P2.3 Performance of rain gauges in a field study at the Hong Kong International Airport

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1. INTRODUCTION

The Hong Kong International Airport (HKIA) is both the aviation weather station and the synoptic weather station of Hong Kong. For weather reporting purpose, accurate measurement of the rainfall amount is essential. Following the requirement as stipulated in the World Meteorological Organization (WMO) No. 8 (2009), rainfall amount measurement has to achieve an accuracy of 5% with a reporting resolution of 0.1 mm. The operational rain gauges at HKIA, namely, Ogawa Seiki 7182R, is found to fulfill such requirements, but the accuracy is achieved up to a rainfall intensity of about 100 mm/hour. Located in a subtropical coastal region, the rainfall rate of Hong Kong could reach a few hundreds of mm/hour at times in summer monsoonal rain. As a result, a field study has been arranged at the meteorological garden at HKIA since early 2010 to compare the performance of a number of commonly available rain gauges in the market to find out if the latest technology could fulfill all the WMO requirements for the climatological conditions in Hong Kong.

The comparison study has been conducted throughout the spring, summer and early autumn in 2010. There have been more than 100 days with rainfall recorded at HKIA, in which more than 10 days having a daily rainfall of 50 mm or more. Though still rather limited in the number of heavy rain days, such a data sample is considered to be rather useful in studying the performance of the various rain gauges. This paper aims at providing a summary of the preliminary comparison results of the gauges.

The rain gauges used in the present study are briefly described in Section 2. The comparison results are discussed in Sections 3 and 4. The performance of the rain gauges is studied by comparing with human measurements of the daily rainfall, which are taken as ground truth of the daily total rain amount. In particular, Section 3 presents the comparison between the human-measured daily total and the gauge-measured daily total in terms of the root-mean-square difference, and the same figures are presented in terms of the percentage differences in Section 4 in order to adopt the 5% accuracy requirement of WMO No. 8 directly. The conclusions and the future work are mentioned in Section 5.

2. RAIN GAUGES AT HKIA

The setup of the rain gauges is shown in Figure 1. The study period is from February to September 2010, covering all the major rain events in the year. The following rain gauges are used in the present study:

(i) Three units of Ogawa rain gauge 7182R. They are drop-counting rain gauges. The optimum drop size is determined for each rain gauge based on annual calibration in the laboratory at HKIA. Using the optimum drop size, the rain gauge is found to fulfill WMO accuracy requirement up to a rainfall rate of about 100 mm/hour.

(ii) One of the Ogawa rain gauges, labelled as Ogawa B, has also been calibrated in Department of Construction, Environmental and Territorial Engineering, University of Genova. In this process, a variable drop size (as a function of the rainfall rate) has been established, and the results are published in a calibration report. This variable drop size is implemented in real-time by considering the 1-minute rainfall amount. Using the variable drop size, it has been suggested that the Ogawa rain gauge could fulfill WMO accuracy requirement up to 140 mm/hour.

(iii) A 0.1-mm tipping bucket rain gauge of Logotronic MRF-C ZAMG Version. According to the manufacturer, besides the normal tipping of the bucket, additional tips are added to compensate for loss of rainfall in between the tips, particularly for high rainfall rate. Based on laboratory calibration at HKIA, this rain gauge fulfills WMO accuracy requirement up to 230 mm/hour.

(iv) A 0.5-mm tipping bucket rain gauge from Casella (known as CL1). This does not fulfill WMO's resolution requirement of 0.1 mm, but it has been used for long time at the outstations at the Hong Kong Observatory due to its robustness and relatively low cost. Based on laboratory calibration at HKIA, this rain gauge fulfills WMO accuracy requirement up to 210 mm/hour.

(v) A tilting siphon rain gauge of Casella. It uses a floater to keep track of the amount of rain water accumulated inside a bucket, and the total rainfall amount is updated continuously by drawing a trace on a chart. As a result, the daily rainfall totals have to be read out manually from the charts. Theoretically speaking, the tilting siphon rain gauge does not have an upper limit of the rainfall rate for fulfilling the WMO accuracy requirement. However, the bucket has to be emptied when it is full of rain water, and during the emptying the rainfall record will not be accurate if it is still raining.

For the rain gauges (i) to (iv) above, the digital outputs are sampled by in-house developed electronic

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units with sampling rate of 23 Hz. As a result, the rain gauges could measure up to an instantaneous rainfall rate of at least 300 mm/hour, which should be sufficient for the climatological condition in Hong Kong in the majority of the cases.

3. BIASES AND ROOT-MEAN-SQUARE DIFFERENCES

Tables 1 to 4 show the biases and root-mean-square differences of the daily total rainfall values recorded by the various rain gauges in comparison with the manually measured values. They correspond to all days with non-zero amount of rainfall (i.e. days with rain), 10 mm of rain or more (i.e. days with moderate rain), 25 mm of rain or more (i.e. days with heavy rain), and 50 mm of rain or more (i.e. days with very heavy rain) based on the manual measurement. The manual measurement of each day is taken between 3 p.m. Hong Kong time of the previous day and 3 p.m. of the present day.

The number of cases in each category is given at the top of each table. Please note that the case numbers for different rain gauges could be different because some rain gauges may not function normally on certain days. The bias and the root-mean-square difference of each rain gauge are only calculated based on those days when the rain gauge under consideration is working properly. Normally, the rain gauges were inspected every day during the study period to see if they were functionally well, e.g. whether there appeared to be blockage in the water inflow or problems with the data processing electronics.

From Tables 1 to 4, it could be observed that:

(i) Among the rain gauges under consideration, Logotronics gauge has the best performance in terms of the smallest root-mean-square difference with the manual measurement;

(ii) Ogawa and Casella 0.5-mm tipping bucket gauges are among the batch of the second best gauges in the study, again in terms of the root-mean-square difference with the manual measurement. As a result, the present choice of using Ogawa rain gauge as the official gauge at HKIA appears to be a reasonable choice. The use of Casella 0.5-mm gauge at the outstations is also a good selection, despite the rather coarse reporting resolution;

(iii) There seems to be differences in behaviour among the three Ogawa gauges. In particular, Ogawa A has the best performance, followed by Ogawa B and Ogawa C. As a result, there appears to be unit-to-unit variability in the performance of the three gauges from the same manufacturer. This kind of local random error has already been observed in the previous study. Ogawa C was found to have the worst performance in the study, mainly because of the rather sticky surface of the water collection funnel. This problem was solved in the latter part of the comparison study with the replacement of a better performing funnel;

(iv) Casella 0.5-mm rain gauge shows a negative bias in the rainfall measurement, particularly for larger value of daily accumulated rainfall amount, as could be expected for rain loss in the tipping of the buckets. On the other hand, with tip correction, the Logotronics gauge does not have a negative bias;

(v) For Ogawa B gauge, the application of the variable drop size does not seem to improve the comparison with the manual measurement. In fact, the difference becomes larger using the variable size;

(vi) The tilting siphon gauge does not appear to have particularly good performance. The root-mean-square difference is rather large and the bias is negative for higher rainfall rate, which may be related to the need of emptying the bucket when it is full of rain water.

4. PERCENTAGE DIFFERENCES

As another presentation of the comparison results, Table 5 shows the percentage difference in the daily rainfall between each gauge and the manual measurement from April to September 2010 for the days with the daily rainfall total of 10 mm or more. The mean percentage difference is given at the bottom of the table. As an indication of the intensity of the rain, the maximum value of intensity (expressed in mm/hour) based on the 10-second rainfall values of Ogawa A or Ogawa B is shown on the right hand side of each data row of the table. The largest value of these maximum intensities is about 200 mm/hour.

It could be seen that Ogawa A, Logotronic, tilting siphon and Casella fulfill the WMO accuracy requirement of 5%. Interestingly, Casella 0.5-mm rain gauge has the lowest mean percentage difference, followed by Logotronic, which is in turn followed by tilting siphon and Ogawa A. As a result, the 0.5-mm tipping bucket rain gauge without tip correction appears to be rather robust, though the WMO resolution requirement of rainfall measurement could not be fulfilled. By considering both the root-mean-square difference and the percentage difference as compared with manual measurement, Logotronic rain gauge is found to have the best performance in the field study at HKIA in 2010.

5. CONCLUSIONS

The performance of a number of rain gauges in a rain season in Hong Kong is summarized in this paper. Among the gauges being tested, Logotronic gauge appears to be the best in terms of resolution, root-mean-square difference from manual measurement, and percentage difference from the manual measurement. The study of gauges would continue in the next few years, so that the best-performing rain gauge would be selected for possible replacement of Ogawa rain gauge as the official gauge for HKIA.

References

World Meteorological Organization, 2009: Guide to Meteorological Instruments and Methods of Observation-No. 8, Seventh edition.

Figure 1 Setup of the rain gauges at the Hong Kong International Airport

Ogawa A		Ogawa B		Ogawa B (base on 1 min Drop frequency)		Ogawa C		Logotronic		Tilting Siphon		CL1	
Bias	R.M.S	Bias	R.M.S	Bias	R.M.S	Bias	R.M.S	Bias	R.M.S	Bias	R.M.S	Bias	R.M.S
0.391	1.326	0.491	1.928	2.124	4.489	-0.104	3.193	0.453	0.994	-0.186	1.851	-0.306	1.382

Table 1 The bias and root-mean-square difference (R.M.S.) for all rain gauges on days with non-zero amount of rainfall (unit mm). For Ogawa B, "base on 1 min drop frequency" means the use of variable dropsize.

Ogawa A		Ogawa B		Ogawa B (base on 1 min Drop frequency)		Ogawa C		Logotronic		Tilting Siphon		CL1	
Bias	R.M.S	Bias	R.M.S	Bias	R.M.S	Bias	R.M.S	Bias	R.M.S	Bias	R.M.S	Bias	R.M.S
0.833	2.289	1.348	3.395	5.819	7.938	-0.153	5.453	0.827	1.667	-0.627	3.333	-1.218	2.411

Table 2 Same as Table 1 but for days with at least 10 mm of rainfall.

Ogawa A		Ogawa B		Ogawa B (base on 1 min Drop frequency)		Ogawa C		Logotronic		Tilting Siphon		CL1	
Bias	R.M.S	Bias	R.M.S	Bias	R.M.S	Bias	R.M.S	Bias	R.M.S	Bias	R.M.S	Bias	R.M.S
0.968	2.91	1.785	4.271	8.042	9.971	-0.16	6.876	0.963	2.066	-1.144	4.517	-1.945	3.114

Table 3 Same as Table 1 but for days with at least 25 mm of rainfall.

Ogawa A		Ogawa B		Ogawa B (base on 1 min Drop frequency)		Ogawa C		Logotronic		Tilting Siphon		CL1	
Bias	R.M.S	Bias	R.M.S	Bias	R.M.S	Bias	R.M.S	Bias	R.M.S	Bias	R.M.S	Bias	R.M.S
0.882	3.588	2.467	5.292	10.4	12.2	-0.183	8.018	0.6	2.231	-3.3	5.738	-3.042	3.957

Table 4 Same as Table 1 but for days with at least 50 mm of rainfall.

Date*	Ogawa A (0.1 mm)	Ogawa B (0.1 mm)	Ogawa B (base on 1 min Drop frequency)	Ogawa C (0.1 mm)	Logotronic (0.1 mm)	Tilting Siphon (0.5 mm)	CL1 (0.5 mm)	Manual (0.1 mm)	Max. rainfall intensity (mm/hr)
22/4/2010	17.8	16.7	18.6	15.5	17.2	16	16.5	16.3	108.9
	9.20%	2.45%	14.11%	-4.91%	5.52%	-1.84%	1.23%		
29/4/2010	18.8	18.8	20.9	16.9	18.6	18	18	17.6	75.7
	6.82%	6.82%	18.75%	-3.98%	5.68%	2.27%	2.27%		
30/4/2010	39.6	40.6	45.4	36.6	38.8	38.5	38.5	38.5	44.3
	2.86%	5.45%	17.92%	-4.94%	0.78%	0.00%	0.00%		
7/5/2010	46.6	46	51.1	45.7	50.3	NA	46.5	50.4	203.0
	-7.54%	-8.73%	1.39%	-9.33%	-0.20%	NA	-7.74%		
10/5/2010	27.6	27.7	31	27.6	29.2	27	27	26.6	59.1
	5.21%	4.17%	16.67%	4.17%	5.21%	4.17%	4.17%		
15/5/2010	15.6	15.7	17.5	14.7	15	15	14.5	14.7	42.4
	6.12%	6.80%	19.05%	0.00%	2.04%	2.04%	-1.36%		
20/5/2010	59.2	60.1	67.1	62.7	62	NA	59	60.4	99.7
	-1.99%	-0.50%	11.09%	3.81%	2.65%	NA	-2.32%		
23/5/2010	12.8	12.1	13.4	13.4	12.6	13	12.5	13.5	136.6
	-5.19%	-10.37%	-0.74%	-0.74%	-6.67%	-3.70%	-7.41%		
30/5/2010	53.8	51.4	57.4	57.1	53.3	NA	50.5	51.4	107.0
	4.67%	0.00%	11.67%	11.09%	3.70%	NA	-1.75%		
2/6/2010	41.9	41.5	46.3	44.6	41.8	38.5	36	38.3	60.9
	9.40%	8.36%	20.89%	16.45%	9.14%	0.52%	-6.01%		
10/6/2010	NA	54.1	60.4	58.4	50.9	50.5	50	50.2	83.2
	NA	7.77%	20.32%	16.33%	1.39%	0.60%	-0.40%		
26/6/2010	92.4	97.3	108.7	105.9	94.5	89.5	91.5	98.5	98.8
	-6.19%	-1.22%	10.36%	7.51%	-4.06%	-9.14%	-7.11%		
27/6/2010	26.8	28.4	31.7	30.9	26.4	24	26	26.4	27.4
	1.52%	7.58%	20.08%	17.05%	0.00%	-9.09%	-1.52%		
28/6/2010	56.7	59.9	67	65.3	58.4	56	57	57.5	124.4
	-1.39%	4.17%	16.52%	13.57%	1.57%	-2.61%	-0.87%		
17/7/2010	35.7	34.5	38.5	38.5	37.1	38	36	35.8	146.3
	-0.28%	-3.63%	7.54%	7.54%	3.63%	6.15%	0.56%		
18/7/2010	12.6	12.8	14	14	13.1	12	11.5	12.8	91.5
	-1.56%	0.00%	9.37%	9.37%	2.34%	-6.25%	-10.16%		
21/7/2010	14.1	14.6	16.2	15.7	13.9	13	13.5	13.1	58.6
	7.63%	11.45%	23.66%	19.85%	6.11%	-0.76%	3.05%		
22/7/2010	23.6	24	26.9	26	24.7	24.5	23.5	23.4	86.0
	0.85%	2.56%	14.96%	11.11%	5.56%	4.70%	0.43%		
23/7/2010	12.6	12.8	14.2	13.8	13.3	12	12.5	12.6	65.9
	0.00%	1.59%	12.70%	9.52%	5.56%	-4.76%	-0.79%		
28/7/2010	28.2	27.8	30.7	25.3	29.6	35.5	28.5	28.3	195.8
	-0.35%	-1.77%	8.48%	-10.60%	4.59%	25.44%	0.71%		
29/7/2010	70.4	66.2	74.1	46.3	70	55	66.5	68.2	168.3
	3.23%	-2.93%	8.65%	-32.11%	2.64%	-19.35%	-2.49%		
6/8/2010	23.6	22.6	25.2	16	23.7	23	22.5	22.5	139.1
	4.89%	0.44%	12.00%	-28.89%	5.33%	2.22%	0.00%		
8/8/2010	33.9	34	37.9	22.8	34.1	33	32.5	32.4	82.3
	4.63%	4.94%	16.98%	-29.63%	5.25%	1.85%	0.31%		
15/8/2010	13.6	12	13	12.2	NA	12.5	13.5	13.1	56.7
	3.82%	-8.40%	-0.76%	-6.87%	NA	-4.58%	3.05%		
16/8/2010	39.4	36	39	37.1	39.1	38	37.5	38.1	137.2
	3.41%	-5.51%	2.36%	-2.62%	2.62%	-0.26%	-1.57%		
24/8/2010	12.7	11.9	12.8	11.2	12.6	12.5	11.5	11.5	82.3
	10.43%	3.48%	11.30%	-2.61%	9.57%	8.70%	0.00%		
30/8/2010	14.4	14.5	15.8	13.6	14.8	14	13.5	13.4	93.3
	7.46%	8.21%	17.91%	1.49%	10.45%	4.48%	0.75%		
4/9/2010	158.8	163.8	177.4	154.7	152.1	153	146	153.2	159.2
	3.66%	6.92%	15.80%	0.98%	-0.72%	-0.13%	-4.70%		
5/9/2010	14.2	15.1	16.4	14.2	14	13.5	13.5	13.6	56.7
	4.41%	11.03%	20.59%	4.41%	2.94%	-0.74%	-0.74%		
9/9/2010	61	61.9	67	58.6	63.6	57	56.5	59.1	166.5
	3.21%	4.74%	13.37%	-0.85%	7.61%	-3.55%	-4.40%		
11/9/2010	107.9	114.7	124.3	101.7	103.5	104	98.5	105.1	153.7
	2.66%	9.13%	18.27%	-3.24%	-1.52%	-1.05%	-6.28%		
12/9/2010	23.4	24.2	26.3	22.3	22.5	20.5	21.5	22	95.2
	6.36%	10.00%	19.55%	1.36%	2.27%	-6.82%	-2.27%		
Average of differences (magnitude)	4.42%	5.35%	13.56%	9.28%	4.11%	4.39%	2.70%		

Table 5 Percentage difference between the rain gauge value and the manual measurement for days with manually measured rainfall of 10 mm or more. For Ogawa B, "base on 1 min drop frequency" means the use of variable dropsize.