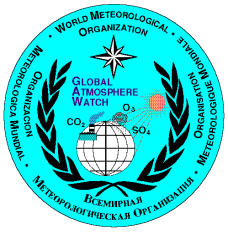

Global Atmosphere Watch
World Calibration Centre for Surface Ozone
Carbon Monoxide and Methane

EMPA

Materials Science & Technology

Laboratory Air Pollution / Environmental Technology

WCC-Empa REPORT 08/2

Submitted to the
World Meteorological Organization

SYSTEM AND PERFORMANCE AUDIT OF SURFACE OZONE AT THE GLOBAL GAW STATION DANUM VALLEY MALAYSIA, JULY 2008

Submitted by
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CONTENTS

ASSESSMENT AND RECOMMENDATIONS

The first system and performance audit at the Global GAW station Danum Valley (DMV) was conducted by WCC-Empa[1] from 1 thru 3 July 2008 in agreement with the WMO/GAW quality assurance system [*WMO*, 2007]. The DMV observatory is operated by the Malaysian Meteorological Department's (MMD) Environmental Studies Division. The audit was jointly conducted with the World Calibration Centre for Aerosol Physics (WCCAP), which is also twinning partner for aerosol measurements at DMV. The aerosol audit report will be available directly from the WCCAP.

Previous audits at Danum Valley: October 2004, November 2005, and March 2006 by WCCAP.

The following people contributed to the audit:

Dr. Christoph Zellweger	Empa Dübendorf, WCC-Empa
Dr. Jörg Klausen	Empa Dübendorf, QA/SAC Switzerland
Ms. Siniarovina Urban	MMD, Head of Monitoring and Air Quality Forecast Unit, GAW Country Contact
Mr. Sei Eng Yong	MMD, Station Manager in-charge
Prof. Dr. Ali Wiedensohler	Leibniz Institute for Tropospheric Research, WCCAP
Dr. Thomas Tuch	Leibniz Institute for Tropospheric Research, WCCAP

Our assessment of the Danum Valley observatory in general, as well as the surface ozone 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 MMD, the station manager, the WCCAP and the World Meteorological Organization in Geneva. The report including 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 Danum Valley Conservation Area is situated in South-eastern Sabah, Malaysian Borneo. It covers 43,800 hectares and comprises almost entirely lowland dipterocarp forest. The Danum Valley Field Centre hosts a number of research programmes managed by the Royal Society's South East Asia Rainforest Research Programme (www.SEARRP.org) and is located approximately 70 km inland from the town of Lahad Datu on Sabah's east coast. The Danum GAW station (04°58'53"N, 117°50'37"E, elevation 426m) is located approximately 10 km from Danum Valley Field Centre on a ridge (Bukit Atur) surrounded by pristine tropical rainforest. It can be accessed by road from Lahad Datu within approximately two hours.

Station Facilities

The DMV GAW site was established in 2005 and consists of a large laboratory building. DMV is equipped with a range of monitoring instruments and an automatic weather station located on a 5 metre rooftop platform. The 100m tower, which adjoins the laboratory, has air-intakes and mounting platforms for sampling equipment at levels of 30, 50, 70 and 100m above ground. It is an ideal platform for atmospheric studies and provides infrastructure for collaborative research between Malaysian and international scientists. During the audit the air condition system was not

[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.

working in all laboratories. Internet connection is available but only with low bandwidth. For regular and secure data transmission a higher bandwidth is recommended.

Recommendation 1 (*, 2008/9)**
The air-conditioning systems need to be repaired. All functional AC units should be continuously running.

Recommendation 2 (, 2009)**
The bandwidth of the internet connection should be enlarged to improve communication and data transmission capabilities.

Station Management and Operation

The station is managed by the Malaysian Meteorological Department's (MMD) Environmental Studies Division. The station is visited once per week usually on Tuesdays by the station manager and/or the station operator. The station manager and operator received only very limited training for the operation of the instrumentation at the DMV site. Continuous training is of utmost importance for the successful operation of the measurements.

Recommendation 3 (*, ongoing)**
MMD should explore all possibilities for operator training. Participation in GAWTEC courses is highly recommended, and the knowledge needs to be shared between MMD staff.

Air Inlet System

Each instrument has its own air inlet. The system is functional but it should be checked for sufficient flow and ozone loss. In addition, it should be considered to replace stainless steel parts of the surface ozone inlet lines by PTFE or PFA parts.

Recommendation 4 (, 2009)**
The ozone inlet system needs to be checked for ozone loss.

Recommendation 5 (, 2009)**
The inlet systems should be replaced in case of ozone loss. Recommended materials are Teflon (PTFE or PFA) and glass. All other materials need be thoroughly checked for ozone loss and require high flow rates.

Surface Ozone Measurements

Instrumentation. One ozone analyser (TEI 49i) is currently used at the station for continuous surface ozone measurements. The instrumentation is adequate for its intended purpose; however, it was not working during the audit because of damage caused by lightning. It was repaired after the audit but some functions (data download) were still not working as of October 2008. It was also noticed during the audit that no maintenance schedule exists, and inlet filters were never exchanged.

Recommendation 6 (*, immediately)**
The lightning protection of the station and the instruments needs to be improved.

Recommendation 7 (*, immediately)**
The ozone instrument must be fully repaired and needs an initial calibration by experienced and trained staff.

Recommendation 8 (*, immediately)**
The instrument should be checked weekly for general operation. In addition recorded instrument parameter such as temperatures, flow rates etc. should be plotted on QC charts. It is further recommended to follow the preventive maintenance chapter of the TEI 49i manual. The inlet filter needs to be replaced at regular intervals, e.g. every two weeks.

Standards. No ozone standard is available at the site, but MMD operates an ozone calibrator which is usually located at the Tanah Rata (TAR) regional GAW station. This Instrument was available during the audit and was calibrated by WCC-Empa.

Recommendation 9 (*, ongoing)**
It is strongly recommended to do yearly calibrations / inter-comparisons with a reference instrument at the site. For this purpose the reference instrument of Tanah Rata could be shipped to the site.

Intercomparison (Performance Audit). Due to failure of the station ozone analyser only the ozone calibrator of Tanah Rata could be inter-compared. The inter-comparisons of the TEI 49i-PS ozone calibrator extended over a period of 16 hours. The results are summarised below and the following equations characterises the instrument bias:

TEI 49i-PS #629719094: 0 – 90 ppb good agreement

Unbiased O_3 mixing ratio (ppb) XO3 (ppb) = ([OA] + 0.60 ppb) / 1.003 (1)

The results of this inter-comparison is presented in Figure 1.

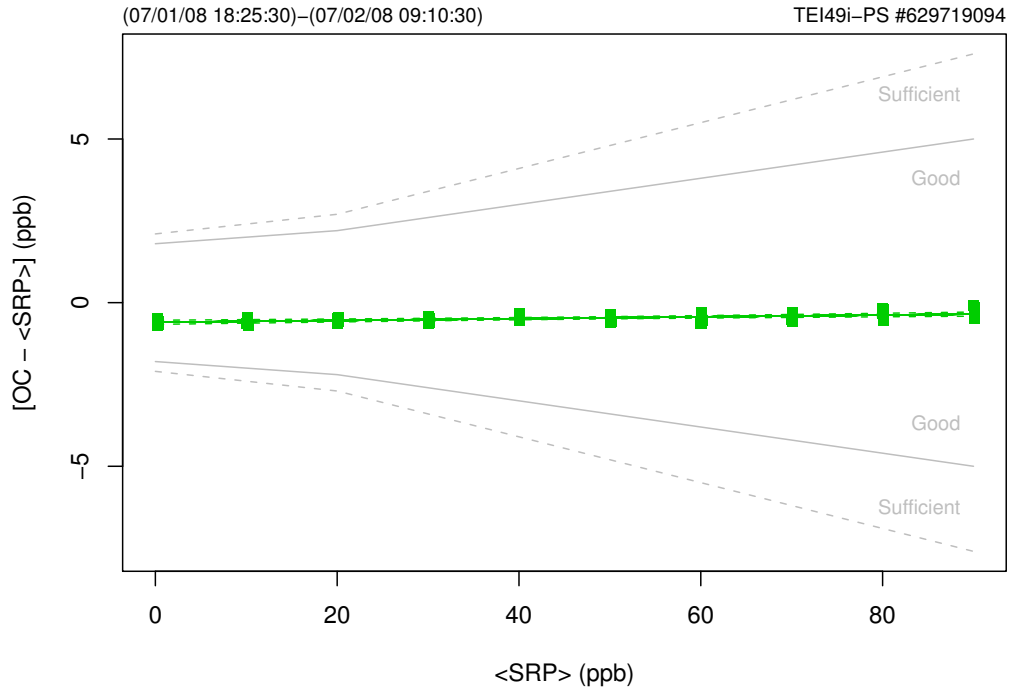

Figure 1. Bias of the MMD ozone standard TEI 49i-PS with respect to the SRP as a function of concentration. Each point represents the average of the last 10 one-minute values at a given level. Areas defining 'good' and 'sufficient' agreement according to GAW assessment criteria [*Klausen, et al.*, 2003]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

Data Acquisition and Management

The TEI iPort Software using TCP/IP connection is used to manually download data of the instrument.

Recommendation 10 (*, 2009)
It should be considered to use a dedicated data acquisition system for the ozone instrument, preferably with remote access. Furthermore a backup strategy is required.

Data Submission

Only few data have been submitted to the World Data Centre for Greenhouse Gases (WDCGG). At the time of the audit only a short period of in-situ carbon dioxide data has been submitted by MMD. Available ozone data has been submitted to WDCGG in November 2008.

Recommendation 11 (, ongoing)**
Data submission is one of the obligations of GAW stations. Available data should be submitted to the corresponding data centres, with a submission delay of maximum one year.

Conclusions

The Global GAW station Danum Valley comprises a growing suite of ongoing measurements, in particular aerosol parameters, and successfully supported international measurement campaigns such as the UK National Environment Research Council OP3 project (www.es.lancs.ac.uk/op3/index.html). Unfortunately, some operations were discontinued due to lightning damage and a lack of resident expertise. Nevertheless, the existing data sets are a valuable contribution to the GAW programme, especially because they cover a geographical region where only sparse 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.

Summary Ranking of Danum Valley Station (a red bar indicates that immediate action is required)

System Audit Aspect	Adequacy[#]	Comment
Access	(5)	Year-round access possible
Facilities		
Laboratory and office space	(4)	Spacious laboratory building
Air Conditioning	(3)	Partly functional units
Power supply	(5)	
Internet access	(3)	Low bandwidth
General Management and Operation		
Organisation	(3)	Well organised , training needed
Competence of staff	(2)	Training needed
Air Inlet System (Ozone)	(3)	Potential ozone loss in stainless steel parts
Instrumentation		
Ozone	(5)	TEI49i (adequate after repair)
Carbon dioxide	(5)	Lowflo NDIR (needs repair)
Aerosol parameters*	(5)	Twinning by WCCAP
Meteo	(5)	
Standards		
Ozone	(1)	Only at Tanah Rata (TEI 49i-PS)
Data Management		
Data acquisition	(3)	Only offline by manual download
Data processing	(3)	Training needed
Data submission	(4)	

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

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Dübendorf, March 2009

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

APPENDIX

Global GAW Station Danum Valley

Site description

The Danum GAW station (04°58'53"N, 117°50'37"E, elevation 426m) is located approximately 10 km from Danum Valley Field Centre on a ridge (Bukit Atur) surrounded by pristine tropical rainforest. Further information can be found on the Royal Society's South East Asia Rainforest Research Programme website (www.SEARRP.org) and GAWSIS (http://gaw.empa.ch/gawsis).

Measurement Programme

An overview of the measurement program and its status as of July 2008 is shown in Table 1. Refer to GAWSIS or the station web page for more details.

Table 1. Measurement Programme at the DMV Station

Parameter*	**Current Instrument**	**Data Coverage (%)#**		
		<12 m	<3 y	Overall
Aerosol				
Mass PM10	TEOM 1400a			
Light absorption coefficient	MAAP model 5012			
Light scattering coefficient	Ecotech M9003			
Multiwavelength optical depth	AOD PFR			
Ozone				
Surface ozone	UV absorption (TEI 49i and 49C)	< 10	NA	< 10
Greenhouse Gas				
CO_2	Li-COR 6251			
Meteo				
PTU, wind speed + direction				
Precipitation	Rain gauge			

* Refer to GAWSIS for more details
# Missing information about data coverage: information was not available.

Ozone Distribution at Danum Valley

To date only very few ozone measurement data is available from DMV. The available data of 2007 is shown in Figure 2. After Mai 2007 no data is available due to instrument failure.

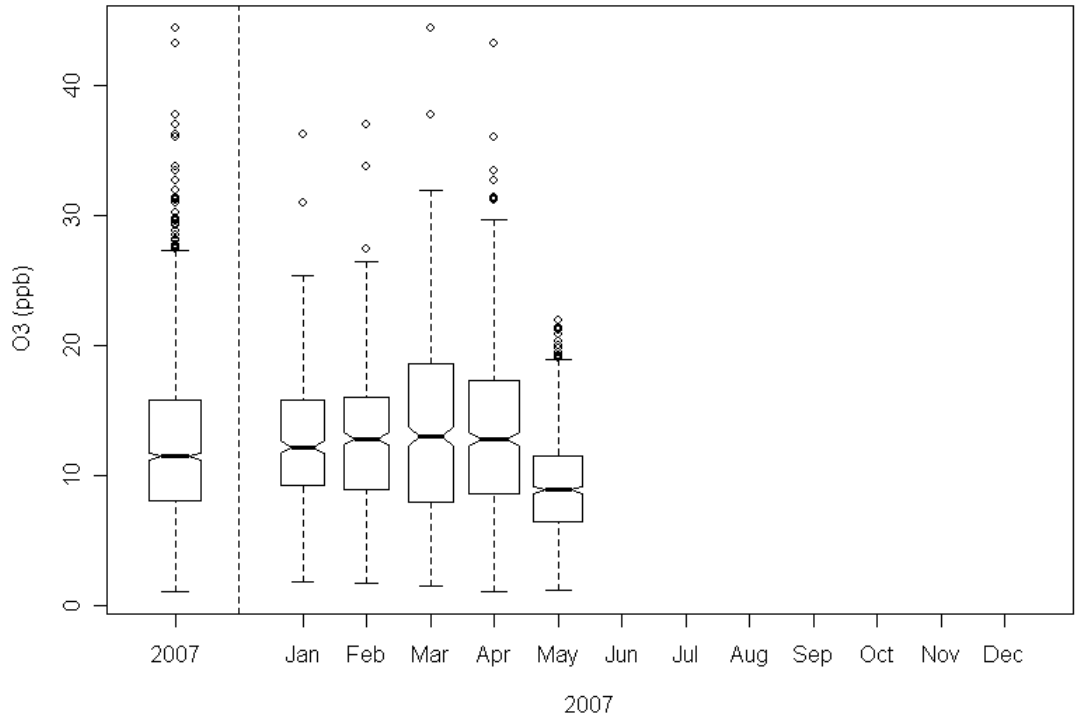


Figure 2. Yearly and monthly box plots of 1-hourly aggregates for surface Ozone. The boxes indicate the 25, 50, and 75 percentile, respectively. Whiskers mark data within 1.5 times the inter-quartile range, and open circles denote data outside this range. The width of the boxes is proportional to the number of data points available for each month.

Organisation and Contact Persons

The GAW activities of Malaysia are coordinated by the Malaysian Meteorological Department's (MMD) Environmental Studies Division. An organisational chart is shown in Figure 3.

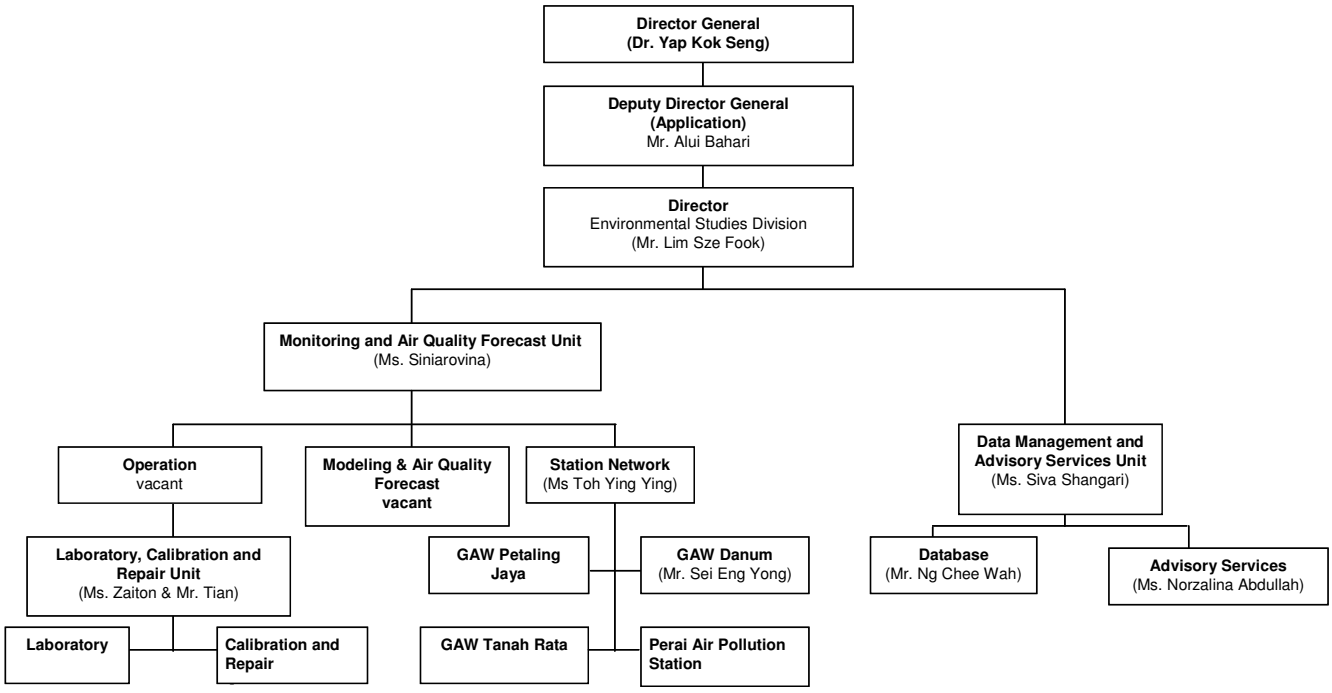


Figure 3. Organisation of the Malaysian GAW activities as of July 2008.

Surface Ozone Measurements

Surface ozone measurements started in January 2007 at the Danum Valley site. Only limited data is available since then due to instrument failures caused by lightning. Data availability however is expected to improve in the near future. Only the Ozone standard of MMD could be assessed during the audit.

All inter-comparisons were done according to Standard Operating Procedures [*WMO*, in preparation].

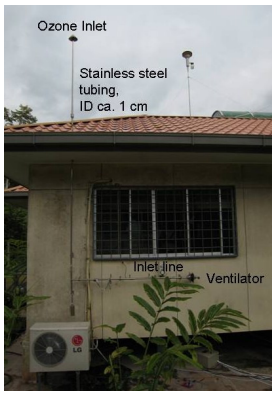
Monitoring Set-up and Procedures

Air Conditioning

The DMV station is usually air-conditioned but the air condition unit of the ozone laboratory was not working during the audit. The laboratory temperature was approximately 30°C during the audit.

Air Inlet System

The DMV ozone analyser has a dedicated inlet system for surface ozone measurements. The inlet consists of an stainless steel tube (approx. 4m) with an inner diameter of approx. 1 cm. The inlet is protected by an upside-down beaker. A blower is used to achieve a high air flow speed of approx. 4 m/sec through the stainless steel part. The ozone analyser is connected with 0.9 m PTFE tubing to the inlet line. The residence time is estimated to be less than 2 seconds. The ozone instrument is protected by a PTFE inlet filter at the sample port of the analyser.



Instrumentation

The station is equipped with one ozone analyser (TEI 49i). Instrumental details for the ozone analysers (OA) are summarised in Table 2 below.

Standards

No ozone standard is available at the site, but the ozone calibrator of Tanah Rata (TAR) was available during the audit. Details are summarised in Table 2.

Operation and Maintenance

Only a weekly check of general instrument operation is made. Until now no other checks have been made. No maintenance has been done until the date of the audit, and the inlet filter was never exchanged (cf. recommendation 9).

Data Acquisition and Data Transfer

TEI i-Port using TCP/IP connection is used to manually download the data to the station computer. These files are sent to MMD on a CD.

Data Treatment

Data validation is carried out at MMD in Petaling Jaya using Microsoft Office software. Only very limited QA/QC checks are made. The station look book is not available during data treatment because it is only a paper log book exists at the DMV site.

Data Submission

Available ozone data has been submitted to WDCGG in November 2008.

Documentation

The instrument manuals are available at the site. In addition station and instrument log books (non-electronic) is available at the site.

Inter-Comparison of Ozone Analyser

The ozone analyser TEI 49i could not be inter-compared because the instrument was not working during the audit. The problem was identified (damaged motherboard caused by lightning stroke) and the motherboard was replaced by end October 2008 after the audit.

Inter-Comparison of Ozone Calibrator (Tanah Rata Ozone Standard)

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

Setup and Connections

Table 2 details the experimental setup during the inter-comparison of the transfer standard with the TAR calibrator. The data used for the evaluation was recorded by the WCC-Empa data acquisition system as indicated. In addition, data of the TAR instrument was downloaded using the TEI iPort software. No further corrections were applied to the data.

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

Transfer standard (TS)	Model, S/N	TEI 49C-PS #54509-300 (WCC-Empa)
	Settings	BKG = -0.5; COEFF = 1.008
Ozone analyser (OA) (not inter-compared)	Model, S/N	TEI 49i #628919007
	Principle	UV absorption
	Range	1 ppm
	Settings	Could not be check because instrument was not working
Ozone calibrator (OC) (normally at TAR)	Model, S/N	TEI 49i-PS #629719094
	Principle	UV absorption
	Range	1 ppm
	Settings	BKG = 0.0; COEFF = 1.024
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 and OC	One minute aggregates from digital output (custom de-signed LabView programme)
Pressure readings at beginning of inter-comparison (hPa)	Ambient	962.0 (WCC-Empa reference)
	TS	960.0, adjusted to 962.0
	OC	976.6, adjusted to 962.0
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		6 runs (1 - 2 July, 2008)

Results

Each ozone level was applied for 15 minutes, and the last 10 one-minute averages were aggregated. The results are shown in **Table 3**. These aggregates were used in the assessment of the inter-comparison as described elsewhere [Klausen, et al., 2003]. All results refer to the calibration factors as given in Table 2 above. The readings of the transfer standard (TS) were compensated for bias with respect to the Standard Reference Photometer (SRP) prior to the evaluation of the ozone analyser (OA) values.

Table 3. Ten-minute aggregates computed from the last 10 of a total of 15 one-minute values for the inter-comparison of the DMV ozone analyser (OA) TEI 49i-PS #629719094 with the WCC-Empa transfer standard (TS).

DateTime (UTC+1)	Run	Level	TS (ppb)	OA (ppb)	Flag[#]	sdTS (ppb)	sdOA (ppb)
2008-07-01 18:30	1	0	0.28	-0.35	0	0.09	0.10
2008-07-01 18:45	1	30	30.06	29.51	0	0.09	0.09
2008-07-01 19:00	1	60	60.02	59.58	0	0.05	0.10
2008-07-01 19:15	1	40	40.03	39.58	0	0.07	0.05
2008-07-01 19:30	1	90	89.99	89.82	0	0.13	0.06
2008-07-01 19:45	1	50	50.02	49.53	0	0.08	0.04
2008-07-01 20:00	1	10	10.18	9.51	0	0.07	0.09
2008-07-01 20:15	1	20	20.05	19.61	0	0.10	0.07
2008-07-01 20:30	1	80	79.99	79.59	0	0.07	0.06
2008-07-01 20:45	1	70	70.00	69.54	0	0.06	0.11
2008-07-01 21:00	2	0	0.22	-0.45	0	0.08	0.07
2008-07-01 21:15	2	40	40.00	39.64	0	0.11	0.14
2008-07-01 21:30	2	70	69.99	69.74	0	0.08	0.22
2008-07-01 21:45	2	30	30.08	29.68	0	0.09	0.02
2008-07-01 22:00	2	90	89.96	89.84	0	0.07	0.08
2008-07-01 22:15	2	20	20.07	19.55	0	0.08	0.05
2008-07-01 22:30	2	10	10.05	9.62	0	0.07	0.06
2008-07-01 22:45	2	60	59.96	59.51	0	0.08	0.07
2008-07-01 23:00	2	50	49.96	49.71	0	0.06	0.08
2008-07-01 23:15	2	80	79.93	79.69	0	0.08	0.07
2008-07-01 23:30	3	0	0.28	-0.27	0	0.08	0.07
2008-07-01 23:45	3	90	89.93	89.62	0	0.08	0.05
2008-07-02 00:00	3	70	69.94	69.75	0	0.05	0.14
2008-07-02 00:15	3	40	39.97	39.73	0	0.09	0.16
2008-07-02 00:30	3	50	49.94	49.64	0	0.11	0.09
2008-07-02 00:45	3	20	20.03	19.59	0	0.10	0.12
2008-07-02 01:00	3	30	29.95	29.39	0	0.11	0.10
2008-07-02 01:15	3	60	59.93	59.40	0	0.10	0.10
2008-07-02 01:30	3	10	10.06	9.50	0	0.13	0.07
2008-07-02 01:45	3	80	79.86	79.83	0	0.05	0.14
2008-07-02 02:00	4	0	0.28	-0.37	0	0.13	0.04
2008-07-02 02:15	4	30	29.95	29.58	0	0.08	0.05
2008-07-02 02:30	4	60	59.91	59.69	0	0.08	0.06
2008-07-02 02:45	4	40	39.96	39.57	0	0.09	0.05
2008-07-02 03:00	4	90	89.90	89.70	0	0.08	0.09
2008-07-02 03:15	4	50	49.96	49.61	0	0.05	0.07
2008-07-02 03:30	4	10	10.06	9.48	0	0.09	0.07
2008-07-02 03:45	4	20	19.98	19.47	0	0.09	0.07
2008-07-02 04:00	4	80	79.88	79.69	0	0.10	0.08
2008-07-02 04:15	4	70	69.95	69.75	0	0.07	0.05
2008-07-02 04:30	5	0	0.24	-0.26	0	0.07	0.08
2008-07-02 04:45	5	40	39.94	39.54	0	0.10	0.04
2008-07-02 05:00	5	70	69.88	69.50	0	0.07	0.07

DateTime (UTC+1)	Run	Level	TS (ppb)	OA (ppb)	Flag[#]	sdTS (ppb)	sdOA (ppb)
2008-07-02 05:15	5	30	29.99	29.50	0	0.13	0.09
2008-07-02 05:30	5	90	89.89	89.96	0	0.08	0.08
2008-07-02 05:45	5	20	20.04	19.63	0	0.05	0.11
2008-07-02 06:00	5	10	10.07	9.52	0	0.13	0.08
2008-07-02 06:15	5	60	59.92	59.73	0	0.08	0.16
2008-07-02 06:30	5	50	49.97	49.64	0	0.10	0.07
2008-07-02 06:45	5	80	79.92	79.86	0	0.08	0.11
2008-07-02 07:00	6	0	0.22	-0.25	0	0.03	0.07
2008-07-02 07:15	6	90	89.91	89.91	0	0.06	0.09
2008-07-02 07:30	6	70	69.93	69.74	0	0.10	0.12
2008-07-02 07:45	6	40	39.94	39.54	0	0.10	0.10
2008-07-02 08:00	6	50	49.94	49.44	0	0.08	0.09
2008-07-02 08:15	6	20	20.00	19.40	0	0.09	0.13
2008-07-02 08:30	6	30	29.95	29.50	0	0.08	0.11
2008-07-02 08:45	6	60	59.91	59.40	0	0.05	0.10
2008-07-02 09:00	6	10	10.03	9.44	0	0.08	0.09
2008-07-02 09:15	6	80	79.83	79.65	0	0.08	0.10

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

Figure 4 shows the regression residuals of the ozone calibrator with respect to the SRP as a function of ozone concentration for the range 0 – 90 ppb and as a function of time.

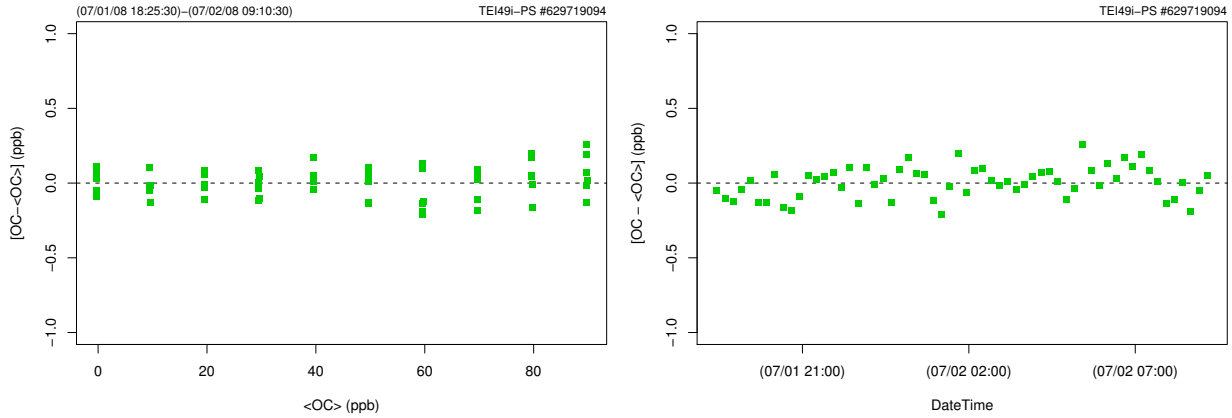


Figure 4. Regression residuals of the MMD ozone calibrator (TEI 49i-PS) as a function of concentration (left panel) and time (right panel).

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 49i-PS #629719094:

$$X_{O3}\ (\text{ppb}) = ([\text{OA}] + 0.60\ \text{ppb}) / 1.003$$

$$u_{O3}\ (\text{ppb}) = \text{sqrt}\ (0.28\ \text{ppb}^2 + 2.59\text{e-}05 * X_{O3}^2) \qquad (1)$$

Conclusions

The results of the performance audit demonstrate good agreement between TAR ozone calibrator and the measurements of WCC-Empa. The calibrator should now regularly be used to calibrate the DMV ozone analyser.

WCC-Empa Traveling 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 4, the inter-comparison data is given in Table 3.

Table 4. 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 = -0.5; COEFF = 1.008
Ozone source		Internal generator of SRP
Zero air supply		Pressurized air - zero air generator (Purafil, charcoal, filter) (WCC-Empa)
Connection between instruments		Ca. 1 meter of 1/4" PFA tubing between SRP manifold and TS inlet
Data acquisition		SRP data acquisition system, 1-minute averages with standard deviations
Levels (ppb)		0, 30, 60, 90, 140, 190
Duration per level (min)		Variable based on standard deviation criterion, the last 10 30-second readings are aggregated
Sequence of Levels		Repeated runs of randomised sequence
Runs		3 runs before shipment of TS (27 May, 2008) 3 runs after return of TS (6 August, 2008)

Table 5. Five-minute aggregates computed from 10 valid 30-second values for the inter-comparison of the Standard Reference Photometer (SRP) with the WCC-Empa travelling standard (TS).

Date	Run	Level[#]	SRP (ppb)	sdSRP (ppb)	TS (ppb)	sdTS (ppb)
2008-05-27	1	0	-0.01	0.25	0.03	0.09
2008-05-27	1	140	133.97	0.47	134.16	0.31
2008-05-27	1	30	28.29	0.23	28.36	0.08
2008-05-27	1	60	58.55	0.43	58.77	0.10
2008-05-27	1	190	178.21	0.48	178.26	0.63
2008-05-27	1	90	86.59	0.36	86.74	0.12
2008-05-27	1	0	-0.04	0.31	0.10	0.08
2008-05-27	2	0	0.09	0.23	0.06	0.10
2008-05-27	2	30	28.80	0.48	28.74	0.07
2008-05-27	2	140	133.52	0.69	133.63	0.32
2008-05-27	2	190	177.20	0.62	177.39	0.56
2008-05-27	2	60	56.66	0.25	56.48	0.24
2008-05-27	2	90	87.22	0.16	86.93	0.17
2008-05-27	2	0	0.02	0.17	-0.01	0.09
2008-05-27	3	0	-0.14	0.23	-0.06	0.08
2008-05-27	3	60	59.33	0.21	59.12	0.09
2008-05-27	3	140	133.15	0.49	133.13	0.38
2008-05-27	3	30	28.35	0.16	28.18	0.08
2008-05-27	3	190	178.00	0.88	177.95	0.72
2008-05-27	3	90	86.44	0.33	86.33	0.18
2008-05-27	3	0	-0.02	0.20	0.07	0.08
2008-08-06	4	0	-0.28	0.34	-0.21	0.09
2008-08-06	4	140	192.89	0.13	192.50	0.13
2008-08-06	4	30	142.25	0.34	141.80	0.13
2008-08-06	4	60	61.53	0.29	61.29	0.07
2008-08-06	4	190	91.82	0.30	91.49	0.10
2008-08-06	4	90	31.82	0.34	31.65	0.08
2008-08-06	4	0	-0.10	0.30	-0.22	0.07
2008-08-06	5	0	-0.21	0.39	-0.15	0.08
2008-08-06	5	30	61.34	0.36	61.39	0.10
2008-08-06	5	140	192.95	0.45	192.58	0.13
2008-08-06	5	190	142.27	0.48	141.83	0.06
2008-08-06	5	60	31.90	0.31	31.68	0.09
2008-08-06	5	90	91.79	0.27	91.41	0.07
2008-08-06	5	0	-0.09	0.30	-0.17	0.07
2008-08-06	6	0	-0.22	0.19	-0.16	0.09
2008-08-06	6	60	91.70	0.19	91.43	0.05
2008-08-06	6	140	61.79	0.39	61.34	0.11
2008-08-06	6	30	31.91	0.28	31.77	0.07
2008-08-06	6	190	192.95	0.28	192.49	0.19
2008-08-06	6	90	142.18	0.23	141.88	0.09
2008-08-06	6	0	-0.02	0.23	-0.21	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 5). The data were pooled and evaluated by linear regression analysis, considering uncertainties in both instruments. From this, the unbiased ozone mixing ratio produced (and measured) by the TS can be computed (equation 3). The uncertainty of the TS was estimated previously (cf. equation 19 in [*Klausen, et al.*, 2003]).

$$X_{TS}\ (\text{ppb}) = ([TS] + 0.02\ \text{ppb}) / 0.9984$$

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

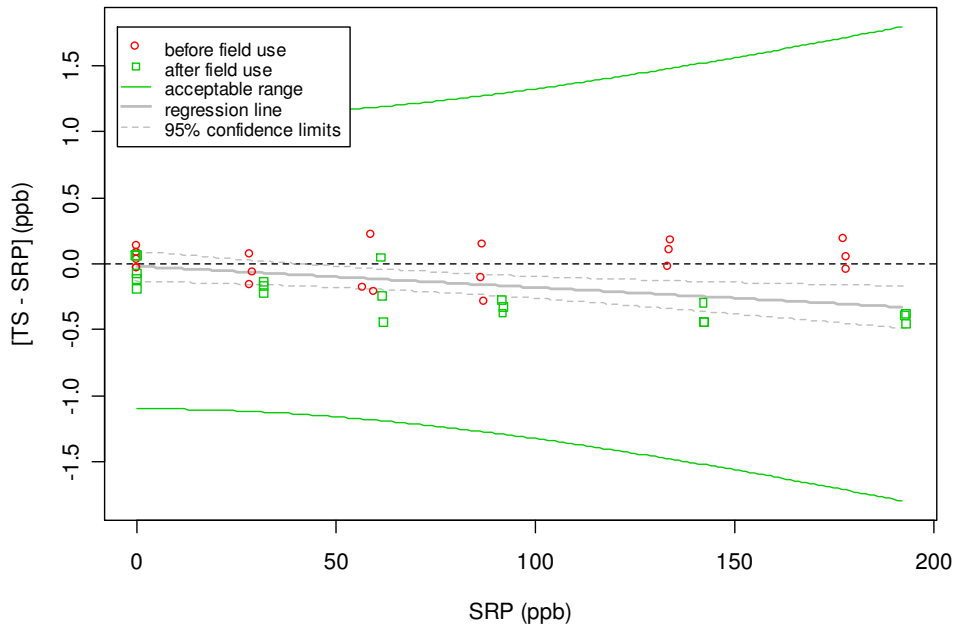


Figure 5. Deviations between travelling standard (TS) and Standard Reference Photometer (SRP) before and after use of the TS at the field site.

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Ozone Audit Executive Summary (DMV)

0.1	Station Name:	Danum Valley
0.2	GAW ID:	DMV
0.3	Coordinates/Elevation:	4.981°N 117.884°E (426 m a.s.l.)
Parameter:		Surface Ozone

1.1	Date of Audit:	1 – 3 July, 2008
1.2	Auditor:	Dr. C. Zellweger, Dr. J. Klausen
1.2.1	Station staff involved in audit:	Mr. Sei Eng Yong
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):	$(0.9984 \pm 0.0010) \times [SRP] - (0.02 \pm 0.13)$
1.5	Ozone Calibrator [OC]	
1.5.1	Model:	TEI 49i-PS #629719094
1.5.2	Range of calibration:	0 – 100 ppb
1.5.3	Coefficients at start of audit	BKG 0.0 ppb, SPAN 1.024
1.5.4	Calibration at start of audit (ppb):	$[OA] = (1.003 \pm 0.000) \times [SRP] - (0.60 \pm 0.05)$
1.5.5	Unbiased ozone mixing ratio (ppb) at start of audit:	$X = ([OA] + 0.60) / 1.003$
1.5.6	Standard uncertainty remaining after compensation of calibration bias (ppb):	$u_X \approx (0.28\ ppb^2 + 2.59e\text{-}5 \times X^2)^{1/2}$
1.5.7	Coefficients after audit	unchanged
1.5.8	Calibration after audit (ppb):	unchanged
1.5.9	Unbiased ozone mixing ratio (ppb) after audit:	unchanged
1.5.10	Standard uncertainty remaining after compensation of calibration bias (ppb):	unchanged
1.6	Comments:	Ozone calibrator of Malaysian Meteorological Dep. was inter-compared instead of on-site analyser
1.7	Reference:	WCC-Empa Report 08/2

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

REFERENCES

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.

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

WMO (in preparation), 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.

LIST OF ABBREVIATIONS

a.s.l.	above sea level
DAQ	Data Acquisition System
GAW	Global Atmosphere Watch
NIST	National Institute of Standards and Technology
OA	Ozone Analyser
OC	Ozone Calibrator
DMV	Danum Valley GAW Station
MMD	Malaysian Meteorological Department
PFA	Teflon (**p**er**f**luoro**a**lkoxy copolymer)
PTFE	Teflon (**p**oly**t**etra**f**luoro**e**thylene)
SOP	Standard Operating Procedure
SRP	Standard Reference Photometer
TAR	Tanah Rata GAW Station
TS	Travelling Standard
WCCAP	World Calibration Centre for Aerosol Physics,
WCC-Empa	World Calibration Centre for Surface Ozone, Carbon Monoxide and Methane
WDCGG	World Data Centre for Greenhouse Gases
WMO	World Meteorological Organisation