HONG KONG OBSERVATORY

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Comparison of the Hong Kong Standard Barometer with the Primary Standard Barometer of the Japan Meteorological Agency, 2007-2008

by

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ABSTRACT

The Hong Kong Observatory (HKO) has been carrying out comparisons between the Hong Kong Standard Barometer and the reference standard barometer of the Japan Meteorological Agency (JMA) since 1957.

A comparison between the Hong Kong Standard Barometer and the Primary Standard Barometer of the JMA was conducted from December 2007 to January 2008. Three precision digital barometers were used as travelling standards during the comparison. The comparison results show that the Hong Kong Standard Barometer is read, on average, 0.07 hPa higher than the Primary Standard Barometer of the JMA. This index correction is within the limit acceptable under the recommended practice of the World Meteorological Organization (WMO).

摘要

香港天文台自 1957 年開始安排香港標準氣壓表與日本氣象廳的基準氣壓表進行比對。

香港標準氣壓表與日本氣象廳的一級標準氣壓表在 2007 年 12 月至 2008 年 1 月進行了比對，這次比對利用了三個精密數字氣壓表作為巡檢標準氣壓表。比對結果顯示香港標準氣壓表平均較日本氣象廳的一級標準氣壓表高出 0.07 hPa。根據世界氣象組織的操作建議，這指標訂正值是在可接受範圍內。

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1. Introduction

To ensure consistency in the standards of barometers and to maintain continuity in pressure data across international boundaries, the World Meteorological Organization (WMO) recommends regional comparisons of national standard barometers with an absolute standard barometer recognized by WMO, on a decadal basis (WMO, 1995). WMO's definitions on various categories of barometers and its recommended practice on the permissible changes in index correction of mercury barometers are shown in Appendices I and II respectively (WMO, 2008).

Comparisons between the Hong Kong Standard Barometer and the reference standard mercury barometer at the Japan Meteorological Agency (JMA) in Tokyo were carried out in 1973 (Chen and Wong 1973), 1983 (Lee and Yeung 1987) and 1994 (Wong 1994).

A comparison of the Hong Kong Standard Barometer with the JMA Primary Standard Barometer through the use of travelling standards was conducted from December 2007 to January 2008. This note reports the comparison procedures and results.

2. Classification of barometers and equipment used for comparisons

The Hong Kong Standard Barometer (Figure 1) is a Kew-pattern mercury barometer of category C. It consists of a vertical glass tube in which the barometric column is supported, a cistern to contain the mercury which seals the lower end of the tube, and a contracted-scale to measure the height of the column. As the mercury density is a function of the temperature, a thermometer is attached to the barometer to provide the required temperature information for the determination of pressure.

In the place of the reference mercury barometer used in earlier comparisons, JMA has been using a precision dead weight tester (Figure 2) as its Primary Standard Barometer since 1999. The precision dead weight tester is of category A, capable of providing absolute pressure measurements to an accuracy of 0.05 hPa. The instrument consists of a piston-cylinder assembly enclosed in an airtight transparent dome. The space above the assembly is evacuated by means of a vacuum pump. The weighted piston requires a particular pressure to keep it suspended so that given the effective surface area and mass of the piston, and the mass of the weight being supported, the exact absolute pressure for balance can be determined.

As mercury is classified nowadays as corrosive material, it is no longer possible to take a mercury barometer on board an aircraft. For this reason, travelling standards of category Q (Figure 3) were used in the present comparison. The three travelling standards used were precision digital barometers meeting the level of reliability recommended by WMO (WMO, 2008). Each of them consists of three pressure transducers to detect pressure and produce an electrical signal for conversion to barometric pressure.

The characteristics and other relevant information on the aforementioned barometers are listed in Appendix III.

3. Procedures for Comparison

Following the recommended procedures of WMO (WMO, 2008), the comparison of the Hong Kong Standard Barometer with the JMA Primary Standard Barometer was carried out in 3 phases:

(a) Initial comparison at the Hong Kong Observatory Headquarters (phase I);
(b) Comparison at JMA's Meteorological Instrument Centre (MIC) in Tsukuba, Japan (phase II);
(c) Final comparison at the Hong Kong Observatory Headquarters (phase III).

In phase I, the initial comparison at the Hong Kong Observatory Headquarters (HKOHq) between the Hong Kong Standard Barometer and the three travelling standard barometers was performed between 26 November and 7 December 2007. During the comparison, pressure readings were taken only when the pressure at HKOHq as measured by a pressure gauge was either steady or changed by less than 1 hPa per hour and wind speed at HKOHq was less than 12 ms^{-1}, in accordance with WMO's requirements (WMO, 2008). The hourly pressure change was based on measurements taken 30 minutes before and 30 minutes after the observation which was normally carried out on the hour.

In phase II, the comparison between the JMA Primary Standard Barometer and the three travelling standard barometers took place at the MIC of JMA in Tsukuba during 10-14 December 2007. Comparisons at five different nominal pressures, viz. 880hPa, 920hPa, 960hPa, 1000hPa and 1040hPa were conducted. During the comparisons, connecting tubes were mounted to the Primary Standard Barometer and the travelling standard barometers, while a vacuum pump evacuated the air above the piston-cylinder assembly of the Primary Standard Barometer. At each nominal pressure produced by the Primary Standard Barometer, it was related to the precision weights used and the local gravity field. As the comparisons were carried out in a closed environment not exposed to the atmosphere, the results would not be affected by any change in atmospheric pressure or wind conditions as in the case involving mercury barometers. At each nominal pressure, a set of comparison data was collected for each of the travelling standard barometers, enabling the subsequent determination of the average index error for each of them.

In phase III, the final comparison between the Hong Kong Standard Barometer and the three travelling standard barometers was performed at HKOHq from 19 December 2007 to 3 January 2008. As in phase I, pressure readings were taken only when the pressure at HKOHq was either steady or changed by less than 1 hPa per hour and wind speed at HKOHq was less than 12 ms^{-1}.

4. Data Analysis

All readings taken during the comparison between the Hong Kong Standard Barometer and the three travelling standard barometers in phases I and III are shown in Tables 1 and 7 respectively. Pressure readings from the Hong Kong Standard Barometer were reduced to standard conditions, i.e. reference temperature and reference gravity as specified by the equipment manufacturer. The aim was to remove errors associated with the temperature-induced change in the density of mercury and the influence of local gravity. The following corrections were thus calculated:

(a) Manufacturer's index correction (see Appendix IV)

P′ = P (as read) + manufacturer's index correction

(b) Attached thermometer correction (see Appendix IV)

T′ = T (as read) + thermometer correction

(c) Temperature correction (CFT) (see UK Meteorological Office 1956)

$$CFT = -\left[P' \frac{(\beta-\alpha)(T'-32)+30\alpha}{1+\beta(T'-32)} + \frac{V}{A}(\beta-3\gamma)(T'-62)\right]$$

for Kew-pattern inch type the Hong Kong Standard Barometer with P′ in inches of mercury and T′ in degree Fahrenheit.

where

α = coefficient of expansion (length) of brass (1.84×10^{-5}/°C)

β = coefficient of expansion of mercury (1.82×10^{-4}/°C)

γ = composite coefficient of linear expansion of the glass and steel (1.0×10^{-5}/°C)

V = total volume of mercury in the barometer

A = total cross-sectional area of the cistern

V/A = 1.5 inches for the Hong Kong Standard Barometer

(d) Gravity correction (CFG) (see UK Meteorological Office 1956)

$$CFG = (P' + CFT)\frac{(g_h - g_0)}{g_0}$$

where

g_0 = reference gravity
= 9.8062 ms^{-2} for the Hong Kong Standard Barometer
(see Appendix III and UK Meteorological Office 1956)

g_h = local gravity
= 9.78754 ms^{-2}
(based on gravity measurements at HKOHq conducted by the State Bureau of Surveying and Mapping of China, 中國國家測繪局, in 2000)

Information on the change of atmospheric pressure and surface winds conditions at HKOHq during the comparison periods in phases I and III is shown in Tables 2 and 8 respectively. As mentioned in Section 2 above, any change in the atmospheric pressure and surface winds in Tsukuba was not expected to have an effect on the comparison results in phase II. The information is thus not presented here.

The comparison results between the JMA Primary Standard Barometer and the three travelling standard barometers in phase II are shown in Tables 3, 4 and 5 respectively with a summary in Table 6. For the JMA Primary Standard Barometer, the pressure reduced to standard conditions was calculated as follows:

$$P = \frac{P_n g_1}{g_s[1 + \beta(t - t_\gamma)]}$$

where

P = pressure in standard condition (hPa)

P_n = total pressure of weight (hPa)

g_1 = local gravity (piston level, 9.79949 ms^{-2})

g_s = reference gravity (9.80665 ms^{-2})

β = temperature coefficient of piston cross-sectional area
(2.3 x 10^{-5}/°C)

t = measured piston temperature (°C)

t_γ = reference temperature (23.8 °C)

5. Results

Mean differences for barometer readings were calculated using the following equations:

(a) Mean differences between the Hong Kong Standard Barometer (C) and the travelling standard barometers (Q1, Q2 and Q3):

i) For Q1

$$\overline{C - Q1} = 1/2 \left[\overline{(C - Q1)}_{before} + \overline{(C - Q1)}_{after} \right] \text{hPa}$$
$$= 1/2 \left[0.04(1) + 0.03(8) \right] \text{hPa}$$
$$= 0.04(0) \text{ hPa}$$

ii) For Q2

$$\overline{C - Q2} = 1/2 \left[\overline{(C - Q2)}_{before} + \overline{(C - Q2)}_{after} \right] \text{hPa}$$
$$= 1/2 \left[0.04(5) + 0.03(8) \right] \text{hPa}$$
$$= 0.04(2) \text{ hPa}$$

iii) For Q3

$$\overline{C - Q3} = 1/2 \left[\overline{(C - Q3)}_{before} + \overline{(C - Q3)}_{after} \right] \text{hPa}$$
$$= 1/2 \left\{ [-0.09(5)] + [-0.13(2)] \right\} \text{hPa}$$
$$= - 0.11(4) \text{ hPa}$$

where the overbars denote mean values and subscripts denote readings at HKOHq before (phase I) and after (phase III) the journey to Tsukuba respectively. Figures in brackets indicate the extra significant digits used in the mathematical computation for reducing rounding-off errors as pressure readings from the travelling standard barometers are accurate to two decimal places while those from the Hong Kong Standard Barometer and the JMA Primary Standard Barometer are accurate to three decimal places.

b) Mean differences between the JMA Primary Standard Barometer (A) and the travelling barometers (Q1, Q2, Q3) at 1000 hPa, which was closest to the atmospheric pressure experienced during the comparisons in phase I and phase III among the five nominal pressures used in the comparison (phase II):

i) For Q1

$$\overline{(A - Q1)_{1000}} = - 0.03(1) \text{ hPa}$$

ii) For Q2

$$\overline{(A - Q2)_{1000}} = - 0.02(4) \text{ hPa}$$

iii) For Q3

$$\overline{(A - Q3)_{1000}} = - 0.19(6) \text{ hPa}$$

c) Mean differences between the JMA Primary Standard Barometer (A) and the Hong Kong Standard Barometer (C):

i) Using Q1

$$\begin{aligned} \overline{A - C} &= \overline{(A - Q1)} - \overline{(C - Q1)} \\ &= \{ [- 0.03(1)] - [0.04(0)] \} \text{ hPa} \\ &= - 0.07(1) \text{ hPa} \end{aligned}$$

ii) Using Q2

$$\begin{aligned} \overline{A - C} &= \overline{(A - Q2)} - \overline{(C - Q2)} \\ &= \{ [- 0.02(4)] - [0.04(2)] \} \text{ hPa} \\ &= - 0.06(6) \text{ hPa} \end{aligned}$$

iii) Using Q3

$$\begin{aligned} \overline{A - C} &= \overline{(A - Q3)} - \overline{(C - Q3)} \\ &= \{ [- 0.19(6)] - [-0.11(4)] \} \text{ hPa} \\ &= - 0.08(2) \text{ hPa} \end{aligned}$$

Therefore, $$\begin{aligned} \overline{(A - C)_{Q1, Q2, Q3}} &= 1/3\{ [-0.07(1)] + [-0.06(6)] + [-0.08(2)] \} \text{ hPa} \\ &= - 0.07(3) \text{ hPa} \end{aligned}$$

The results showed that the mean difference of -0.07 hPa between the Hong Kong Standard Barometer and the JMA Primary Standard Barometer was within the WMO recommended value of ± 0.1 hPa (see Appendix II). Accordingly, this difference of -0.07 hPa can be neglected and there is no need to apply it as an index correction to the Hong Kong Standard Barometer.

6. Conclusion

The present pressure comparison showed that the Hong Kong Standard Barometer has an index correction of -0.07 hPa, i.e. it gives pressure readings on average 0.07 hPa higher than the JMA Primary Standard Barometer.

Compared with the index correction of +0.16 hPa in 1973, -0.04 hPa in 1983 and -0.15 hPa in 1994, the downward drift of the Hong Kong Standard Barometer's index correction previously observed was no longer evident.

Following WMO's recommended practice on the permissible changes in index correction of mercury barometers, there is no need to apply -0.07 hPa as an index correction to the Hong Kong Standard Barometer.

Acknowledgment

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Reference

1. Chen, T.Y. and Wong, N.Y. (1973), International Comparison of Barometers between Hong Kong and Tokyo, Hong Kong Observatory Technical Note (Local) No. 15.

2. Lee, H.N. and Yeung, M.Y. (1987), Comparison of Barometers and Pyrheliometers between Hong Kong and Tokyo, Hong Kong Observatory Technical Note (Local) No. 38.

3. U.K. Meteorological Office (1956), Handbook of Meteorological Instruments, Part I, M.O. 577.

4. Wong, On (1994), Comparison of Hong Kong Standard Barometer with Sub-regional Standard Barometer in Tokyo 1994, Hong Kong Observatory Technical Note (Local) No. 64.

5. WMO (1995), Manual on the Global Observing System, Volume II Regional Aspects, WMO-No. 544

6. WMO (2008), Guide to Meteorological Instruments and Methods of Observations, WMO-No. 8.

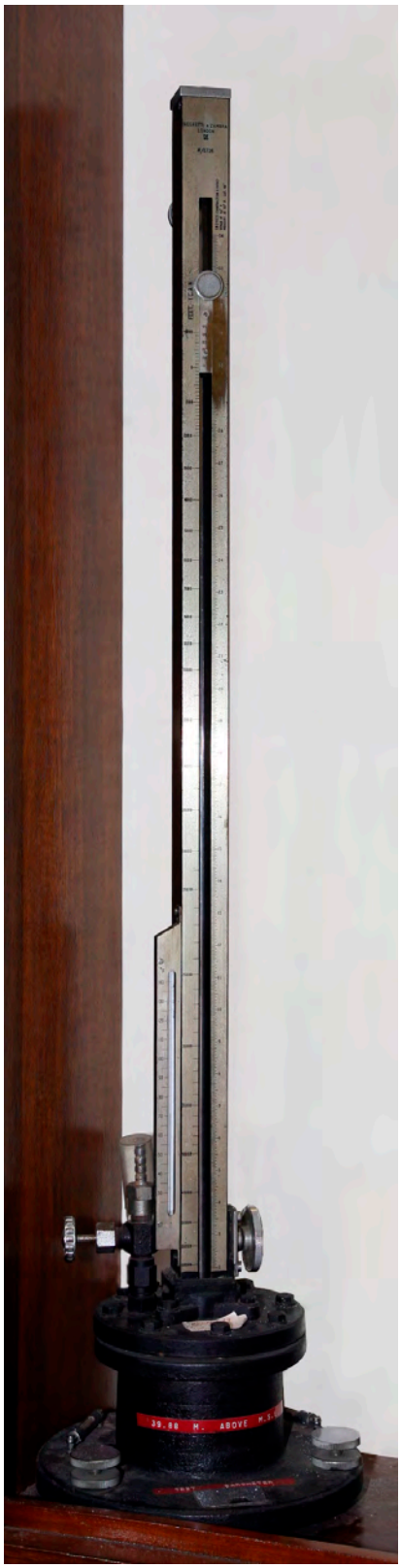

Figure 1 The Hong Kong Standard Barometer

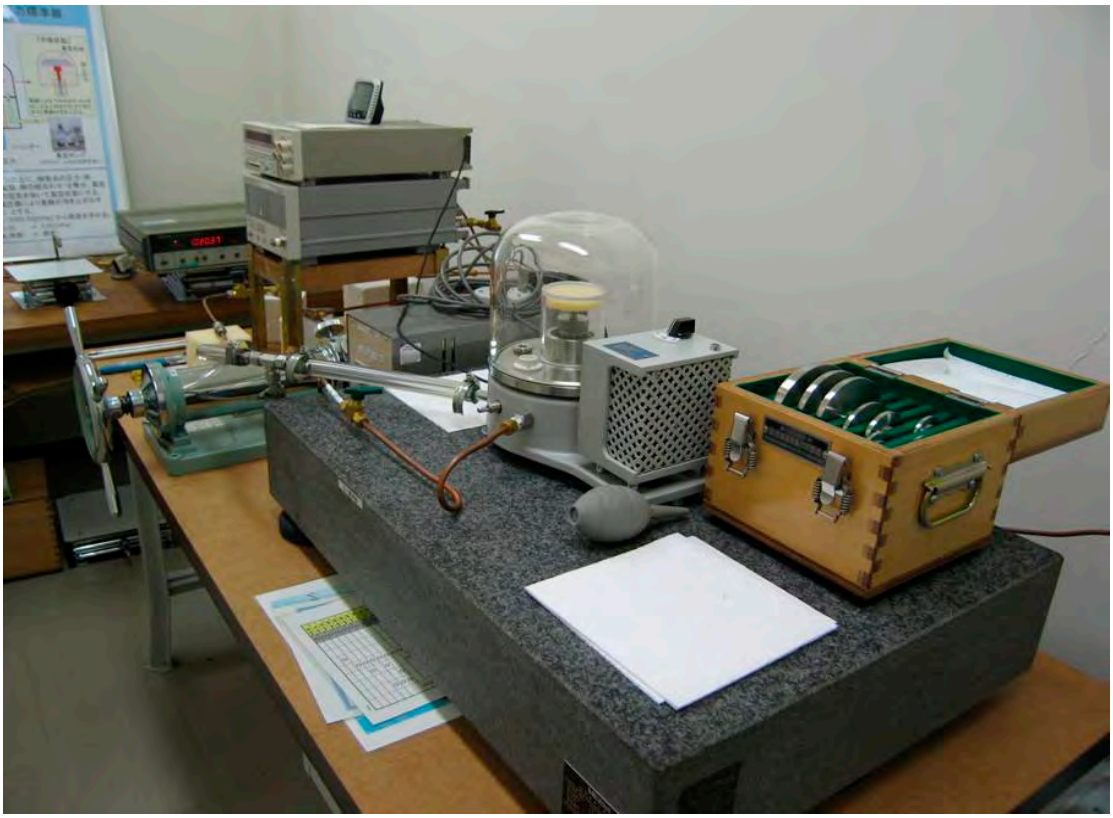

Figure 2 The Japan Meteorological Agency Primary Standard Barometer

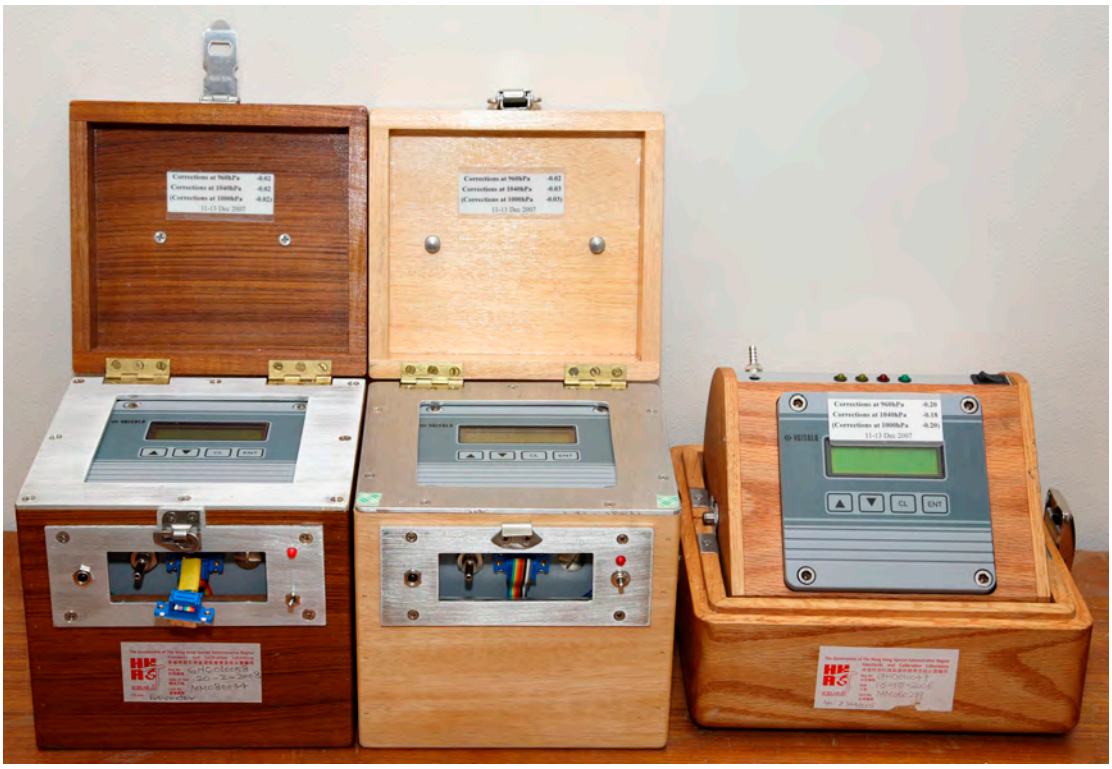

Figure 3 Travelling Standard Precision Digital Barometers

Table 1: Result of Comparison between the Hong Kong Standard Barometer (C) and Travelling Barometers (Q1, Q2, Q3) in November – December 2007 at HKOHq

Time of Readings	HK Standard Barometer (C)			Travelling Barometers (Q1, Q2, Q3)					
	Pressure As read	Corrected Attached Thermometer	Pressure reduced to Std Condition	Pressure As Read (C0140003) Q1	Difference (C-Q1)	Pressure As Read (C0140004) Q2	Difference (C-Q2)	Pressure As Read (Z3440005) Q3	Difference (C-Q3)
(HK Local Time)	(inHg)	(°F)	(hPa)	(hPa)	(hPa)	(hPa)	(hPa)	(hPa)	(hPa)
26 Nov 10:00	30.004	68.8	1010.573	1010.50	0.073	1010.49	0.083	1010.66	-0.087
11:00	30.010	68.8	1010.775	1010.68	0.095	1010.67	0.105	1010.81	-0.035
14:00	29.924	69.6	1007.803	1007.71	0.093	1007.70	0.103	1007.84	-0.037
27 Nov 09:00	29.976	68.8	1009.630	1009.69	-0.060	1009.69	-0.060	1009.74	-0.110
11:00	29.968	69.3	1009.313	1009.37	-0.057	1009.37	-0.057	1009.52	-0.207
14:00	29.890	69.3	1006.686	1006.58	0.106	1006.58	0.106	1006.74	-0.054
15:00	29.878	69.3	1006.282	1006.21	0.072	1006.21	0.072	1006.34	-0.058
16:00	29.878	69.5	1006.263	1006.17	0.093	1006.17	0.093	1006.33	-0.067
29 Nov 09:00	30.184	68.0	1016.712	1016.67	0.042	1016.66	0.052	1016.83	-0.118
10:00	30.190	67.8	1016.933	1016.95	-0.017	1016.95	-0.017	1017.09	-0.157
11:00	30.176	67.9	1016.452	1016.42	0.032	1016.41	0.042	1016.56	-0.108
14:00	30.106	67.8	1014.104	1014.05	0.054	1014.05	0.054	1014.19	-0.086
15:00	30.098	67.8	1013.835	1013.90	-0.065	1013.89	-0.055	1013.95	-0.115
16:00	30.122	67.8	1014.643	1014.60	0.043	1014.60	0.043	1014.73	-0.087
17:00	30.140	67.8	1015.249	1015.21	0.039	1015.21	0.039	1015.34	-0.091
30 Nov 09:00	30.308	68.6	1020.830	1020.84	-0.010	1020.84	-0.010	1020.99	-0.160
10:00	30.304	68.3	1020.724	1020.70	0.024	1020.68	0.044	1020.80	-0.076
11:00	30.290	68.3	1020.253	1020.20	0.053	1020.19	0.063	1020.34	-0.087
12:00	30.260	68.3	1019.243	1019.23	0.013	1019.22	0.023	1019.38	-0.137
3 Dec 09:00	30.234	68.8	1018.319	1018.29	0.029	1018.29	0.029	1018.43	-0.111
10:00	30.230	68.8	1018.184	1018.11	0.074	1018.10	0.084	1018.25	-0.066
12:00	30.198	68.8	1017.106	1017.11	-0.004	1017.10	0.006	1017.25	-0.144
4 Dec 09:00	30.312	68.3	1020.994	1020.94	0.054	1020.93	0.064	1021.10	-0.106
10:00	30.310	68.3	1020.926	1020.90	0.026	1020.90	0.026	1021.03	-0.104
11:00	30.294	68.3	1020.388	1020.33	0.058	1020.32	0.068	1020.47	-0.082
5 Dec 14:00	30.216	68.3	1017.761	1017.77	-0.009	1017.77	-0.009	1017.83	-0.069
17:00	30.220	68.6	1017.867	1017.78	0.087	1017.78	0.087	1017.92	-0.053
6 Dec 09:00	30.258	67.9	1019.214	1019.06	0.154	1019.06	0.154	1019.23	-0.016
10:00	30.226	68.3	1018.097	1018.05	0.047	1018.06	0.037	1018.21	-0.113
12:00	30.202	68.3	1017.289	1017.22	0.069	1017.22	0.069	1017.38	-0.091
7 Dec 09:00	30.194	67.8	1017.068	1017.01	0.058	1017.01	0.058	1017.17	-0.102
				N = 31 Sum = 1.266 Mean (C – Q1) = 0.041 Std deviation = 0.050		N = 31 Sum = 1.396 Mean (C – Q2) = 0.045 Std deviation = 0.050		N = 31 Sum = -2.934 Mean (C – Q3) = -0.095 Std deviation = 0.040	

Table 2 : Wind and Pressure Information during Barometer Comparison in November and December 2007 at HKOHq

Time (HK local Time)		Pressure Change (hPa/h)	Surface Wind	
			Hourly Mean (m/s)	Max Gust (m/s)
26 Nov	10:00	0.1	2.5	3.2
	11:00	-0.5	2.6	4.1
	14:00	-0.6	2.4	3.8
27 Nov	09:00	0.1	2.2	0.3
	11:00	-0.6	2.6	2.0
	14:00	-0.6	2.3	2.8
	15:00	0.0	1.8	3.1
	16:00	-0.2	2.3	5.5
29 Nov	09:00	0.5	1.5	2.3
	10:00	-0.1	1.3	0.3
	11:00	-0.5	1.2	0.9
	14:00	-0.5	2.0	2.7
	15:00	0.2	1.4	2.8
	16:00	0.7	2.2	3.8
	17:00	0.7	3.0	3.8
30 Nov	09:00	0.6	2.2	2.3
	10:00	-0.4	3.8	6.2
	11:00	-0.7	4.3	4.5
	12:00	-0.8	3.6	6.5
3 Dec	09:00	0.2	1.1	0.2
	10:00	-0.3	0.6	4.0
	12:00	-0.8	0.5	1.4
4 Dec	09:00	0.3	2.4	3.8
	10:00	-0.3	2.6	2.3
	11:00	-0.7	2.9	4.2
5 Dec	14:00	-0.8	3.6	6.5
	17:00	0.4	3.1	5.7
6 Dec	09:00	0.1	0.5	1.7
	10:00	-0.2	0.2	0.4
	12:00	-0.9	1.5	2.3
7 Dec	09:00	0.6	0.4	2.7

Table 3 : Result of Comparison between the Primary Standard Barometer (A) of the Japan Meteorological Agency (JMA) and Travelling Barometer (Q1) in December 2007 at Tsukuba

Time of Readings (Japan Standard Time)		Temp. (°C)	R.H. (%)	Nominal Pressure (hPa)	The JMA Primary Standard Barometer (A)		Vacuum Pressure (hPa)	Corrected Vacuum Pressure V_c (hPa)	Travelling Barometers (Q1) Pressure As Read (hPa)	Difference ($A_s + V_c - Q1$) or ($A - Q1$) (hPa)
					Calibrated Pressure (hPa)	Pressure reduced to Std Condition A_s (hPa)				
11 Dec	13:05	20.41	43.86	960	959.978	959.352	0.0354	0.038	959.41	-0.020
	14:00	20.76	44.27	920	919.983	919.376	0.0358	0.039	919.44	-0.025
	14:45	21.03	44.83	880	879.985	879.398	0.0346	0.038	879.44	-0.004
	16:00	21.44	42.55	1000	999.973	999.297	0.0336	0.037	999.36	-0.026
	17:30	21.80	47.36	920	919.983	919.354	0.0340	0.037	919.41	-0.019
	18:00	21.94	47.78	880	879.985	879.380	0.0347	0.038	879.43	-0.012
12 Dec	09:30	19.58	40.61	1040	1039.972	1039.314	0.0267	0.03	1039.37	-0.026
	10:00	19.81	41.60	1000	999.973	999.335	0.0332	0.036	999.4	-0.029
	10:40	20.19	43.01	960	959.978	959.357	0.0350	0.038	959.42	-0.025
	11:20	20.54	45.87	920	919.983	919.381	0.0351	0.038	919.43	-0.011
	12:00	20.88	43.85	880	879.985	879.401	0.0344	0.037	879.45	-0.012
	13:05	21.26	44.00	1040	1039.972	1039.273	0.0310	0.034	1039.34	-0.033
	13:50	21.45	43.46	1000	999.973	999.297	0.0307	0.034	999.37	-0.039
	14:40	21.56	43.73	960	959.978	959.327	0.0311	0.034	959.39	-0.029
	15:50	21.76	46.64	1040	1039.972	1039.261	0.0318	0.035	1039.33	-0.034
						Sum (A- Q1)		Mean (A- Q1)		
				1040	N = 3	- 0.093		- 0.031		
				1000	N = 3	- 0.094		- 0.031		
				960	N = 3	- 0.074		- 0.025		
				920	N = 3	- 0.055		- 0.018		
				880	N = 3	- 0.028		- 0.009		

Table 4 : Result of Comparison between the Primary Standard Barometer (A) of the Japan Meteorological Agency (JMA) and Travelling Barometer (Q2) in December 2007 at Tsukuba

Time of Readings (Japan Standard Time)		Temp. (°C)	R.H. (%)	Nominal Pressure (hPa)	The JMA Primary Standard Barometer (A)		Vacuum Pressure (hPa)	Corrected Vacuum Pressure V_c (hPa)	Travelling Barometers (Q2) Pressure As Read (hPa)	Difference ($A_s + V_c - Q2$) (hPa)
					Calibrated Pressure (hPa)	Pressure reduced to Std Condition A_s (hPa)				
11 Dec	11:55	19.76	43.87	1000	999.973	999.336	0.0428	0.046	999.41	-0.028
	13:05	20.41	43.86	960	959.978	959.352	0.0354	0.038	959.41	-0.020
	14:00	20.76	44.27	920	919.983	919.376	0.0358	0.039	919.44	-0.025
	14:45	21.03	44.83	880	879.985	879.398	0.0346	0.038	879.44	-0.004
	16:00	21.44	42.55	1000	999.973	999.297	0.0336	0.037	999.36	-0.026
	17:30	21.80	47.36	920	919.983	919.354	0.0340	0.037	919.41	-0.019
	18:00	21.94	47.78	880	879.985	879.380	0.0347	0.038	879.43	-0.012
12 Dec	9:30	19.58	40.61	1040	1039.972	1039.314	0.0267	0.030	1039.36	-0.016
	10:00	19.81	41.60	1000	999.973	999.335	0.0332	0.036	999.39	-0.019
	10:40	20.19	43.01	960	959.978	959.357	0.0350	0.038	959.42	-0.025
	11:20	20.54	45.87	920	919.983	919.381	0.0351	0.038	919.43	-0.011
	12:00	20.88	43.85	880	879.985	879.401	0.0344	0.037	879.46	-0.022
	13:05	21.26	44.00	1040	1039.972	1039.273	0.0310	0.034	1039.34	-0.033
	14:40	21.56	43.73	960	959.978	959.327	0.0311	0.034	959.38	-0.019
	15:50	21.76	46.64	1040	1039.972	1039.261	0.0318	0.035	1039.32	-0.024
						Sum (A- Q2)		Mean (A- Q2)		
				1040	N = 3	- 0.073		- 0.024		
				1000	N = 3	- 0.073		- 0.024		
				960	N = 3	- 0.064		- 0.021		
				920	N = 3	- 0.055		- 0.018		
				880	N = 3	- 0.038		- 0.013		

Table 5 : Result of Comparison between the Primary Standard Barometer (A) of the Japan Meteorological Agency (JMA) and Travelling Barometer (Q3) in December 2007 at Tsukuba

Time of Readings (Japan Standard Time)		Temp. (°C)	R.H. (%)	Nominal Pressure (hPa)	The JMA Primary Standard Barometer (A)		Vacuum Pressure (hPa)	Corrected Vacuum Pressure V_c (hPa)	Travelling Barometers (Q3) Pressure As Read (hPa)	Difference $(A_s + V_c - Q3)$ (hPa)
					Calibrated Pressure (hPa)	Pressure reduced to Std Condition A_s (hPa)				
12 Dec	16:40	22.06	49.04	1000	999.973	999.283	0.0323	0.035	999.52	-0.202
	17:15	22.12	48.53	960	959.978	959.314	0.0303	0.033	959.55	-0.203
	18:00	22.16	45.56	920	919.983	919.346	0.0303	0.033	919.57	-0.191
	18:35	22.21	46.76	880	879.985	879.375	0.0311	0.034	879.61	-0.201
13 Dec	9:45	20.06	45.97	1000	999.973	999.329	0.0302	0.033	999.56	-0.198
	10:30	20.40	46.67	960	959.978	959.352	0.0343	0.037	959.59	-0.201
	11:15	20.70	47.25	920	919.983	919.377	0.0338	0.037	919.62	-0.206
	12:05	20.98	47.66	880	879.985	879.399	0.0315	0.035	879.64	-0.206
	13:10	21.26	45.52	1040	1039.972	1039.273	0.0304	0.033	1039.49	-0.184
	13:50	21.43	47.55	1000	999.973	999.297	0.0306	0.034	999.52	-0.189
	14:40	21.58	46.07	960	959.978	959.326	0.0302	0.033	959.55	-0.191
	15:25	21.73	47.28	920	919.983	919.356	0.0298	0.033	919.58	-0.191
	16:05	21.85	46.74	880	879.985	879.382	0.0282	0.031	879.61	-0.197
	16:55	21.97	45.67	1040	1039.972	1039.256	0.0290	0.032	1039.48	-0.192
	18:30	22.18	46.74	1040	1039.972	1039.251	0.0282	0.031	1039.46	-0.178
						Sum (A- Q3)		Mean (A- Q3)		
			1040		N = 3	- 0.554		- 0.185		
			1000		N = 3	- 0.589		- 0.196		
			960		N = 3	- 0.595		- 0.198		
			920		N = 3	- 0.588		- 0.196		
			880		N = 3	- 0.604		- 0.201		

Table 6 : Summary of the Comparison Results between the Primary Standard Barometer (A) of the Japan Meteorological Agency (JMA) and Travelling Barometers (Q1, Q2, Q3) in December 2007 at Tsukuba

Travelling Barometers	Calibrated Pressure (hPa)	880	920	960	1000	1040
Q1	Index Error (hPa)	- 0.009	- 0.018	- 0.025	- 0.031	- 0.031
Q2		- 0.013	- 0.018	- 0.021	- 0.024	- 0.024
Q3		- 0.201	- 0.196	- 0.198	- 0.196	- 0.185

Index error = [JMA Primary Standard Barometer (A)] – [HKO travelling standard barometer (Q)]
Expanded uncertainty, U for Q1, Q2, Q3 is: 0.04 hPa (The expanded uncertainty, U, corresponds to a 95% probability that the Index Error, Y, lies within the interval Y-U to Y+U).

Table 7 : Result of Comparison between the Hong Kong Standard Barometer (C) and Travelling Barometers (Q1, Q2, Q3) in December 2007 and January 2008 at HKOHq

Time of Readings (HK Local Time)		HK Standard Barometer (C)			Travelling Barometers (Q1, Q2, Q3)					
		Pressure As read (inHg)	Corrected Attached Thermometer (°F)	Pressure reduced to Std Condition (hPa)	Pressure As Read (C0140003) Q1 (hPa)	Difference (C-Q1) (hPa)	Pressure As Read (C0140004) Q2 (hPa)	Difference (C-Q2) (hPa)	Pressure As Read (Z3440005) Q3 (hPa)	Difference (C-Q3) (hPa)
19 Dec	14:00	30.042	68.8	1011.853	1011.81	0.043	1011.80	0.053	1011.98	-0.127
	15:00	30.026	69.1	1011.285	1011.18	0.105	1011.18	0.105	1011.36	-0.075
	16:00	30.024	69.3	1011.199	1011.15	0.049	1011.15	0.049	1011.31	-0.111
	17:00	30.044	69.3	1011.872	1011.74	0.132	1011.74	0.132	1011.91	-0.038
20 Dec	10:00	30.150	68.8	1015.490	1015.45	0.040	1015.45	0.040	1015.64	-0.150
	14:00	30.032	69.3	1011.468	1011.43	0.038	1011.43	0.038	1011.60	-0.132
	15:00	30.026	69.8	1011.218	1011.21	0.008	1011.21	0.008	1011.38	-0.162
	16:00	30.026	69.8	1011.218	1011.28	-0.062	1011.28	-0.062	1011.44	-0.222
	17:00	30.036	69.8	1011.555	1011.61	-0.055	1011.61	-0.055	1011.79	-0.235
21 Dec	09:00	30.088	69.3	1013.354	1013.28	0.074	1013.28	0.074	1013.46	-0.106
	14:00	29.982	70.3	1009.689	1009.61	0.079	1009.61	0.079	1009.79	-0.101
	15:00	29.964	70.3	1009.083	1009.00	0.083	1009.00	0.083	1009.20	-0.117
	16:00	29.960	70.6	1008.919	1008.84	0.079	1008.84	0.079	1009.08	-0.161
	17:00	29.970	70.8	1009.237	1009.14	0.097	1009.14	0.097	1009.31	-0.073
24 Dec	10:00	30.070	68.8	1012.796	1012.76	0.036	1012.75	0.046	1012.94	-0.144
	11:00	30.050	69.3	1012.074	1012.11	-0.036	1012.12	-0.046	1012.28	-0.206
	15:00	29.992	69.8	1010.073	1010.00	0.073	1010.00	0.073	1010.17	-0.097
27 Dec	10:00	30.102	68.8	1013.873	1013.79	0.083	1013.79	0.083	1013.96	-0.087
	14:00	29.980	68.8	1009.765	1009.66	0.105	1009.66	0.105	1009.83	-0.065
	15:00	29.960	69.3	1009.044	1008.93	0.114	1008.93	0.114	1009.10	-0.056
	16:00	29.948	69.3	1008.639	1008.58	0.059	1008.58	0.059	1008.75	-0.111
	17:00	29.948	69.3	1008.639	1008.71	-0.071	1008.71	-0.071	1008.88	-0.241
28 Dec	09:00	30.036	68.3	1011.699	1011.60	0.099	1011.60	0.099	1011.81	-0.111
	10:00	30.030	68.3	1011.497	1011.41	0.087	1011.42	0.077	1011.60	-0.103
	11:00	30.020	68.8	1011.112	1011.08	0.032	1011.08	0.032	1011.25	-0.138
31 Dec	10:00	30.256	67.8	1019.156	1019.04	0.116	1019.04	0.116	1019.21	-0.054
	11:00	30.242	67.8	1018.685	1018.62	0.065	1018.62	0.065	1018.78	-0.095
	14:00	30.154	67.8	1015.721	1015.69	0.031	1015.69	0.031	1015.86	-0.139
2 Jan	09:00	30.334	67.8	1021.783	1021.83	-0.047	1021.83	-0.047	1022.03	-0.247
	10:00	30.332	67.8	1021.716	1021.74	-0.024	1021.74	-0.024	1021.89	-0.174
	11:00	30.328	67.8	1021.581	1021.47	0.111	1021.47	0.111	1021.63	-0.049
	14:00	30.240	67.8	1018.617	1018.61	0.007	1018.61	0.007	1018.76	-0.143
	15:00	30.230	67.8	1018.280	1018.25	0.030	1018.25	0.030	1018.41	-0.130
	16:00	30.226	67.8	1018.146	1018.15	-0.004	1018.15	-0.004	1018.32	-0.174
	17:00	30.240	67.8	1018.617	1018.61	0.007	1018.62	-0.003	1018.78	-0.163
3 Jan	09:00	30.302	68.3	1020.657	1020.65	0.007	1020.64	0.017	1020.79	-0.133
	10:00	30.302	68.3	1020.657	1020.66	-0.003	1020.66	-0.003	1020.80	-0.143
	11:00	30.286	68.3	1020.118	1020.18	-0.062	1020.18	-0.062	1020.33	-0.212
	14:00	30.180	67.8	1016.596	1016.55	0.046	1016.55	0.046	1016.70	-0.104
	15:00	30.160	67.8	1015.923	1015.89	0.033	1015.89	0.033	1016.04	-0.117
	16:00	30.146	67.8	1015.451	1015.45	0.001	1015.45	0.001	1015.60	-0.149
	17:00	30.146	67.8	1015.451	1015.46	-0.009	1015.46	-0.009	1015.62	-0.169
					N = 42		N = 42		N = 42	
					Sum = 1.589		Sum = 1.589		Sum = -5.562	
					Mean (C - Q1) = 0.038		Mean (C - Q2) = 0.038		Mean (C - Q3) = -0.132	
					Std deviation = 0.055		Std deviation = 0.055		Std deviation = 0.052	

Table 8 : Wind and Pressure Information during Barometer Comparison in December 2007 and January 2008 at HKOHq

Time (HK local Time)		Pressure change (hPa/h)	Surface Wind	
			Hourly Mean (m/s)	Max Gust (m/s)
19 Dec	14:00	-0.7	2.2	3.0
	15:00	-0.5	0.9	3.1
	16:00	0.4	0.4	0.3
	17:00	0.5	0.3	1.7
20 Dec	10:00	-0.3	5.1	5.8
	14:00	-0.7	4.1	5.0
	15:00	0.0	4.0	7.6
	16:00	0.1	4.5	5.3
	17:00	0.4	4.1	7.0
21 Dec	09:00	-0.1	4.6	5.8
	14:00	-0.7	3.7	3.6
	15:00	-0.5	2.8	4.8
	16:00	0.1	2.2	1.9
	17:00	0.2	2.4	3.3
24 Dec	10:00	-0.2	0.4	0.3
	11:00	-0.4	0.4	0.3
	15:00	-0.1	1.7	2.3
27 Dec	10:00	-0.2	2.1	3.8
	14:00	-0.8	3.4	5.2
	15:00	-0.6	3.5	6.3
	16:00	-0.1	3.4	3.5
	17:00	0.1	2.8	3.0
28 Dec	09:00	0.2	2.9	2.7
	10:00	-0.3	3.1	5.3
	11:00	-0.5	3.1	5.2
31 Dec	10:00	0.2	2.6	3.0
	11:00	-0.8	2.4	3.9
	14:00	-0.6	1.5	0.3
2 Jan	09:00	0.2	1.9	3.0
	10:00	-0.3	2.0	0.3
	11:00	-0.4	1.2	2.2
	14:00	-0.6	2.5	3.2
	15:00	-0.3	2.8	3.5
	16:00	0.2	2.9	2.4
	17:00	0.5	3.2	4.6
3 Jan	09:00	0.3	0.6	2.2
	10:00	0.1	1.6	0.3
	11:00	-0.9	2.2	3.0
	14:00	-0.8	2.5	4.5
	15:00	-0.6	3.3	4.1
	16:00	-0.2	3.0	3.7
	17:00	0.1	2.1	3.0

Appendix I

WMO's definitions on various categories of barometers (WMO, 2008)

A — A primary or secondary standard barometer capable of independent determination of pressure to an uncertainty of at least 0.05hPa;

B — A working standard barometer of a design suitable for routine pressure comparisons ad with known errors, which have been established by comparison with a primary or secondary standard;

C — A reference standard barometer used for comparisons of travelling standard and station barometers at field supervising stations of a National Meteorological Service;

S — A barometer (mercury, aneroid, electronic) located at an ordinary meteorological station;

P — A mercury barometer of good quality and accuracy, which may be carried from one station to another and still retain calibration;

N — A portable precision aneroid barometer of first quality;

Q — A portable precision digital barometer of first quality, to be used as a travelling standard (Q stands for quality).

The Primary Standard Barometer at JMA's MIC is of category A. The Hong Kong Standard Barometer is of category C. The precision digital travelling standard barometers are of category Q.

Appendix II

Permissible changes in index correction of mercury barometers (WMO, 2008)

Changes in index correction should be treated as follows:

(a) A change in correction within 0.1 hPa may be neglected unless persistent;

(b) A change in correction exceeding 0.1 hPa but not exceeding 0.3 hPa may be provisionally accepted unless confirmed by at least one subsequent inspection;

(c) A change in correction exceeding 0.3 hPa may be accepted provisionally only if the barometer is cleaned and a spare barometer with known correction is not available. This barometer should be replaced as soon as a correctly calibrated barometer becomes available.

Appendix III

Characteristics of Barometers and Locations Concerned

1. The JMA Primary Standard Barometer in Tsukuba – (A)

Type : Pressure Balance AV-02
Manufacturer : Futaba Sokki Co. Ltd.
Serial number : 365
Date of construction : February 1996
Reference temperature : 23.8 °C
Reference gravity : 9.80665 ms^{-2}
Measurement range : 50 – 1150 hPa
Index error : calibrated against the pressure balance of the National Metrology Institute of Japan (NMIJ)/Advanced Industrial Science and Technology (AIST) in September-October 2006. The index error is less than 3.0 Pa. Details are as follows:

Nominal Pressure (hPa)	Calibrated Pressure (hPa)	Vacuum Pressure (Pa)
50	50.008	0.4
100	100.005	0.5
200	199.999	0.6
500	499.988	0.9
800	799.980	1.1
900	899.976	1.1
1000	999.973	1.1
1150	1149.969	1.2

Location: 1-2 Nagamine, Tsukuba-shi, Ibaraki, Japan
Latitude : 36° 03.4’ N
Longitude : 140° 07.5’ E
Elevation : 22.9 m above M.S.L.
Value of local gravity (piston level) 9.79949 ms^{-2}

2. Standard Barometer of Hong Kong – (category C)

Type :	Kew-pattern mercury barometer
Manufacturer :	Negretti & Zambra, London
Serial Number :	M 6726
Date of construction :	1950
Bore of tube :	12.7 mm
Reference temperature :	0 °C for mercury, 16.7 °C for scale
Reference gravity :	9.8062 ms^{-2}
Range of scale :	2-34 inHg
Least count of vernier :	0.002 inHg

Index error : -0.15 hPa by reference standard in Tokyo in 1994

Location : Tsim Sha Tsui, Kowloon, Hong Kong
Latitude : 22° 18' 08" N
Longitude : 114° 10' 28" E
Height of cistern above M.S.L. 40m
Value of local gravity 9.78754 ms^{-2}

3. Travelling Standard Barometers – (category Q)

According to WMO's recommendation, three precision digital barometers were used as travelling standards. They are used because of their portability and good short-term stability (WMO, 2008).

i) Precision Digital Barometer (Q1)

Type :	Digital, PTB220TS
Manufacturer :	Vaisala
Serial number :	C0140003
Date of construction :	2007
Measurement range :	500 – 1100 hPa
Resolution :	0.01 hPa
Long-term stability :	± 0.01 hPa / year

Index error : ± 0.01 hPa in the range of 500-1100 hPa according to the calibration certificate issued by Vaisala in January 2007.

ii) Precision Digital Barometer (Q2)

Type : Digital, PTB220TS
Manufacturer : Vaisala
Serial number : C0140004
Date of construction : 2007
Measurement range : 500 – 1100 hPa
Resolution : 0.01 hPa
Long-term stability : ± 0.01 hPa / year
Index error : less than 0.01 hPa in the range of 500-1100 hPa according to the calibration certificate issued by Vaisala in January 2007.

iii) Precision Digital Barometer (Q3)

Type : Digital, PTB220TS
Manufacturer : Vaisala
Serial number : Z3440005
Date of construction : 2004
Measurement range : 500 – 1100 hPa
Resolution : 0.01 hPa
Long-term stability : ± 0.01 hPa / year
Index error* : 0.14-0.16 hPa in the range of 800-1100 hPa according to the calibration certificate issued by the Hong Kong Standards and Calibration Laboratory in October 2006.

*Note: Albeit with larger index correction, comparison between the precision digital barometer (Q3) and the Hong Kong Standard Barometer from November 2006 to November 2007 (before the journey to Tsukuba) showed that Q3 had a history of reliability with low drift corrections (drift rate < 0.05 hPa / year), making it suitable to serve as a travelling standard barometer (WMO, 2008).

Appendix IV

Corrections for the Hong Kong Standard Barometer

1. Corrections for attached thermometer

Temperature as read (°F)	Corrections (°F)
30.0 – 42.0	0.0
42.0 – 62.0	-0.1
62.0 – 122.0	-0.2

2. Corrections for manufacturer’s index error

Pressure as read (inHg)	Corrections (inHg)
22.50 – 23.50	0.006
23.50 – 24.50	0.005
24.50– 25.50	0.004
25.50 – 26.50	0.003
26.50 – 27.50	0.004
27.50 – 28.50	0.004
28.50 – 29.50	0.005
29.50 – 30.50	0.005
30.50 – 31.50	0.003