figure 8. Figure 9 shows the linear regression together with the assessment criteria for GAW field instruments.

Table 4: Inter-comparison of the ozone field instrument

run index	WCC TEI 49C-PS conc.	WCC TEI 49C-PS s_d	TEI 49 #51974-290 conc.	TEI 49 #51974-290 s_d	deviation from reference	
	ppb	ppb	ppb	ppb	ppb	%
1	-0.1	0.1	0.4	0.3	0.6	
2	30.2	0.1	30.1	0.4	-0.1	-0.4%
3	10.2	0.1	10.1	0.8	-0.1	-1.1%
4	50.2	0.1	50.2	0.9	0.1	0.1%
5	20.1	0.1	20.4	0.9	0.3	1.4%
6	80.2	0.1	79.9	0.8	-0.3	-0.4%
7	-0.1	0.1	0.0	0.6	0.2	
8	-0.2	0.1	0.2	1.1	0.4	
9	80.2	0.1	80.2	1.3	0.1	0.1%
10	20.2	0.1	20.0	1.2	-0.2	-1.0%
11	10.2	0.1	10.4	0.8	0.2	2.1%
12	50.2	0.1	50.2	0.7	0.0	-0.1%
13	30.2	0.1	30.2	1.1	0.1	0.2%
14	-0.1	0.1	0.9	0.9	1.0	
15	-0.1	0.1	-0.1	0.8	0.0	
16	10.2	0.1	10.1	1.0	-0.1	-0.7%
17	30.1	0.1	30.2	1.0	0.0	0.0%
18	20.1	0.1	20.5	1.0	0.3	1.7%
19	80.2	0.1	80.2	0.9	0.0	0.0%
20	50.2	0.1	50.0	0.8	-0.2	-0.4%
21	-0.2	0.2	0.2	0.7	0.4	

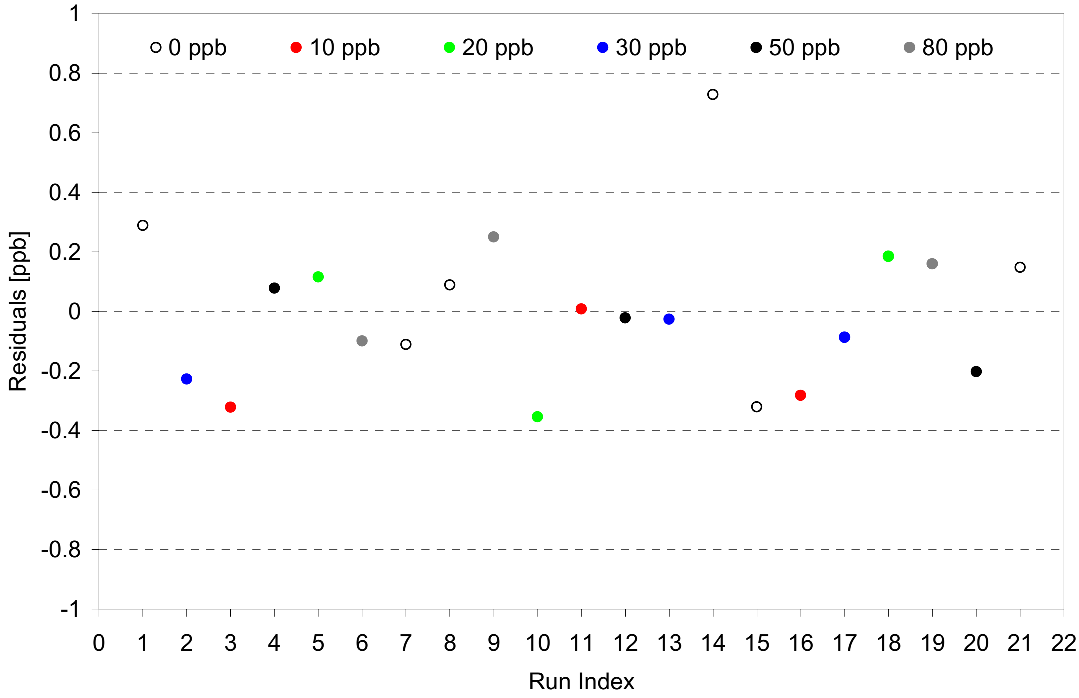

Figure 7: Residuals of the linear regression function (TEI 49 #51974-290) vs the run index (time dependence)

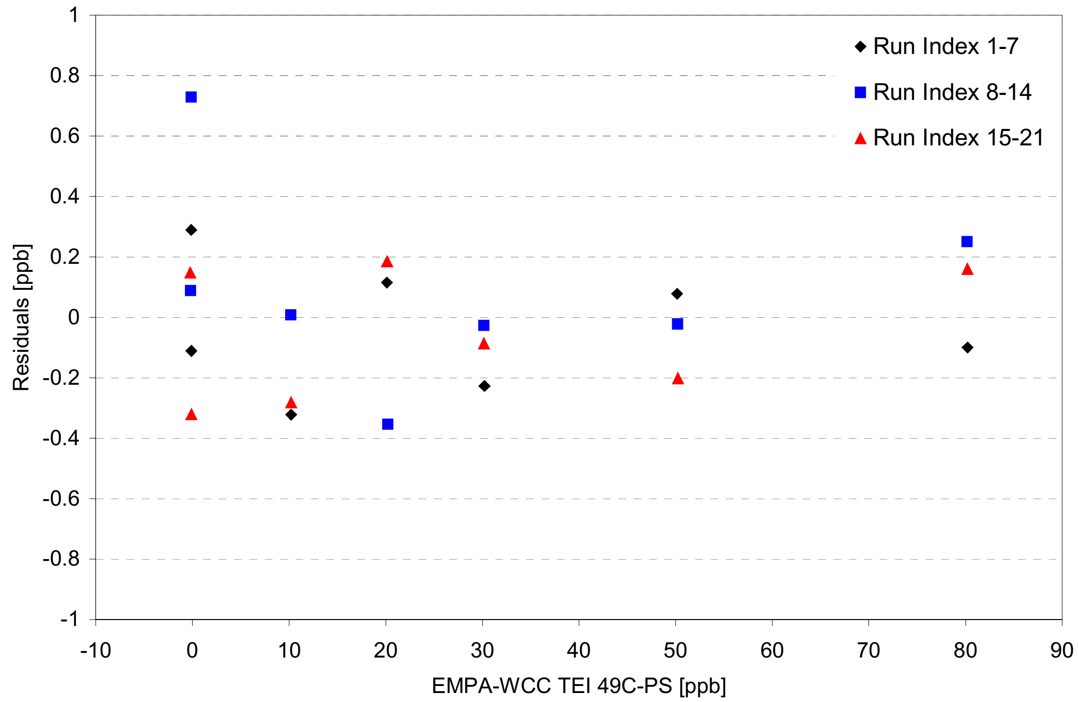

Figure 8: Residuals of the linear regression function (TEI 49 #51974-290) vs the concentration of the WCC transfer standard (concentration dependence)

The inter-comparisons of the TEI 49 field instrument with the TEI 49C-PS transfer standard from EMPA for the range of 0-100 ppb ozone can be summarised by the linear relationship:

TEI 49C #51974-290:

$$\text{TEI 49} = 0.994 \times \text{TEI 49C-PS} + 0.3 \text{ ppb}$$

TEI 49 = O_3 mixing ratio in ppb, determined with TEI 49C #51974-290

TEI 49C-PS = O_3 mixing ratio in ppb, determined with TEI 49C-PS #54509-300

Standard deviation of:	- slope s_m	0.002	(f = 19) f = degree of freedom
	- offset S_b in ppb	0.08	(f = 19)
	- residuals in ppb	0.23	(n = 21)

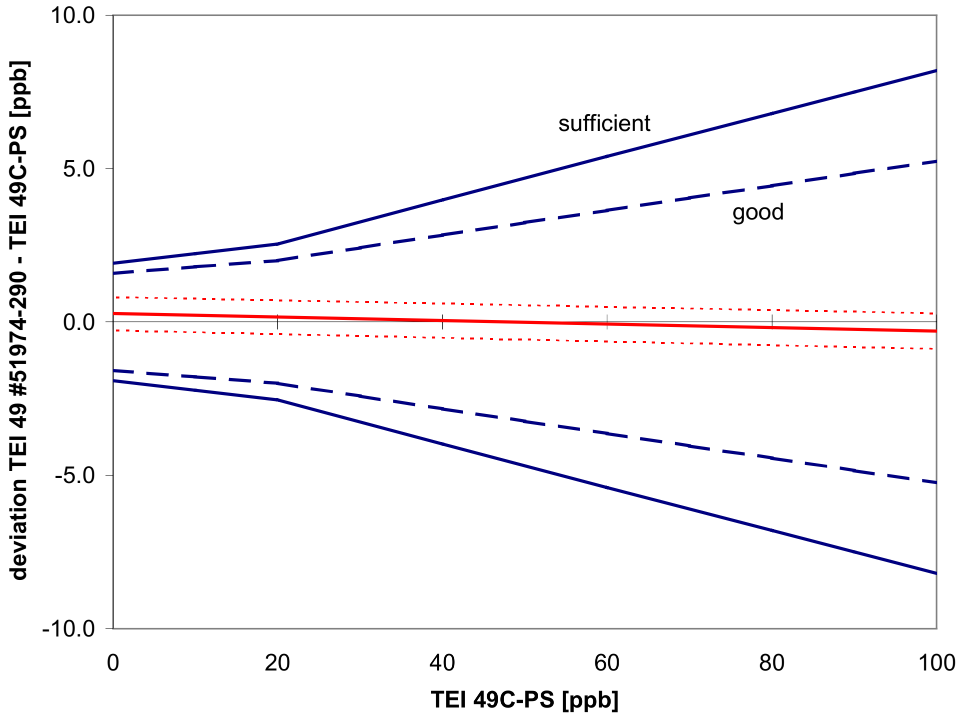

Figure 9: Inter-comparison of instrument TEI 49 #51974-290

Ozone Calibrator

In addition to the ozone analyser, an inter-comparison of the station ozone calibrator TEI 49 PS with the WCC transfer standard was made. Experimental details are also summarised in Table 3.

The resulting mean values of each ozone concentration and the standard deviations (s_d) of ten 30-second-means are presented in Table 5. For each mean value the differences between the tested instrument and the transfer standard are calculated in ppb and in %.

Figures 10 and 11 show the residuals of the linear regression analysis of the field instrument compared to the EMPA transfer standard. The residuals versus the run index are shown in Figure 10 (time dependence), and the residuals versus the concentration of the WCC transfer standard are shown in Figure 11 (concentration dependence). The summary result is presented in Figure 12 with the assessment criteria for GAW field instruments.

Table 5: Inter-comparison of the ozone calibrator TEI 49 PS

	WCC TEI 49C-PS		TEI 49 PS #52307-291			
run index	conc.	s_d	conc.	s_d	deviation from reference	
	ppb	ppb	ppb	ppb	ppb	%
1	-0.4	0.1	0.0	0.3	0.4	
2	80.1	0.1	78.1	0.4	-2.1	-2.6%
3	50.1	0.1	48.9	0.3	-1.2	-2.4%
4	30.1	0.0	29.1	0.2	-1.0	-3.4%
5	10.1	0.1	9.5	0.3	-0.6	-6.0%
6	19.9	0.2	18.9	0.3	-1.0	-5.0%
7	-0.4	0.1	0.2	0.3	0.6	
8	-0.3	0.1	0.1	0.4	0.4	
9	30.1	0.1	29.2	0.1	-0.9	-2.9%
10	10.0	0.1	9.6	0.3	-0.4	-4.0%
11	50.1	0.1	49.0	0.3	-1.1	-2.1%
12	80.1	0.1	78.1	0.5	-2.1	-2.6%
13	20.1	0.1	19.2	0.4	-1.0	-4.8%
14	-0.4	0.0	-0.2	0.3	0.2	
15	-0.4	0.1	0.0	0.4	0.4	
16	30.0	0.4	29.2	0.3	-0.8	-2.7%
17	9.8	0.2	9.4	0.5	-0.4	-4.1%
18	19.9	0.1	19.0	0.2	-0.8	-4.2%
19	80.0	0.1	78.0	0.3	-2.1	-2.6%
20	50.1	0.0	49.0	0.3	-1.1	-2.2%
21	-0.3	0.1	0.1	0.3	0.4	

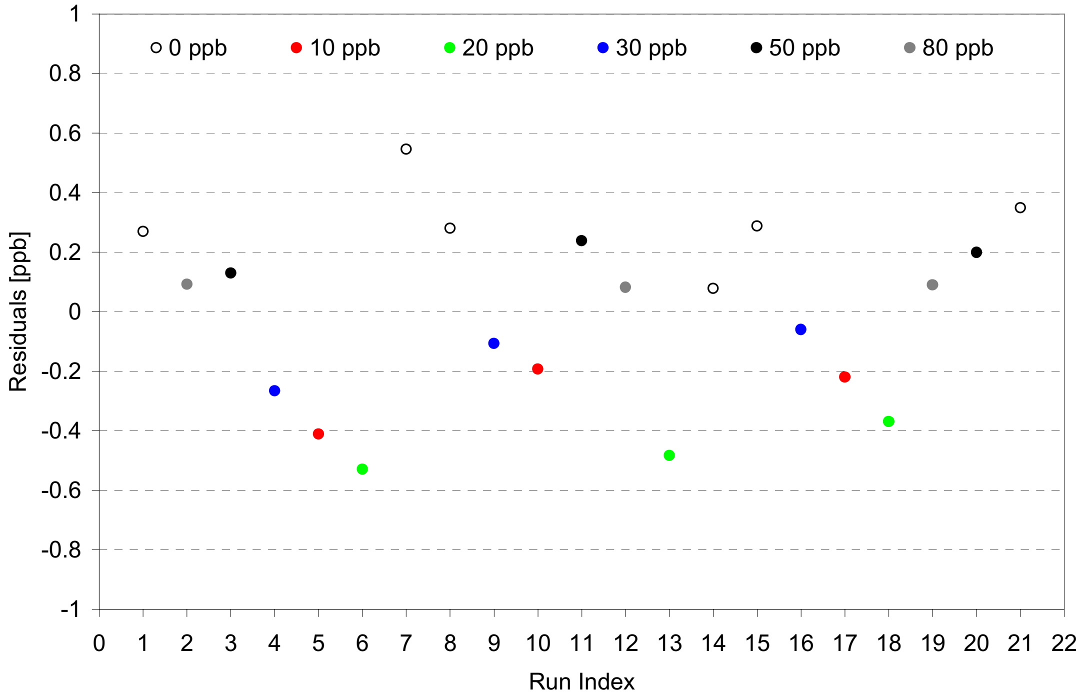

Figure 10: Residuals of the linear regression function (TEI 49PS #52307-291) vs the run index (time dependence)

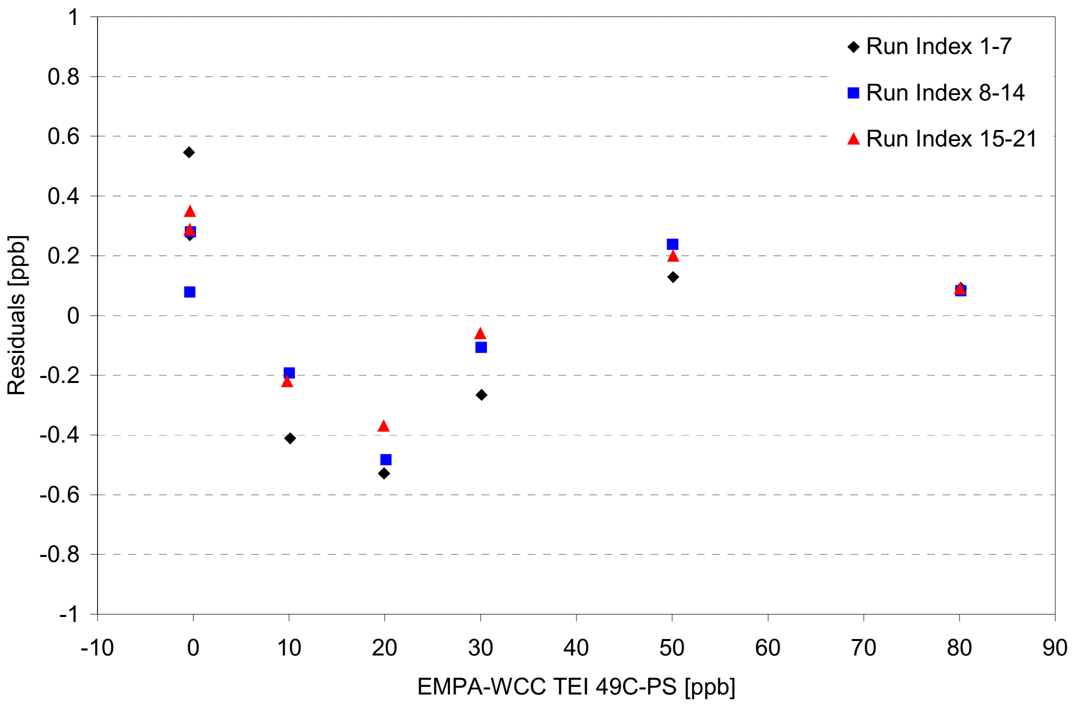

Figure 11: Residuals of the linear regression function (TEI 49PS #52307-291) vs the concentration of the WCC transfer standard (concentration dependence)

The inter-comparisons of the TEI 49PS field calibrator with the TEI 49C-PS transfer standard from EMPA-WCC for the range of 0-100 ppb ozone can be summarised by the linear relationship:

TEI 49PS #52307-291:

$$\text{TEI 49PS} = 0.972 \times \text{TEI 49C-PS} + 0.1 \text{ ppb}$$

TEI 49PS = O_3 mixing ratio in ppb, determined with TEI 49PS #52307-291

TEI 49C-PS = O_3 mixing ratio in ppb, determined with TEI 49C-PS #54509-300

Standard deviation of:	- slope s_m	0.002	(f = 19) f = degree of freedom
	- offset S_b in ppb	0.09	(f = 19)
	- residuals in ppb	0.21	(n = 21)

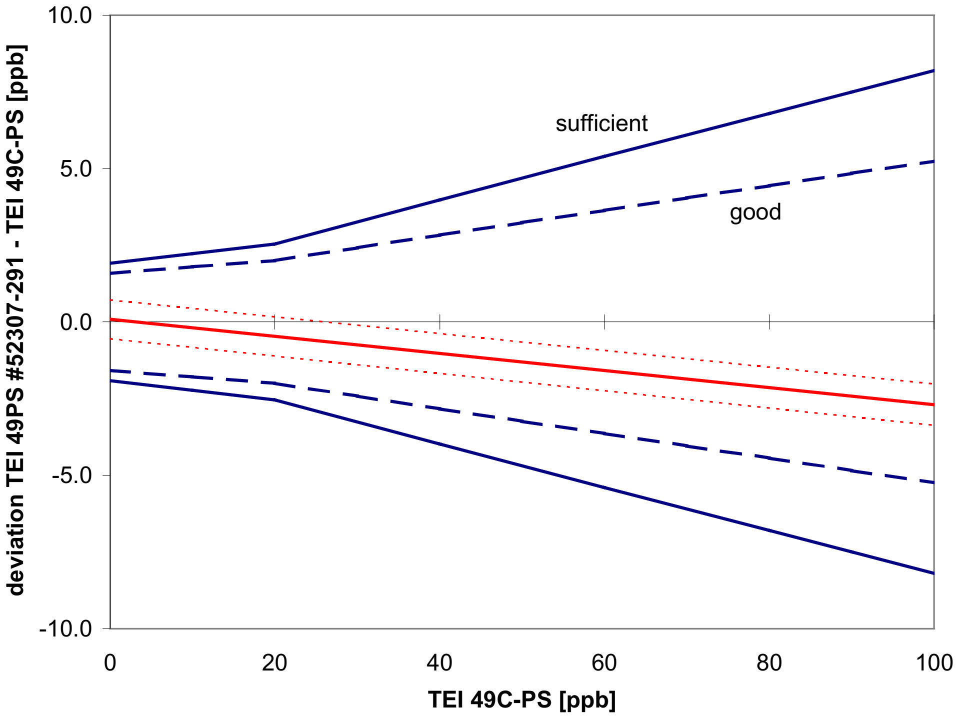

Figure 12: Inter-comparison of instrument TEI 49PS #52307-291

Comment

The ozone concentrations observed at Bukit Kototabang (1998) ranged between 3 and 28 ppb (5 and 95 percentile of hourly mean values), defining the station's relevant concentration range. Both instruments (ozone analyser and calibrator) clearly fulfilled the assessment criteria as "good" over the tested range up to 100 ppb. The calibration factors of the analyser were changed by EMPA-WCC (Span: old 500, new: 536, Offset: old 50, new 47) for an optimal result. The inter-comparison of the station calibrator confirmed the result of the previous audit in 1999.

4.3. Recommendations for Ozone Measurements

The following recommendations are made by EMPA-WCC concerning the ozone measurements. Please refer also to section 6 for general recommendations suggested by EMPA-WCC.

- All actions concerning ozone measurements should be carefully documented in a log book. If malfunction of an instrument is detected and the problem persists and can not be solved within reasonable time, contact EMPA-WCC or CSIRO Aspendale for assistance.
- The weekly checklists should be filled in by the responsible person for the ozone measurements. It was also agreed that checklist and data should be submitted to EMPA-WCC.
- Documentation should be inventoried, and all relevant information should be available at the station (log books, manuals etc.).
- Data should be checked weekly for plausibility using time series plots.
- Regular back-ups of the measurement data are strongly encouraged.
- The inter-comparisons with the station calibrator have to be performed manually with the new instrument set-up. A 3-monthly interval for inter-comparisons is suggested by EMPA-WCC.
- The dehumidifier should be carefully checked for ozone losses. It is important that the dehumidifier and the inlet line is kept clean. The use of a 500 ml flask (instead of 1 L) should be considered to reduce the residence time in the inlet system.
- The UPS used for the ozone instrument was not functional, leading to cold-starts of the TEI49 and the PC several times each day. The batteries read >13 V. Either the UPS is too slow or seriously damaged. The unit should be serviced.
- Submission of the data to the GAW World Data Centre for Surface Ozone (WDCSO) at NILU is recommended. QA/SAC Switzerland is ready to offer assistance as needed.

5. Carbon Monoxide Measurements at Bukit Kototabang

As part of the WMO/GEF program No. 340-99 (GLO/91/G32) 1115-99 and a proposal by EMPA-WCC to WMO from November 15, 1999, a measurement system for carbon monoxide was installed by EMPA-WCC during the audit. The installation of the system was carried out in close collaboration with the station staff and included an intensive training on the new instrument. The instrument set-up is described below.

5.1. Monitoring Set-up and Procedures

5.1.1. Air Inlet System

Sampling-location:

on the north-western edge of the flat roof of the one-story building, approx. 7.5 m above ground, about 3 m above the roof and 20 away from the tower.

Sample inlet:

Rain protection:	The Inlet is protected against rain by a small, inverse funnel.
Dehumidifier:	Komatsu Thermo-electric Dehumidifier DH-109
Inlet-filter:	Teflon inlet filter dehumidifier, exchange interval 2 weeks.

Sampling-line:

Dimensions:	inlet to dehumidifier:	length = 10 m,	inner diameter = 4 mm
	dehumidifier to TEI 48C:	length = 2 m,	inner diameter = 4 mm
Material:	inlet: PFA		
	dehumidifier: PFTE, PVC, PE		
Flow rate:	1 ℓ/min		

Residence time in the sampling line: ca. 10 s

Comment

Air masses are not considered to be influenced by the slightly taller traditional roof construction and the 30 m tower.

5.1.2. Instrumentation

CO Instrument

The CO monitoring system at the global GAW station Bukit Kototabang consists of a commercially available NDIR CO monitor, that was modified with a drying system to remove all water vapor in the sample air. The monitor is installed in an environmentally controlled room with an average temperature of approx. 20°C. Details of the instrument are shown in Table 6.

The following tests were performed at the EMPA-WCC laboratory before installation:

- loss of CO in the drying system (both thermoelectric dehumidifier and nafion drier)
- Zero drift
- Multipoint calibration and linearity check for the range 0 to 1500 ppb CO
- Interference of humidity with and without drying system
- Intercomparison measurements with different measurement technique (AL5001, UV Fluorescence)

The results of the above tests showed that the instrumentation and the setup is suitable for carbon monoxide measurements at remote sites.

Table 6: CO Instrument at Bukit Kototabang

	CO Instrument
type	TEI 48C Trace Level #66839-352
method	NDIR, Gas Filter Correlation Technique
modification	nafion drier PERMAPURE PD-50-24'' reflux mode using critical orifice and pump of instrument
at Bukit Kototabang	since July 2001, installed by EMPA-WCC
range	0-1000 ppb
settings	CO COEFF: 1.042; BKG: frequent calibrations
analog output	0-10 V (not used)
serial output	RS 232

Calibration Equipment

The calibration equipment used for zero / span checks and calibrations is listed in Table 7.

Table 7: CO calibration equipment at Bukit Kototabang

Standard gas for direct calibrations	1015 ppb CO ± 2%, SL76529 (CO 99.997% in synth. air 99.9995%) traced back to CMDL scale with AL5001 by EMPA-WCC
Standard gas for calibrations with dilution	15000 ppb CO ± 2%, SL76527 (CO 99.997% in synth. air 99.9995%) traced back to CMDL scale with AL5001 by EMPA-WCC
Zero air unit (for dilution)	Custom made by EMPA-WCC Inlet Filter – Pump – Rubin Gel – Sofnocat 423 – Outlet Filter
Dilution unit	MFC Bronkhorst HI-TEC S/N M1202324A 0 – 100 ml/min MFC Bronkhorst HI-TEC S/N M1202324B 0 – 5000 ml/min Bronkhorst Control Unit S/N M1202324C

A schematic overview of the instrumental set-up is shown in Figure 13, and a picture of the installation at Bukit Kototabang is shown in Figure 14.

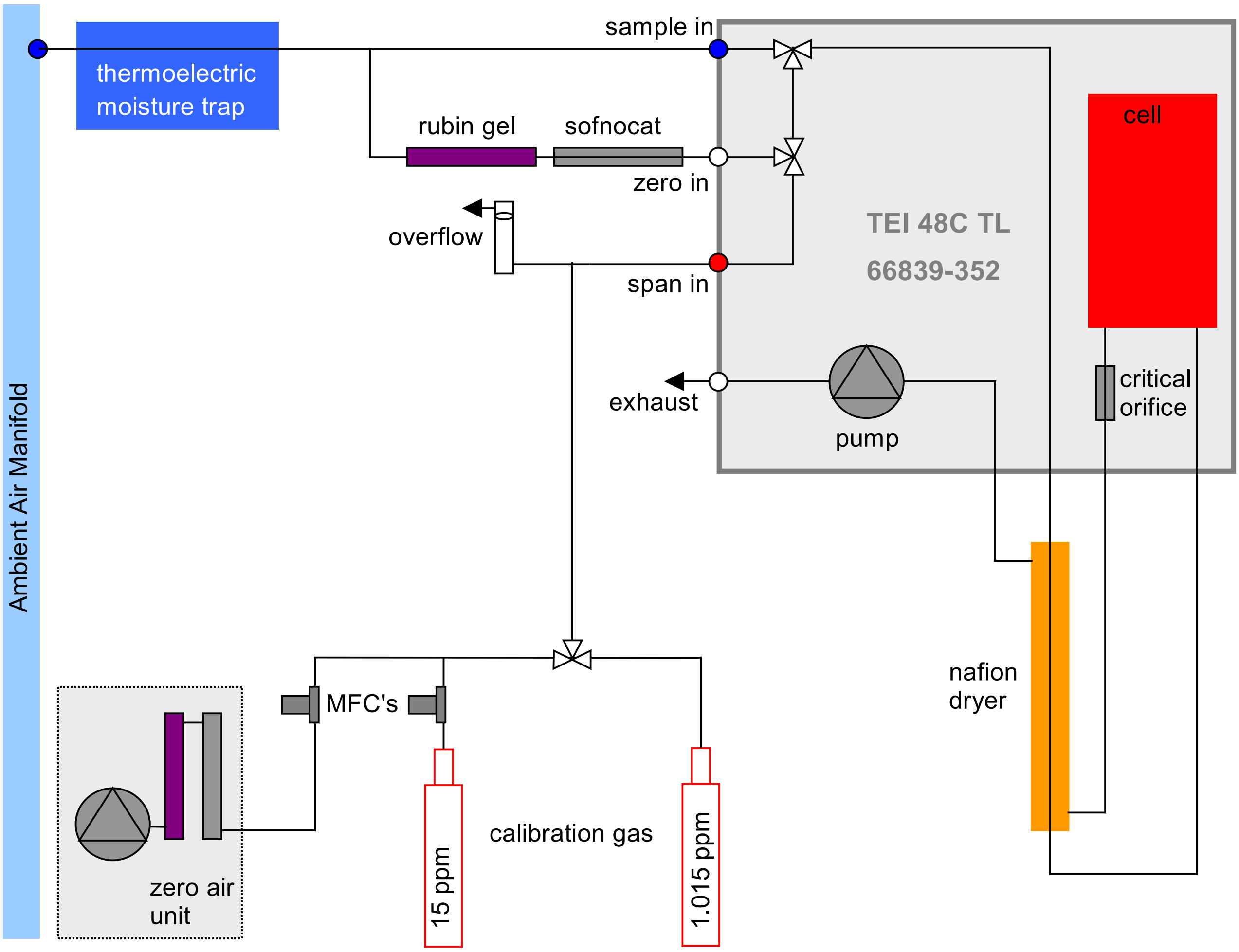

Figure 13: Instrument set-up (carbon monoxide) at Bukit Kototabang

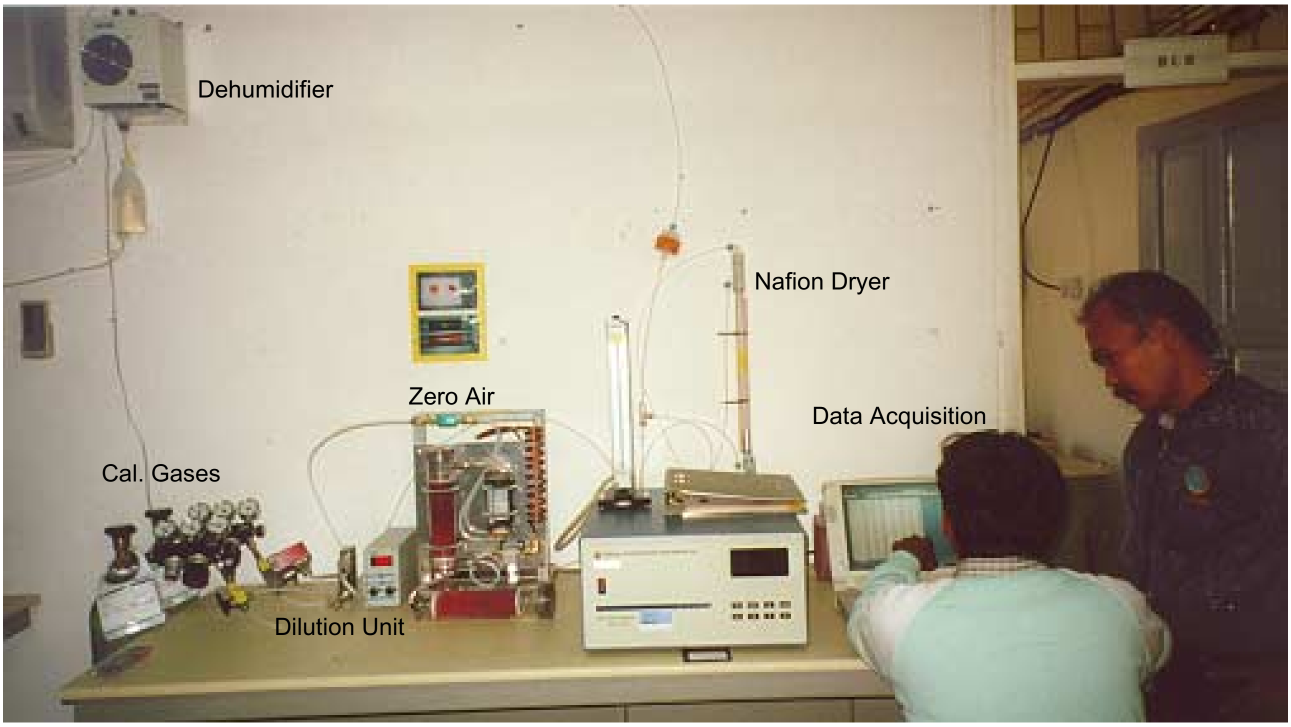

Figure 14: CO Instrumentation at Bukit Kototabang

Operation and Maintenance

The following operation and maintenance schedule has been agreed upon for the CO measurements at Bukit Kototabang:

- On a regular working day, the person in charge inspects the instruments for general operation.
- A station specific check list (Appendix 2) has to be filled in every 3 to 5 days for the CO analyser. It includes inlet filter exchange (every ~14 days), dehumidifier maintenance, basic instrument checks as well as download and save of the CO data. It was agreed with the station manager that he regularly informs EMPA-WCC about the instrument status. Data files should be submitted to EMPA-WCC.
- A full instrument calibration using the 1 ppm CO standard is performed every three months. For this purpose, a specific check list / SOP is available (Appendix 2).

Automatic zero checks are performed every 2 hours (at 1, 3, 5, 7, 9, and 11 am/pm). This data is used for data processing (correction of zero drift).

5.1.3. Data Handling

Data Acquisition and –transfer

Data Acquisition is made with the C series communication software (version 2.2.0) from Thermo Environmental Instruments. The data (5 minute average values) is stored every 3 to 5 days on a notebook, and the data transfer is done by floppy disc.

Data Treatment

Data treatment is performed after downloading and includes:
- correction of zero drift with the zero values of the automatic zero check
- time series plot, plausibility checks
- data check with station logbook

Data Submission

CO measurements became operational during the audit of EMPA-WCC. Data submission to the GAW World Data centre for Greenhouse Gases at JMA should start as soon as the system is fully operational and a longer data set is available.

5.1.4. Documentation

The Station was supplied by EMPA-WCC with all instrumentation manuals (TEI 48C, Dehumidifier DH-109) including TEI data acquisition programme Version 2.2.0 on floppy disk. A log book including information on instrument operation and maintenance is available at the site.

5.1.5. CO data from Bukit Kototabang

Figure 15 shows first CO measurements with the newly installed instrument starting at July 24, 2001 and ending on August 15, 2001. The measurements are ongoing. A frequency distribution of CO for the above mentioned period is shown in Figure 16. The CO concentrations measured at Bukit Kototabang ranged between 77 and 262 ppb according to the 5- and 95% percentile.

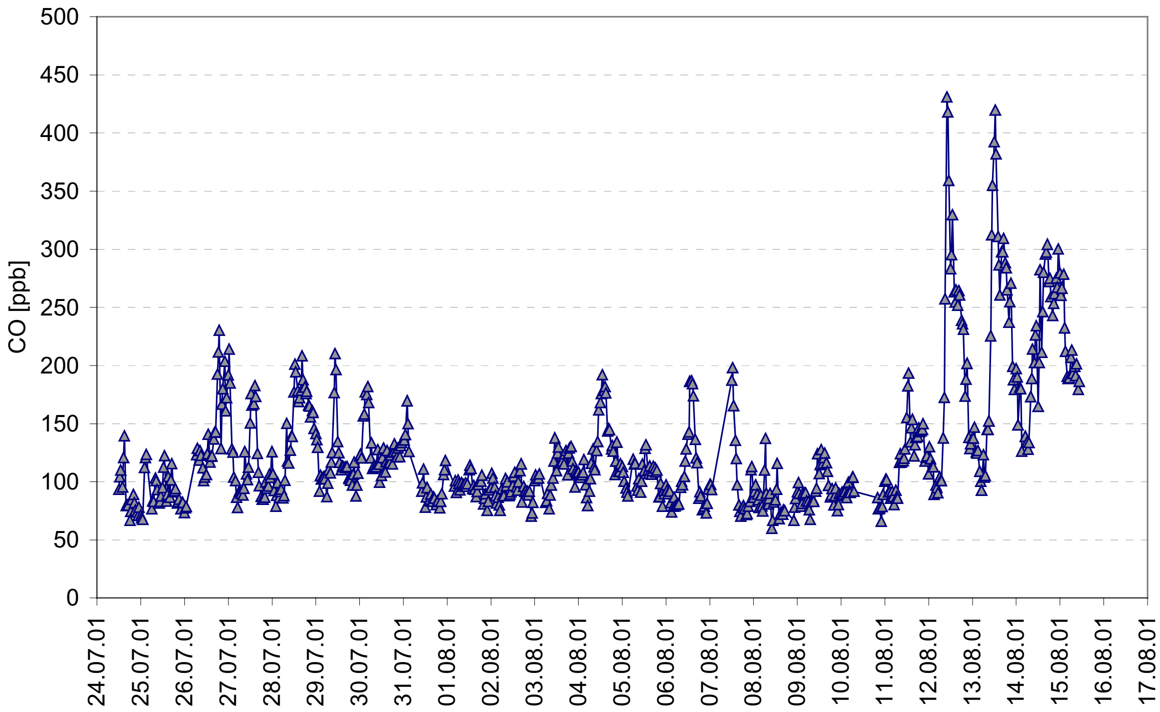

Figure 15: 30-min averages of carbon monoxide measured at Bukit Kototabang.

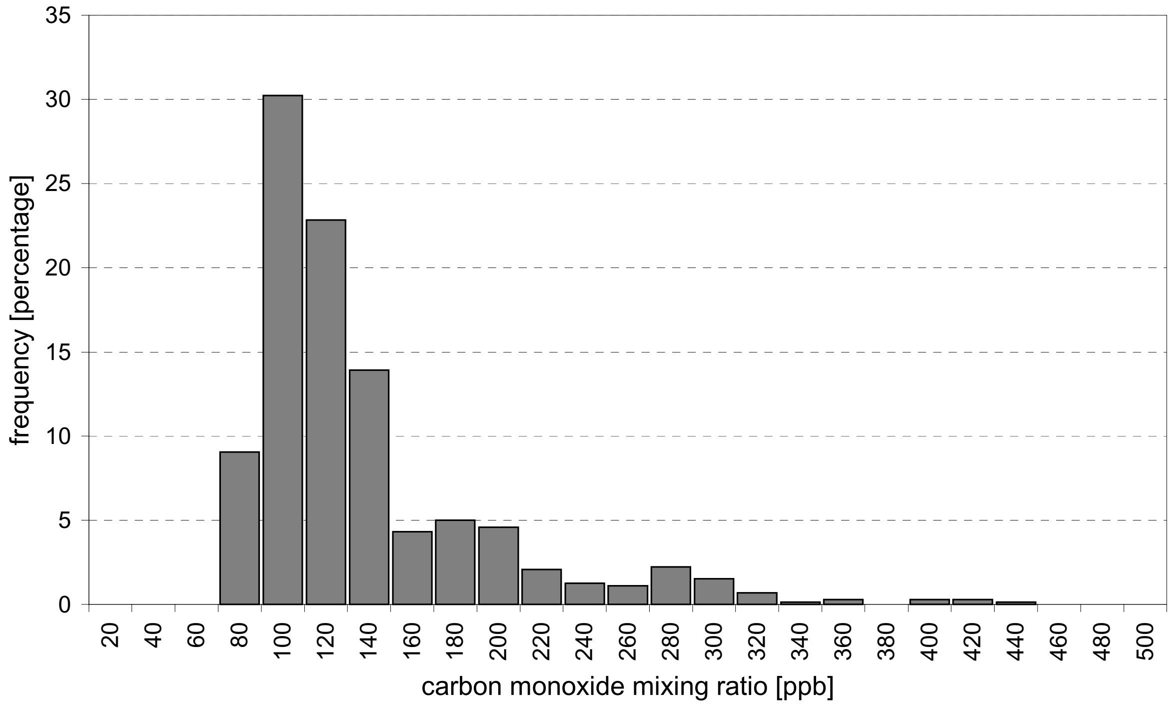

Figure 16: Frequency distribution of the half-hourly mean CO mixing ratio (24.7.-15.8.01) at Bukit Kototabang. Availability of data: 68%.

5.2. Recommendations for Carbon Monoxide Measurements

The following recommendations are made by EMPA-WCC concerning carbon monoxide measurements.

- All actions concerning CO measurements should be carefully documented in the log book. If malfunction of the instrument is noticed and the problem persists, contact EMPA-WCC for assistance.
- The checklists should be filled in by the responsible person for the CO measurements. It was also agreed that checklist and data should be submitted to EMPA-WCC.
- Data should be checked weekly for plausibility with time series plots.
- Regular back-ups of the CO data are strongly encouraged.
- Purchase of a UPS to avoid frequent cold-starts of the instrument is encouraged.
- Submission of the data to the GAW World Data Centre for Greenhouse Gases (WDCGG) at JMA is recommended as soon as more data become available.

6. General Recommendations

The following recommendations are made to ensure the long-term operation of the GAW station Bukit Kototabang. The reason for part of these recommendations is the problem that occurred with the ozone measurements since the last audit of EMPA-WCC in July 1999. Refer to section 4 for details.

- Persistent problems with any of the measurements at Bukit Kototabang should be communicated to external partners and WMO. Communication should be re-established where necessary and maintained to ensure continuing support of external partners. E-mail and internet access should be re-established for all persons involved in the GAW activities at Bukit Kototabang.
- It is recommended to nominate second persons for each parameter with the same background as the primary responsible person to ensure long-term continuity of technical knowledge. It is suggested that the responsible operator trains at least two persons with respect to regular operation and maintenance of a measurement parameter / method.
- A budget, for example in accordance to the GAW measurement guide, should be available for the long-term operation and maintenance of the station. Part of the budget should be at the immediate disposal of the station manager.
- Land use in the vicinity of the station should be closely watched. Anthropogenic activities should be limited wherever possible.

7. Conclusions

The global GAW station Bukit Kototabang opened in 1995. Since then, ozone data became available but time series stopped in August 1999 due to technical problems. It was possible to solve the problems during the visit of EMPA-WCC, and ozone measurements should continue beginning with July 2001. In addition, instrumentation for continuous carbon monoxide measurements was implemented during the audit by EMPA-WCC.

The geographical position of the Bukit Kototabang station within the GAW programme is regarded as important, since ground based measurements of air pollutants from equatorial regions are very limited. Furthermore, the station offers excellent infrastructure concerning accessibility and laboratory facilities. To take advantage of this, national and international co-operation for both technical and scientific staff (workshops, exchange programs, scientific partnerships) is regarded as important.

The station will require regular training for some years to come. All possibilities for twinning should be explored.

Appendix 1: EMPA-WCC O_3 Transfer Standard

I EMPA Transfer Standard TEI 49C-PS

The Model 49C-PS is based on the principle that ozone molecules absorb UV light at a wavelength of 254 nm. The UV absorption is proportional to the concentration as described by the Lambert-Beer Law.

Zero air is supplied to the Model 49C-PS through the zero air bulkhead and is split into two gas streams, as shown in Figure 17. One gas stream flows through a pressure regulator to the reference solenoid valve to become the zero reference gas. The second zero air stream flows through a pressure regulator, ozonator, manifold and the sample solenoid valve to become the sample gas. Ozone from the manifold is delivered to the ozone bulkhead. The solenoid valves alternate the reference and sample gas streams between cells A and B every 10 seconds. When cell A contains reference gas, cell B contains sample gas and vice versa.

The UV light intensities of each cell are measured by detectors A and B. After the solenoid valves switch the reference and sample gas streams to opposite cells, the light intensities are ignored for several seconds to allow the cells to be flushed. The Model 49C-PS then determines the ozone concentration for each cell and outputs the average concentration.

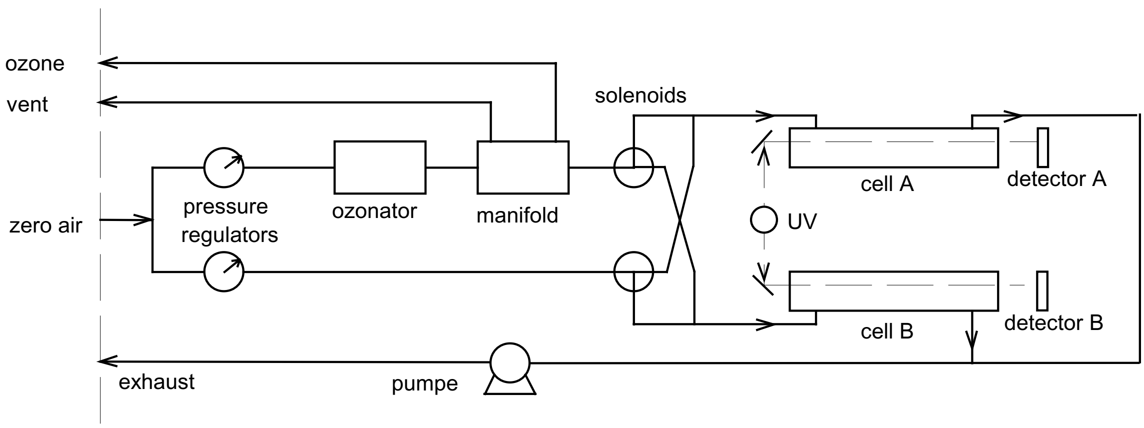

Figure 17: Flow schematic of TEI 49C-PS

II Stability of the Transfer Standard TEI 49C-PS

To exclude errors that might result from transportation of the transfer standard, the TEI 49C PS #54509-300 was compared with the SRP#15 before and after the field audit.

The procedure and instrumental details of this inter-comparison at the EMPA calibration laboratory are summarised in Table 8 and Figure 18.

Table 8: Inter-comparison procedure SRP - TEI 49C-PS

pressure transducer:	zero and span check (calibrated barometer) at start and end of procedure
concentration range:	0 - 200 ppb
number of concentrations:	5 + zero air at start and end
approx. concentration levels:	30 / 60 / 90 / 125 / 190 ppb
sequence of concentration:	random
averaging interval per concentration:	5 minutes
number of runs:	3 before and 3 after audit
zero air supply:	Pressurised air - zero air generator (CO catalyst, Purafil, charcoal)
ozone generator:	internal generator of SRP
data acquisition system:	ADC and acquisition of SRP

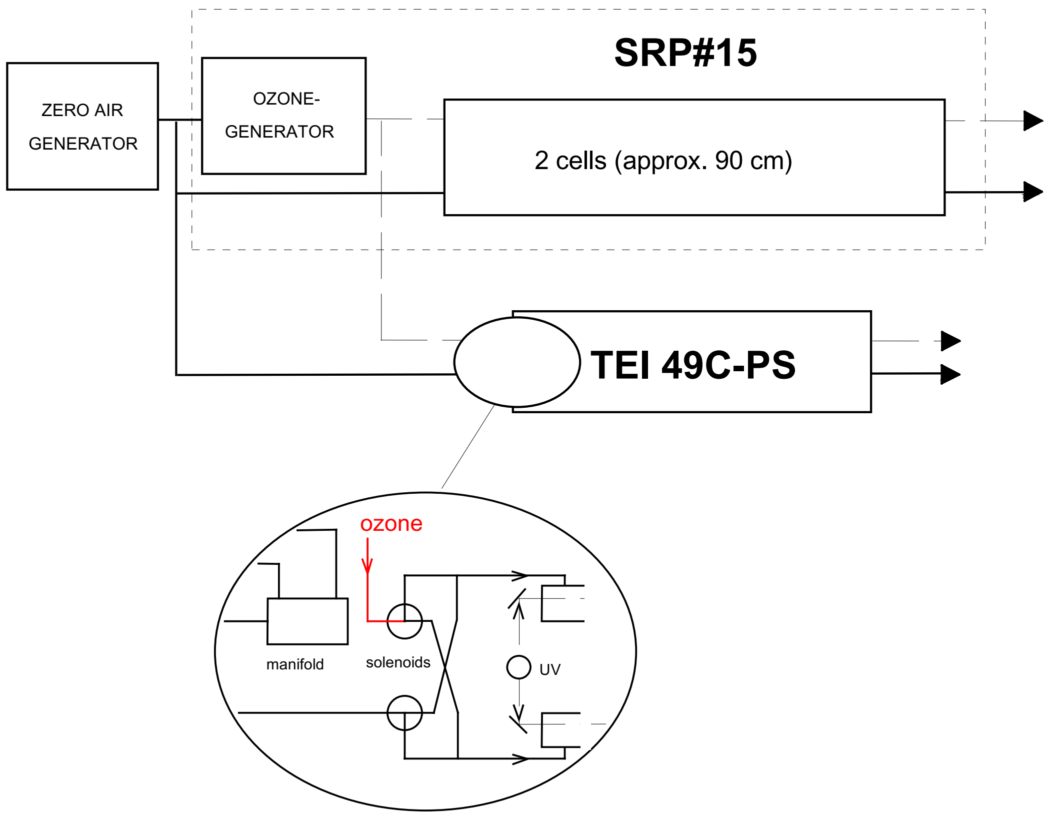

Figure 18: Instruments set up SRP -TEI 49C-PS

The stability of the transfer standard was thoroughly examined with respect to the uncertainties of the different components (systematic error and precision). For the GAW transfer standard of the WCC-O_3 (TEI 49C-PS) the assessment criteria, taking into account the uncertainty of the SRP, are defined to approximately ±(1 ppb + 0.5%).

Figures 19 and 20 show the resulting linear regression and the corresponding 95% precision interval for the comparisons of TEI 49C-PS vs. SRP#15. The results show that the EMPA transfer standard fulfilled the recommended criteria for the period of the audit, including transportation.

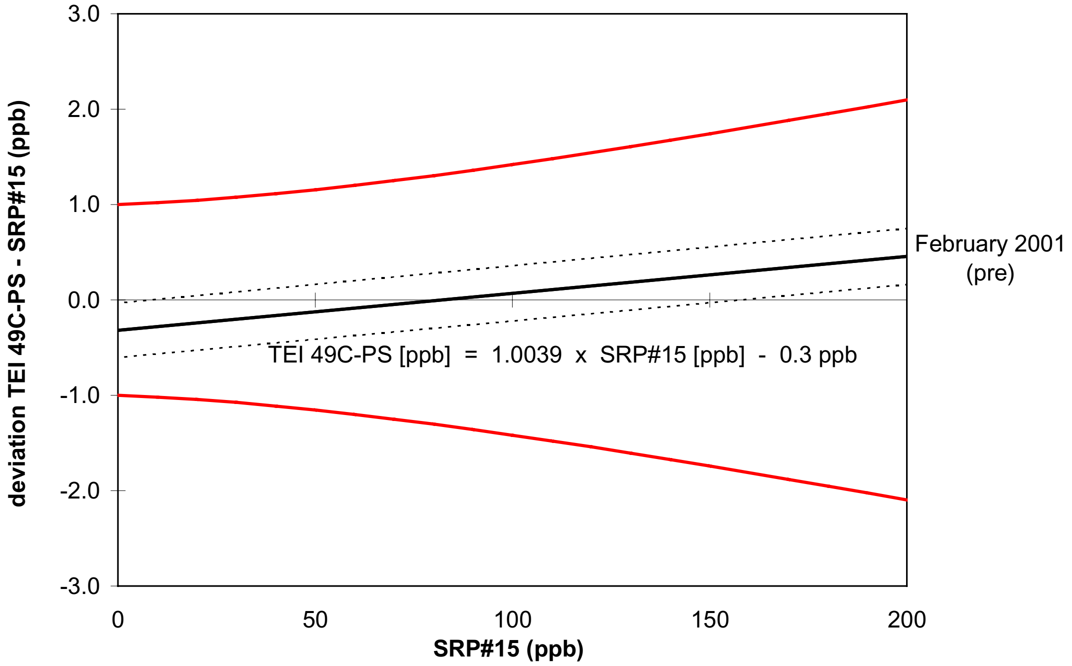

Figure 19: Transfer standard before audit

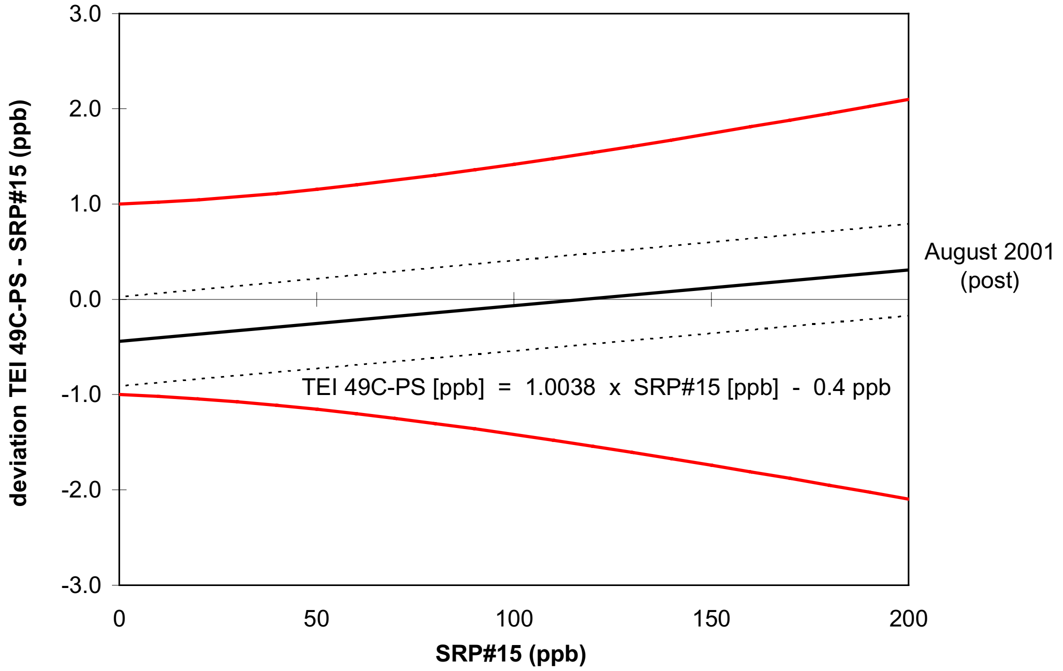

Figure 20: Transfer standard after audit

Appendix 2: Checklists

III Weekly Ozone Checklist

Date: _______ Time: _______ am / pm LST Atmo. Pressure ______ hPa and _____ mmHg

1. **Check dehumidifier and empty bottles. Bottles must be clean.** **O Done**
2. **Change inlet filter.** **O Done**
3. **Time and date at data acquisition correct?** **O Yes**
4. **Perform instrument checks:**

	Cell A	Cell B	limits
Lamp Frequency			70'000 – 120'000 Hz
Lamp Noise			Lower than 4 Hz
Cell Pressure (pump on)			p less than 20 mmHg (between pump on and pump off), P_A & P_B < P ambient air
Cell Temperature			23 – 38 °C
Sample Flow Rate			0.6 – 1.5 l / min
Cell Pressure (pressure sensor disconnected)			Should be very close to ambient pressure; adjust if not

P/T : O On O Off (should be ON)

5. **Press Run ppb**

6. **Download and save data according to Data Acquisition SOP**

Operator Signature: _________________________________

IV 3-Montly Checklist / SOP for Ozone Calibration

Date: _______ Time: _______ am / pm LST Atm. Pressure ______ hPa and _____ mmHg

1. **Before starting with calibration checklist, fill in weekly checklist (analyser)**
2. **Check Rubingel of zero air source. Replace with dry Rubingel if necessary**
3. **Switch on zero air pump**
4. **Switch on Calibrator TEI 49PS**
5. **Check overflow at ozone manifold and zero outlet (inside instrument)**
6. **Wait 1 to 2 hrs**
7. **Connect calibrator to analyzer**
8. **Perform instrument checks (calibrator):**

	Cell A	Cell B	limits
Lamp Frequency			70'000 – 120'000 Hz
Lamp Noise			Lower than 4 Hz
Cell Pressure (pump on)			p less than 20 mmHg (between pump on and pump off), P_A & $P_B < P$ ambient air
Cell Temperature			23 – 38 °C
Sample Flow Rate			0.6 – 1.5 l / min
Cell Pressure (pressure sensor disconnected)			Should be very close to ambient pressure; adjust if not.

P/T : O On O Off (should be ON)

9. **Condition the system with 200 ppb ozone for 30 min**
10. **Perform inter-comparison at different O_3 levels (0, 10, 20, 30, 50, 80 ppb)**

Set point	**Calibrator TEI 49PS**	**Analyzer TEI 49**

11. **Download and save data according to Data Acquisition SOP**
12. **Disconnect the calibrator from the analyzer and connect analyzer to sample line**
13. **Switch off calibrator**
14. **Switch off zero air pump**

Operator Signature: ___________________________________

V Carbon Monoxide TEI 48C – TL Checklist (every 3-5 days)

Date: .... **Time:** .... **Operator** ....

Rubin gel

Dry (dark red, rubin) ? (yes/no) .... if no, replace with dry rubin gel ¤ replaced

Dehumidifier DH-109

working? fan on, red and green light on (yes/no) ....

water level / drain ok? (yes/no) ....

TEI 48C – TL

Alarm? (yes/no) .... If yes, specify: ....

Temperatures: internal ....°C chamber ....°C

Pressure: .... mm Hg = ... hPa

Flow: .... LPM

AGC Intensity: .... Hz

Motor Speed: .... %

Time and date correct ? (yes/no) ....

Zero Calibration

Go to menu CALIBRATION – ZERO/SPAN CHECK – Periods and set to 0 hrs

Start zero air pump

Check Mass Flow Controller (0-5 l/min) is on and set to 25% (=1.25 l/min)

Press RUN at CO instrument to switch valve to SPAN

Check overflow (350-400 ml/min)

Acquire data for at least 60 min

Download data (Instrument – Load Records – short records – starting 60 back – save to file zeroDDMM.dat)

Move file to C:\CO data

Open file with Excel (Space delimited)

Average the last 15 1-minute values and note below
.... ppb

Go to the calibration factors menu of TEI 48C

Note CO BKG
.... ppm

Change CO BKG with zero value from zero calibration (only if > 5 ppb), and note new BKG
.... ppm

Note S/R ratio during zero
....

Span Check

Open calibration gas (15 ppm CO in synth. air)

Note pressure of 15 ppm CO standard .... bar

Check Mass Flow Controller (0-100 ml/min) is on and set to 34.3% (=34.3 ml/min)

Acquire data for at least 25 min

Download data (Instrument – Load Records – short records – starting 30 back – save to file spanDDMM.dat)

Move file to C:\CO data

Open file with Excel (Space delimited)

Average the last 20 1-minute values and note
.... ppb

Result should be 400 pbb (370 – 430 ppb)

If ok, press RUN at CO instrument to switch valve to SAMPLE and turn off pump

Close calibration gas valves

Go to menu CALIBRATION – ZERO/SPAN CHECK – Periods and set to 2 hrs

Operation

Valve on SAMPLE position? (yes/no) ....

Automatic Zero Check set to 2 hrs? (yes/no) ....

Measuring ? (yes/no) ....

Download data from TEI 48C

Go to instrument menu, choose load record, long record (corresponds to 5 min AVG)

Calculate the records that you have to download (12 records per hour)

Save to file DDMMYY.dat, press OK

Move file to C:\CO data (data are stored in C:\Program Files\TEI)

Send files of zero and span check and raw data file to christoph.zellweger@empa.ch (e-mail attachment)

Inlet Filter

Changed (every two weeks) (yes/no) ....

Remarks

....
....
....
....
....
....

VI Carbon Monoxide TEI 48C – TL Checklist (every 3 months)

Date: .... **Time:** .... **Operator** ....

Pressure Sensor

Pressure sensor reading .... mmHg

Ambient Pressure .... hPa = ... mmHg (a)

Pressure sensor reading (sensor disconnected) .... mmHg (b)

Adjustment of Pressure sensor (if difference between a and b > 4 mmHg) yes/no ....

Final pressure sensor comparison: Ambient (a) .... Instrument (b) ....

Zero Calibration

Go to menu CALIBRATION – ZERO/SPAN CHECK – Periods and set to 0 hrs

Start zero air pump

Check Mass Flow Controller (0-5 l/min) is on and set to 25% (=1.25 l/min)

Press RUN at CO instrument to switch valve to SPAN

Check overflow (350-400 ml/min)

Acquire data for at least 40 min

Download data (Instrument – Load Records – short records – starting 40 back – save to file zeroDDMM.dat)

Move file to C:\CO data

Open file with Excel (Space delimited)

Average the last 15 1-minute values and note below
.... ppb

Go to the calibration factors menu of TEI 48C

Note CO BKG
.... ppm

Change CO BKG with zero value from zero calibration (only if > 5 ppb, and note new BKG
.... ppm

Note S/R ratio during zero
....

Turn off zero air pump

Span Calibration

Note calibration factor from the Calibration Factors menu
CO BKG .... ppm CO COEF ....

Switch calibration valve to use 1 ppm standard

Open 1 ppm CO gas standard

Note pressure of 1 ppm CO standard .... bar

Adjust flow with NUPRO valve to approx. 300 ml/min overflow

Acquire data for at least 25 min

Close calibration gas valves

Download data (Instrument – Load Records – short records – starting 30 back – save to file calDDMM.dat)

Move file to C:\CO data

Open file with Excel (Space delimited)

Average the last 20 1-minute values and note
.... ppb

Result should be 1015 pbb (985 - 1045 ppb)

If ok, press RUN at CO instrument to switch valve to SAMPLE
If not ok, adjust CO COEF and note new calibration factor CO COEF .... ppb

Press RUN to switch valve to SAMPLE

Go to menu CALIBRATION – ZERO/SPAN CHECK – Periods and set to 2 hrs

Send files of zero and span calibration to christoph.zellweger@empa.ch (e-mail attachment)

Operation

Valve on SAMPLE position? (yes/no) ....

Automatic Zero Check set to 2 hrs? (yes/no) ....

Measuring ? (yes/no) ....

Remarks

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