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Research Article

Attempt to detect maintenance need rain gauge station by double-mass analysis

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Abstract: Currently, 112 Automatic Weather Stations (AWS) and over 1,000 Automatic Rain Gauges (ARG), approximately 2,000 AWS in total including stations outside the national hydrometeorological network are installed in the nationwide country of Vietnam so that they can be used for Quantitative Precipitation Estimation of weather radars, etc. Meanwhile, it takes a vast amount of time and cost to properly operate and maintain the large number of AWS. Besides, rain gauges cannot be checked whether it has properly operated without a certain amount of rain. This research attempted to detect maintenance-need rain gauges of the AWS by the slope and R^2 values obtained by double-mass analysis against the distance between the stations. Evaluated distances were used for the classification of AWS. As "Class 1 AWS" is the distance within 5 km and "Class 2 AWS" is the distance within 20 km and the criteria were obtained by AMeDAS data of the Japan Meteorological Agency. Additionally, the process is cycled several times to expand the candidate AWS. The result says that stations except 125 Class 1 AWSs and 710 Class 2 AWSs need to be checked. It is suggested that this assessment can be used to detect maintenance-need stations; however, periodical maintenance is still needed for proper observation because this assessment also needs reliable AWSs.

Keywords: Automatic Weather Station; Automatic Rain Gauge; Maintenance; Double-mass Analysis.

1. Introduction

[1] surveyed the status of Automatic Weather Stations (AWS) and Automatic Rain Gauges (ARG) operated by the Viet Nam Meteorological and Hydrological Administration (VNMHA) in 2019 and the VNMHA currently operates 186 Synoptic stations, 112 AWS, and over 1,000 ARG. In total, around 2,000 AWS are operated including stations outside the national hydrometeorological network, according to the data retrieved from the Central Data Hub (CDH). All data observed by the stations have been sent and stored in CDH at the VNMHA headquarters and used for monitoring and forecasting operations, especially Quantitative Precipitation Estimation (QPE) of weather radars [2]. However, because of the large number of stations, it is not easy to maintain the AWS periodically. In fact, it is easy to find some ARG stations that keep 0 mm of precipitation even if the surroundings of the station are observing rainfall. These stations should be detected and maintained as soon as possible, but the detection method exampled above needs to wait for massive rainfall around the station.

In this paper, we proposed an alternate method for the Quality Check of rain gauge data to find AWS/ARG sites that need to be maintained by using the double-mass analysis method as a data assessment. The double-mass analysis is normally used for checking the transformation of the environment of the station [3], but this method analyzes the relationship between other near stations assuming that well-maintained stations have a constant relationship. For this reason, maintenance-need stations can be detected without waiting for massive rainfalls.

2. Used data

2.1. Data period

We used Synoptic station data, AWS data, and JICA-ARG data. All data were provided by Aero-Meteorological Observation (AMO) of VNMHA. Each data period is shown in Table 1. The date and time are stamped with Vietnamese local time (GMT+7:00). As AWS data are not sufficient until 31 December 2020, this assessment is conducted with data from January to December 2021.

Table 1. Data period.

Station type (data storing interval)	From	To
Synoptic (6 hours)	2019/01/01 01:00	2022/01/05 19:00
AWS (10 minutes)	2020/03/05 00:00	2021/12/30 23:50
ARG (st1 – st15) (10 minutes) *	2019/09/25 15:20	2022/01/13 14:20
ARG (st16 – st18) (10 minutes)	2021/07/14 11:20	2022/01/13 14:20

*The beginning time of observation is different at each ARG station.

2.2. Synoptic station

Synoptic data used in the assessment were provided by the AMO (not CDH or forecast division) in a DAT file (kind of a text file of which the extension is ".dat"). The total number of stations in the file is 174. The station's geo-coordinate information was provided by the AMO as well. As Synoptic data are stored all observation data such as temperature, precipitation, etc. into a 6-hourly DAT file with a space-separated method. Only assessment data (precipitation) were extracted and realigned.

2.3. AWS

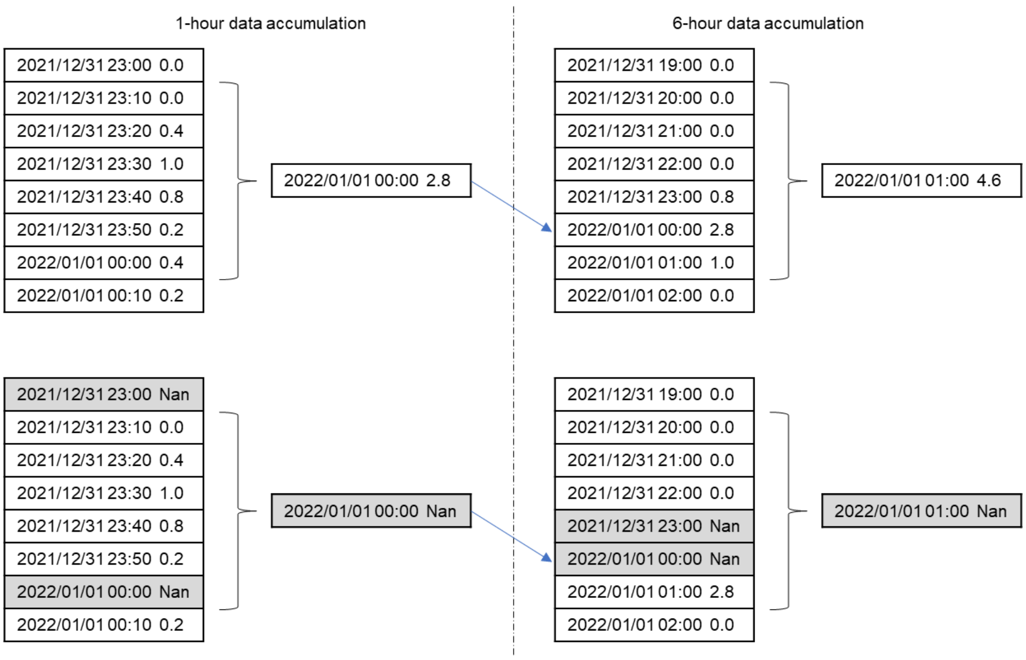

Figure 1. An example of data error (left: 1- hour data, right: 6- hour data).

AWS data used in the assessment were obtained via JICA Linux PC. The total number of data is 2,332 stations as far as JICA Linux PC could obtain after June 2021.

AWS data are separated into 10-minute data. Therefore, AWS data were accumulated into 1-hour and 6-hour data were used for the assessment. 1-hour accumulation data are calculated from 10, 20, 30, 40, 50, and 00 minutes of data. If one of the 10-minute data is lost, the accumulation data of the time is regarded as NaN (Not a number, or blank). 6-hour data processing is calculated in the same manner. An example is shown in Figure 1.

2.4. JICA–ARG

ARG data used in the assessment were obtained from the ARG server directly. The total number of ARGs is 18 stations. These stations were installed in 2019 and 2021, therefore, the beginning time of observation is different for each data. Geo-coordinated data were provided by Mr. Ichijo who oversees these ARGs.

ARG data is saved every 10-minute data into one DAT file for one station with a comma-separated method. ARG data were accumulated into 1-hour and 6-hour data used for the assessment. The accumulation manner is the same as the manner used for AWS.

3. Assessment method

3.1. Classification of AWS

In the assessment, AWS and ARG were classified into two classes. The Class 1 AWS is to be located around the Synoptic station and compared with Synoptic data. The Class 2 AWS is categorized as the site whose distance from the reference site is within a few kilometers and compared with the Class 1 or 2 AWS so that candidates for Class 2 AWS can be sampled as much as possible even in remote areas. Both classes have their criteria.

3.2. Assessment method

The assessment was conducted by an evaluation of a slope of the regression line whose intercept is set to be 0.0 and the R^2 value (square of Pearson's correlation coefficient) of the double-mass analysis curve between each candidate station and a reference. The slope and the R^2 value were computed every month by using the past three-month observation data.

If the candidate station is located at the same place as the reference, although there is an uneven catching rate of rain, the candidate will observe almost the same value. Therefore, in the double-mass analysis, the slope will be nearly 1.0, and the R^2 value will also be nearly 1.0. However, the slope and the R^2 value will enlarge a gap from 1.0 if the station is located farther and farther away from a reference.

Slope calculation: The slope in the result of the double-mass analysis is obtained by single regression analysis by the least-squares method. In the regression analysis, the intercept is set as 0.0 because the initial precipitation is 0.0 mm for both rain gauge stations.

R^2 calculation: Although there are a lot of methods to obtain the R^2 value, the R^2 value in this assessment is calculated as the square of Pearson's correlation coefficient. The R^2 value is obtained from the result of the double-mass analysis because the scatter plot of hourly precipitation cannot find any relativeness, but the result of the double-mass analysis showed relativeness.

Distance calculation: Distance between reference and candidate stations was calculated with Hubeny's distance formula (by Geodetic Reference System 1980, Pole radius 6,356,752.314 m, Equator radius: 6,378,137 m).

These calculations were computed with Python 3x. After computing the slope and R^2 value, Class 1 and 2 AWSs were retrieved as per the criteria. These program flowcharts are shown in Figure 2.

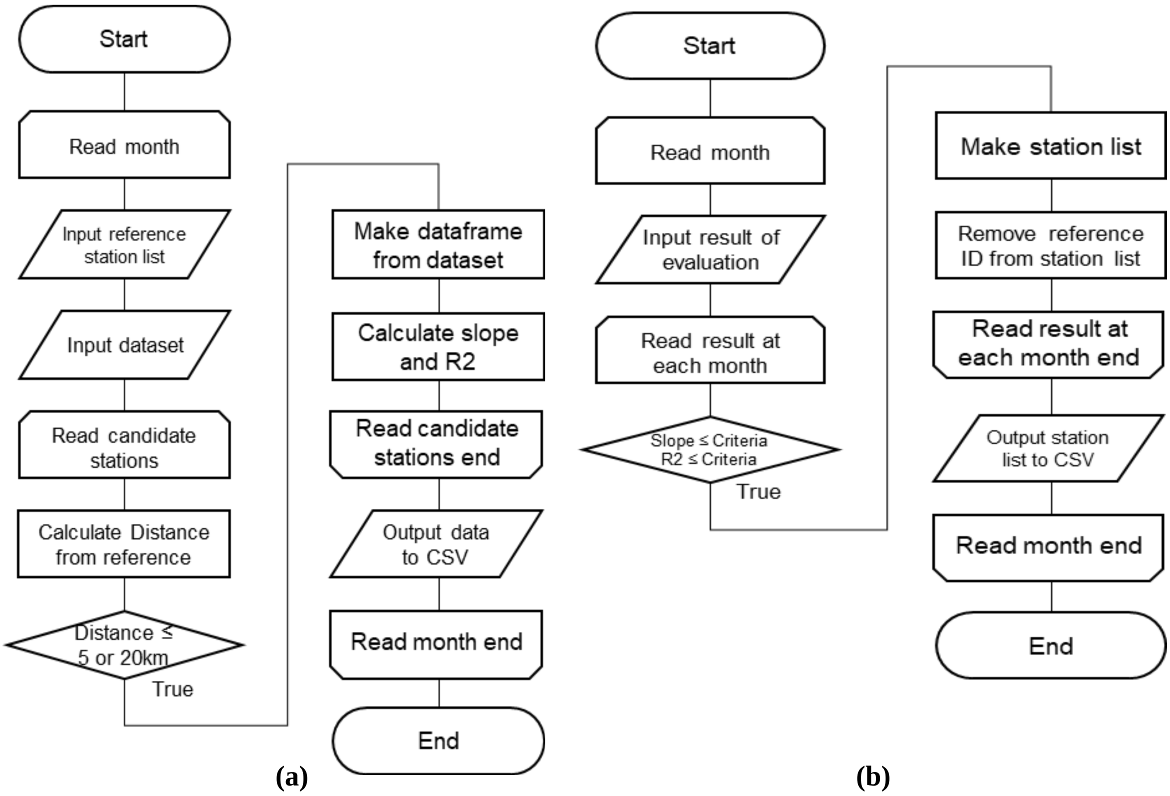

Figure 2. Program flowcharts: (a) Calculation of the slope and the R^2 value; (b) Screen the stations.

3.3. Criteria of the assessment

Used data for the criteria: To provide criteria of the slope and the R^2 value for the assessment, AMeDAS (Automated Meteorological Data Acquisition System: the AWSs in Japan operated by Japan Meteorological Agency (JMA)) data in Okinawa prefecture of Japan located in a tropical zone was evaluated. AMeDAS is well maintained every year and its rain gauge is calibrated every five years by JMA. Evaluated stations are listed in Table 2. Data used for this examination was 30-year data from May 1992 to April 2022 (some stations are from the 2000s).

Table 2. Reference stations and evaluated stations.

Name	Data available	Distance from the reference
Naha	**01/05/1992**	**Reference**
Naha Ashimine	01/01/2003	5.0 km (Naha)
Itokazu	01/05/1992	9.8 km (Naha)
Goya	01/05/1992	17.8 km (Naha)
Yomitan	01/05/1992	22.7 km (Naha)
Tokashiki	01/05/1992	32.3 km (Naha)
Miyagijima	19/12/2007	33.3 km (Naha)
Nago	**01/05/1992**	**Reference**
Motobe	01/05/1992	12.2 km (Nago)
Higashi	01/05/1992	19.2 km (Nago)
Miyagijima	19/12/2007	25.6 km (Nago)
Kunigami	20/12/2005	26.0 km (Nago)
Yomitan	01/05/1992	31.0 km (Nago)
Goya	01/05/1992	33.7 km (Nago)
Miyakojima	**01/05/1992**	**Reference**
Kagamihara	01/01/2003	2.1 km (Miyako)
Shimojijima	01/01/2003	14.1 km (Miyako)

Name	Data available	Distance from the reference
Gusukube	01/05/1992	14.4 km (Miyako)
Ishigakijima	**01/05/1992**	**Reference**
Moriyama	07/03/2013	10.5 km (Ishigaki)
Kabira	01/05/1992	14.6 km (Ishigaki)
Ibaruma	01/05/1992	22.3 km (Ishigaki)
Oohara	01/05/1992	30.6 km (Ishigaki)
Kumejima	**01/05/1992**	**Reference**
Kitahara	01/01/2003	9.4 km (Kumejima)
Tonaki	26/08/2014	34.0 km (Kumejima)

Method to define the criteria of the slope

The slope is computed with three-month data for each month. 95 percentiles of the slope at respective distances are to be evaluated as the criteria.

Method to define the criteria of the R^2

The R^2 value is also computed with three-month data and output per month too. 95 percentiles of the R^2 value at respective distances are to be evaluated as the criteria.

Method to define the distance

Representativeness of localized rainfall can be around 2.5 km in hourly precipitation and around 5 km in 24-hourly precipitation [4]. Therefore, the range of Class 1 AWS is to be 5 km from a reference. Whereas it is difficult to find AWS located within 5 km, especially in remote areas, another range for the remote stations is temporarily defined by using the results of the slope and the R^2 value.

Result of the criteria for the assessment

AMeDAS evaluation results are shown in Table 3. The slope values show differences as absolute values of calculated slope value minus one. The slope values were rounding up by five-tenth units and the R^2 values were rounding down by one-tenth unit.

Table 3. Result of the slope and the R^2 values at a respective distance.

Reference	Compared station	Total number of results (month)	Distance (km)	Slope 95 percentiles	R^2 95 percentiles
Miyakojima	Kagamihara	230	2.1	1.0 ± 0.25	0.99
Naha	Naha Ashimine	230	5.0	1.0 ± 0.35	0.98
Kumejima	Kitahara	230	9.4	1.0 ± 0.40	0.97
Naha	Itokazu	355	9.8	1.0 ± 0.45	0.94
Ishigakijima	Moriyama	107	10.5	1.0 ± 0.35	0.96
Nago	Motobe	355	12.2	1.0 ± 0.35	0.95
Miyakojima	Shimojijima	230	14.1	1.0 ± 0.45	0.94
Miyakojima	Gusukube	355	14.4	1.0 ± 0.40	0.95
Ishigakijima	Kabira	355	14.6	1.0 ± 0.65	0.93
Naha	Goya	355	17.8	1.0 ± 0.40	0.95
Nago	Higashi	355	19.2	1.0 ± 0.45	0.93
Ishigakijima	Ibaruma	355	22.3	1.0 ± 0.70	0.91
Naha	Yomitan	355	22.7	1.0 ± 0.45	0.93
Nago	Miyagijima	170	25.6	1.0 ± 0.55	0.90
Nago	Kunigami	194	26.0	1.0 ± 0.60	0.94
Ishigakijima	Oohara	355	30.6	1.0 ± 0.50	0.93
Nago	Yomitan	355	31.0	1.0 ± 0.45	0.93
Naha	Tokashiki	355	32.3	1.0 ± 0.50	0.90
Naha	Miyagijima	170	33.3	1.0 ± 0.50	0.89
Nago	Goya	355	33.7	1.0 ± 0.50	0.92
Kumejima	Tonaki	90	34	1.0 ± 0.45	0.97

It can be found a tendency that the slope and the R^2 values will be widened farther in the Table above. However, as it is difficult to set a range of the assessment with only this result, the distance is temporarily set as 20 km, in which the AMeDAS network is installed on average.

According to thresholds of distance, the criteria of the slope will be between 1.0 ± 0.35, and the R^2 value will be under 0.98 for Class 1 AWS. For Class 2 AWS, the criteria of the slope will be between 1.0 ± 0.65, and the R^2 value will be under 0.93. A summary of the results is in Table 4.

Table 4. Criteria for the assessment.

	Slope	**R^2**	**Remarks**
Class 1 AWS	1.0 ±0.35 (Including)	0.98 (Including)	Within 5 km from a reference
Class 2 AWS	1.0 ±0.65 (Including)	0.93 (Including)	Within 20 km from a reference

4. Definition of Class 1 AWS

4.1. Dataset

Referring provided 191 Synoptic station names, IDs, and geo-coordinates, 179 AWSs were extracted as Class 1 AWS candidates.

4.2. Result of Class 1 AWS

As per the criteria for Class 1 AWS, evaluation was done each month by using the past three-month data from the evaluation month. The result of the Class 1 AWSs from March to December 2021 (the data set is from 1st January to 31st December 2021) is listed in Table 5.

Table 5. Class 1 AWS (March to December 2021).

	Station ID of Class 1 AWS as of evaluation month/year									
	3/2021	**4/2021**	**5/2021**	**6/2021**	**7/2021**	**8/2021**	**9/2021**	**10/2021**	**11/2021**	**12/2021**
1	004811	004811	004811	004811	004811	004811	004811	090889	090889	091052
2	090018	090018	090660	091052	090660	092203	090904	091052	091052	1010404003
3	090660	090660	1010404003	092101	091052	1010404003	090912	1010404003	091920	1010404301
4	090889	1010404003	1010404301	092203	091920	1010404301	1010404003	1010404301	1010404003	1010404702
5	091052	1010404301	1010404702	1010404003	092203	1010404702	1010404301	1010404702	1010404301	1010405204
6	1010404003	1010404702	1010405204	1010404301	1010404003	1010405204	1010404702	1010405204	1010404702	1012017804
7	1010404301	1012018001	1012018001	1010404702	1010404301	1012017804	1010405204	1012017804	1010405204	1012018001
8	1010404702	1012219307	1012018502	1010405204	1010404702	1012018001	1012017804	1012018001	1012017804	1012018502
9	1012017804	1012219504	1012219307	1012018001	1010405204	1012018502	1012018001	1012018905	1012018001	1012018905
10	1012018001	1012219605	1012219504	1012018502	1012017804	1012219401	1012219401	1012219401	1012018502	1012219401
11	1012018502	1012219903	1012219605	1012219307	1012018001	1012219504	1012219903	1012219903	1012018905	1012219504
12	1012219307	1012220706	1012219903	1012219401	1012018502	1012219903	1012220102	1012220102	1012219401	1012219903
13	1012219504	1012422002	1012220706	1012219605	1012219903	1012220706	1012220706	1012422002	1012219903	1012220102
14	1012219605	1013130701	1012422002	1012219903	1012220706	1012422002	1012422002	1012422303	1012220102	1012421304
15	1012219903	1013130802	1012422303	1012220706	1012422002	1012422303	1012422303	1012725601	1012422303	1012421901
16	1012220102	1013131803	1013130701	1012422002	1012422303	1012725601	1012725601	1013130802	1012725601	1012422303
17	1012220706	129145	1013130802	1012422303	1012725601	1013130701	1013130701	129145	1013130802	1012725601
18	1012422002	351435	129145	1013130701	1013130701	1013130802	1013130802	219512	129145	1013130802
19	1012422303	48/25	232043	1013130802	129145	129145	129145	232043	219512	129145
20	1013130701	48/61	351435	129145	197706	197706	219512	351435	232043	219512
21	1013130802	48/63	48/25	197706	232043	351435	232043	48/25	351435	232043
22	1013131803	48800	48/26	232043	351435	48/26	351435	48/26	48/25	351435
23	129145	48802	48/61	351435	48/25	48/61	48/26	48/61	48/26	48/25
24	232043	48810	48/63	48/25	48/26	48/63	48/61	48/63	48/61	48/26
25	351435	48811	48800	48/26	48/61	48800	48/63	48800	48/63	48/61
26	48/25	48812	48802	48/61	48/63	48806	48800	48802	48800	48/63
27	48/26	48815	48806	48/63	48800	48811	48811	48811	48811	48800
28	48/51	48821	48810	48800	48806	48812	48812	48812	48812	48806
29	48/61	48831	48811	48806	48811	48814	48814	48814	48814	48811
30	48800	48835	48812	48811	48812	48815	48815	48815	48815	48812
31	48802	48870	48815	48812	48814	48818	48818	48818	48818	48814
32	48810	48887	48818	48815	48815	48821	48821	48821	48821	48815
33	48811	48890	48821	48818	48818	48823	48823	48827	48827	48821
34	48812	493521	48823	48821	48821	48827	48827	48894	48873	48827
35	48815	552000	48827	48823	48823	48870	48873	48896	48875	48870
36	48818	553800	48831	48831	48870	48873	48894	48898	48894	48873
37	48821	555600	48835	48835	48873	48886	48896	493521	48896	48875

	Station ID of Class 1 AWS as of evaluation month/year									
	3/2021	**4/2021**	**5/2021**	**6/2021**	**7/2021**	**8/2021**	**9/2021**	**10/2021**	**11/2021**	**12/2021**
38	48827	556300	48870	48870	48886	501508	48898	501508	48898	48886
39	48831	556400	48873	48873	48890	555300	493521	552000	493521	48894
40	48835	556500	48887	48886	493521	555600	501508	553400	501508	48896
41	493521	556600	48890	48890	501508	556300	552000	553500	552000	48898
42	501508	556700	493521	493521	553400	556400	553400	553800	553400	493521
43	552000	556800	553800	501508	553800	556500	553500	554700	553500	501508
44	553500	557000	555600	552000	555300	556600	553800	555300	553800	552000
45	553800	557100	556300	555600	555600	556700	554700	555600	554700	553400
46	555300	557200	556400	556300	556300	556800	555300	556300	555300	553500
47	555600	557300	556500	556400	556400	557000	555600	556400	555600	553800
48	556400	557400	556600	556500	556500	557100	556300	556500	556300	554700
49	556500	557500	556700	556600	556600	557200	556400	556600	556400	555300
50	556600	557700	556800	556700	556700	557300	556500	556700	556500	555600
51	556700	561800	557000	556800	556800	557400	556600	556800	556600	556300
52	556800	603900	557100	557000	557000	557500	556700	557000	556700	556400
53	557000	604000	557200	557100	557100	557600	556800	557100	556800	556500
54	557100	604100	557300	557200	557200	557700	557000	557200	557000	556600
55	557200	604200	557400	557300	557300	561800	557100	557300	557100	556700
56	557300	604300	557500	557400	557400	603900	557200	557400	557200	556800
57	557400	604400	557600	557500	557500	604000	557300	557500	557300	557000
58	557500	604600	557700	557600	557600	604100	557400	557600	557400	557100
59	557700	625960	561800	557700	557700	604200	557500	557700	557500	557200
60	561800	653845	603900	561800	561800	604300	557600	561800	557600	557300
61	604000	986042	604000	603900	603900	604600	557700	603900	557700	557400
62	604200	ARG0000045	604100	604000	604000	604700	561800	604000	561800	557500
63	604400	AWS0000009	604200	604100	604100	604800	603900	604200	603900	557600
64	604600	AWS0000011	604300	604200	604200	609600	604000	604300	604000	557700
65	604800	AWS0000012	604600	604300	604300	625960	604200	604400	604200	561800
66	625960	AWS0000013	604700	604400	604600	653200	604300	604600	604300	603900
67	653845	AWS0000015	625960	604600	604700	653845	604600	604700	604400	604000
68	838293	AWS0000016	626493	604700	604800	838293	604700	604800	604600	604200
69	904892	AWS0000018	653200	604800	609600	869500	604800	609600	604700	604300
70	968206	ST001	653845	609600	653200	870000	609600	625960	604800	604400
71	986042	st1	968206	625960	653845	904892	653200	653200	609600	604600
72	ST001	st11	986042	653200	838293	968206	653845	653845	653200	604700
73	st1	st12	ARG0000045	653845	870000	986042	838293	838293	653845	604800
74	st11	st14	AWS0000006	904892	904892	ARG0000045	863700	863700	863700	625960
75	st14	st15	AWS0000007	968206	968206	AWS0000001	863800	863800	863800	653200
76	st15	st2	AWS0000010	ARG0000045	ARG0000045	AWS0000002	869500	865700	865700	653845
77	st2	st3	AWS0000012	AWS0000002	AWS0000002	AWS0000004	904892	869500	869500	838293
78	st3	st4	AWS0000013	AWS0000004	AWS0000004	AWS0000005	968206	904892	904892	863700
79	st4	st5	AWS0000015	AWS0000006	AWS0000005	AWS0000006	986042	968206	968206	863800
80	st5	st6	AWS0000016	AWS0000007	AWS0000006	AWS0000007	ARG0000041	986042	986042	865700
81	st6	st7	AWS0000017	AWS0000008	AWS0000007	AWS0000008	ARG0000045	ARG0000041	ARG0000041	869500
82	st7	st8	AWS0000020	AWS0000010	AWS0000008	AWS0000009	AWS0000001	ARG0000045	ARG0000045	870000
83	st8	st9	ST001	AWS0000012	AWS0000010	AWS0000010	AWS0000002	AWS0000001	AWS0000001	904892
84	st9		st1	AWS0000013	AWS0000012	AWS0000012	AWS0000005	AWS0000002	AWS0000002	968206
85			st11	AWS0000015	AWS0000013	AWS0000013	AWS0000006	AWS0000004	AWS0000005	986042
86			st12	AWS0000016	AWS0000015	AWS0000015	AWS0000007	AWS0000005	AWS0000006	ARG0000041
87			st14	AWS0000017	AWS0000016	AWS0000016	AWS0000008	AWS0000006	AWS0000007	ARG0000045
88			st15	AWS0000020	AWS0000017	AWS0000017	AWS0000009	AWS0000007	AWS0000008	AWS0000001
89			st2	ST001	AWS0000018	AWS0000018	AWS0000010	AWS0000008	AWS0000009	AWS0000002
90			st3	ST002	AWS0000020	AWS0000020	AWS0000011	AWS0000009	AWS0000010	AWS0000004
91			st4	st1	AWS0000022	AWS0000022	AWS0000015	AWS0000010	AWS0000013	AWS0000005
92			st5	st11	ST001	ST001	AWS0000016	AWS0000013	AWS0000015	AWS0000006
93			st6	st12	ST002	ST002	AWS0000017	AWS0000015	AWS0000016	AWS0000007
94			st7	st13	ST013	ST013	AWS0000020	AWS0000016	AWS0000017	AWS0000008
95			st8	st14	ST021	ST021	AWS0000022	AWS0000017	AWS0000019	AWS0000009
96			st9	st15	ST023	ST023	ST001	AWS0000020	AWS0000020	AWS0000010
97				st2	st1	st1	ST002	AWS0000022	AWS0000022	AWS0000015
98				st3	st11	st11	ST013	ST001	ST001	AWS0000016
99				st4	st12	st12	ST021	ST002	ST013	AWS0000017
100				st5	st13	st13	ST023	ST013	ST021	AWS0000020
101				st6	st14	st14	st1	ST021	ST023	AWS0000022
102				st7	st15	st15	st11	ST023	st1	ST001
103				st8	st16	st16	st12	st1	st11	ST002
104				st9	st17	st17	st13	st11	st12	ST013
105					st18	st18	st14	st12	st13	ST021
106					st2	st2	st15	st13	st14	ST023
107					st3	st3	st16	st14	st15	st1
108					st4	st4	st17	st15	st17	st11
109					st5	st5	st18	st16	st18	st12
110					st6	st6	st2	st17	st2	st13
111					st7	st7	st3	st18	st3	st14
112					st8	st8	st4	st2	st4	st15
113					st9	st9	st5	st3	st5	st16
114							st6	st4	st6	st17
115							st7	st5	st7	st18
116							st8	st6	st8	st2

	Station ID of Class 1 AWS as of evaluation month/year									
	3/2021	**4/2021**	**5/2021**	**6/2021**	**7/2021**	**8/2021**	**9/2021**	**10/2021**	**11/2021**	**12/2021**
117							st9	st7	st9	st3
118								st8		st4
119								st9		st5
120										st6
121										st7
122										st8
123										st9

4.3. Details of the result

This assessment method can detect stations well related to observation value at respective Synoptic stations. An example of good relativeness is shown in Figure 3. The left figure shows a double–mass analysis curve, and the right figure shows a scatter plot of observation data.

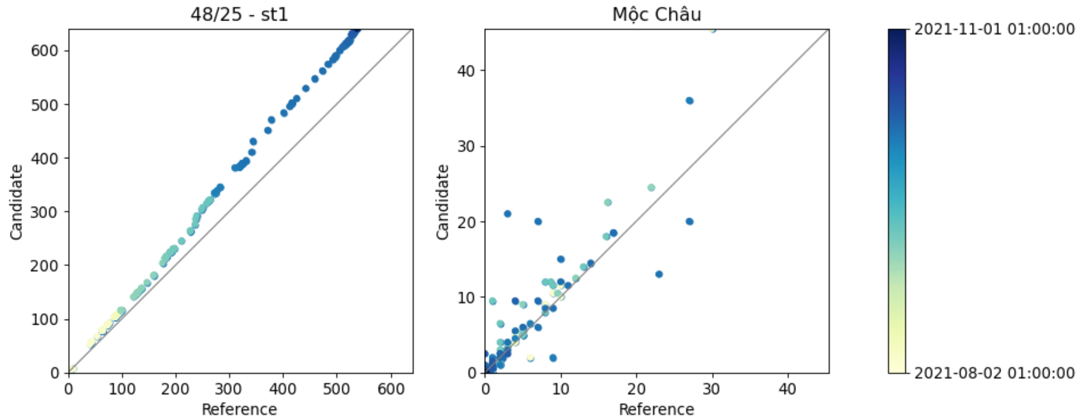

Figure 3. An example of AWS highly correlated to the Synoptic station as of October 2021. [Left: double-mass analysis curve, right: scatter plot of observation data.] ID: st1, Slope: 1.19275, R^2: 0.99962.

4.3.1. Poor example

On the other hand, an example of a station poorly correlated to the Synoptic station is shown in Figure 4. As only the SYNOP axis plot data in the right figure, this station (48810) had not observed precipitation, although the Synoptic station observed.

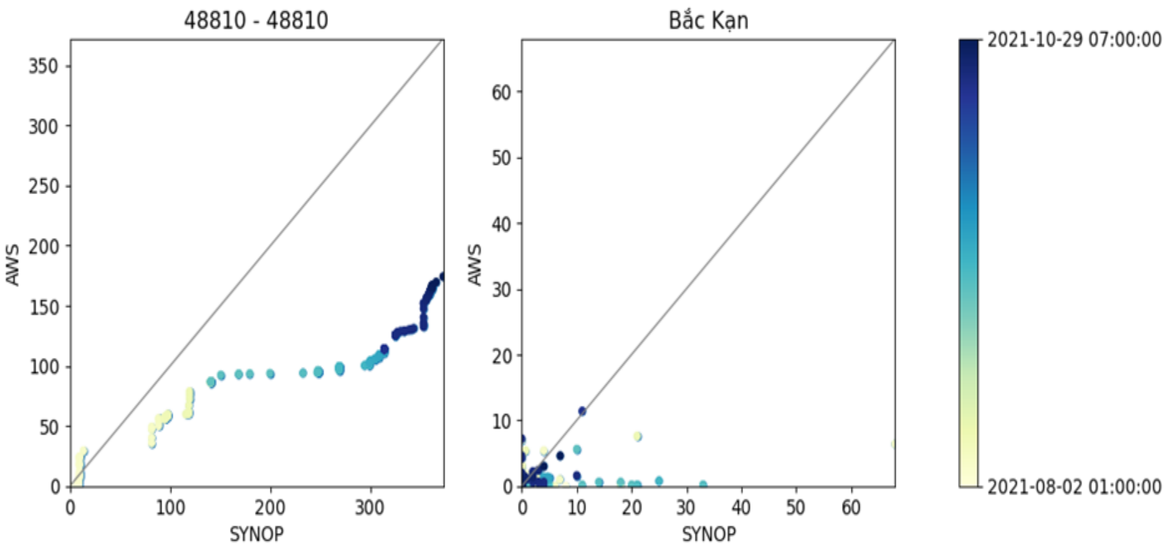

Figure 4. An example of AWS poorly correlated to the Synoptic station as of October 2021. [Left: double-mass analysis curve, right: scatter plot of observation data.] ID: 48810, Slope: 0.40968, R^2: 0.92028.

4.3.2. Slope of the regression line, which does not meet the criteria

If the slope of the regression line of the double-mass analysis curve is steep or too low, the station will be eliminated in the month. The example shown in Figure 5 might have overestimated precipitation compared to Synoptic station values. Some problems might have happened in October because September's slope is 1.18043.

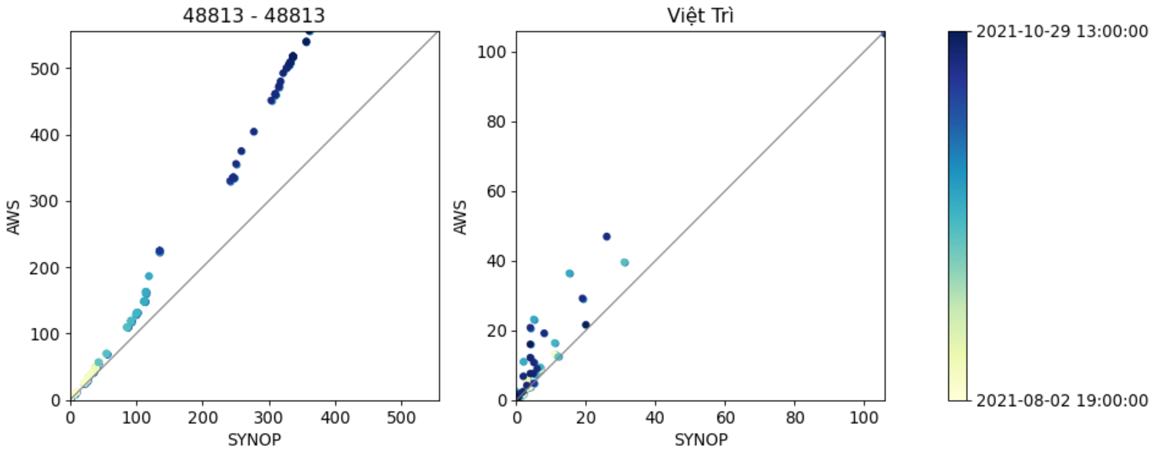

Figure 5. An example of AWS with a steep slope as of October 2021. [Left: double-mass analysis curve, right: scatter plot of observation data.] ID: 48813, Slope: 1.48437, R^2: 0.99363.

4.3.3. Check with time series

Since evaluation was done every month, it is possible to detect when an observation error occurred. An example of the results aligned with periods is shown in Figure 6. AWS 604100 had been observed properly until August 2021, but the data observed from September might have been wrong and its slope and R^2 value had not met the criteria since then.

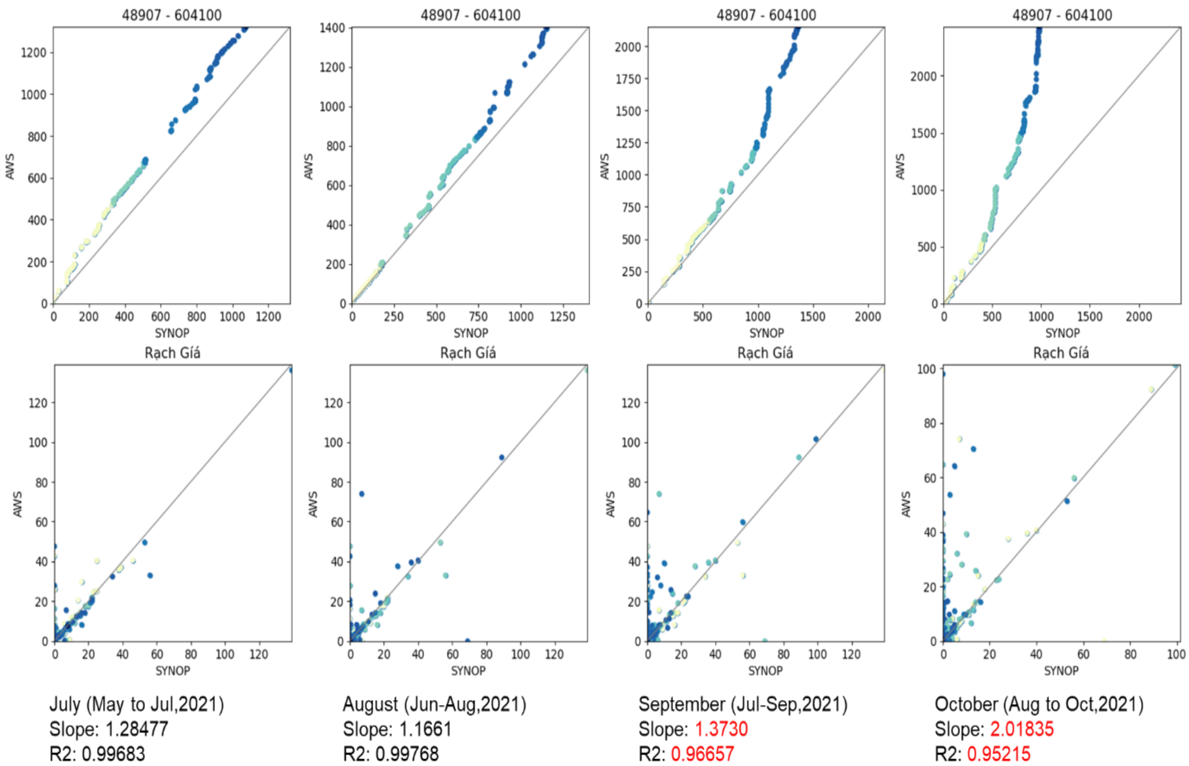

Figure 6. Comparison of before and after an error occurred (ID: 604100). [Upper: double-mass analysis curve, lower: scatter plot of observation data.] *Values written in red do not meet the criteria for Class 1 AWS.

5. Definition of Class 2 AWS

5.1. Dataset

Referring to Class 1 AWS defined in the above monthly, AWSs located around the other AWSs of both Class 1 and Class 2 within 20 km away were extracted as Class 2 AWS candidates.

5.2 Result of Class 2 AWS

As per the criteria for Class 2 AWS, evaluation was done each month by using the past 3-month data from the evaluation month. The result of the Class 2 AWSs in December 2021 (the dataset is from 1st October to 31st December 2021) is 710 stations in total. As reference stations are changed every month, candidates will also be changed according to the reference. Therefore, non-listed Class 2 AWSs have two reasons; observation data had not met the criteria or there was no reference corresponding to the candidate.

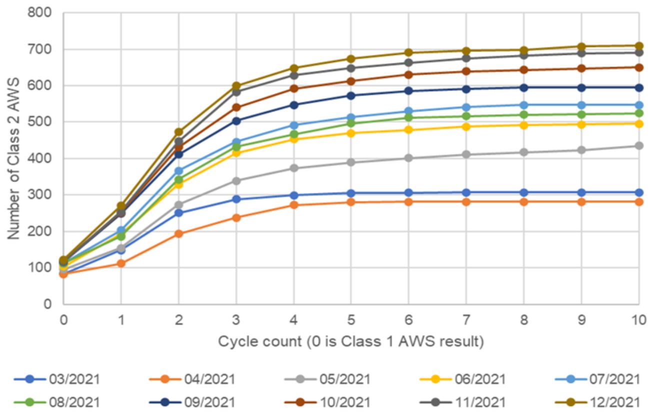

Figure 7. Relativeness between the number of stations and cycle count.

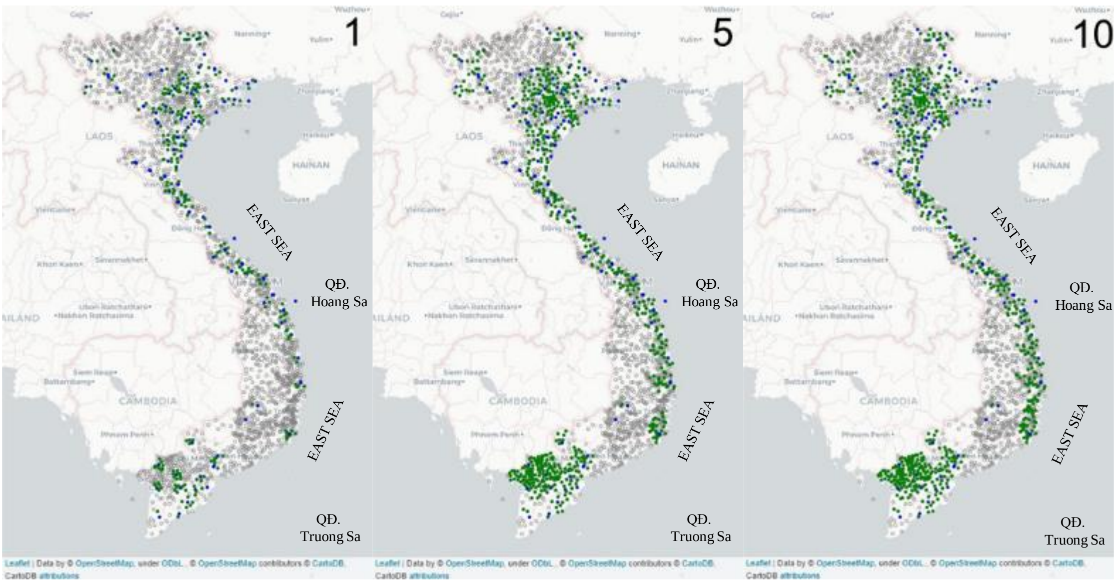

Figure 8. The first assessment, five and ten-cycled-assessment results (October to December 2021). [Blue: Class 1 AWS, Green: Class 1 AWS, Gray: candidate AWS.]. *This map plots the station where data were provided from the AMO in 2022 and the locations of Hoang Sa Islands, Truong Sa Islands, and East Sea are not shown on the map.

Figure 7 shows a relativeness between the number of Class 2 AWS and cycle count, and Figure 8 shows a transition of evaluated AWSs as Class 2 in 10-cycle processing. Since this assessment refers to the latest Class 2 AWS (initial reference is Class 1 AWS) to retrieve candidate stations, repeated assessment cycles can enlarge the number of evaluated stations and the result will converge to a number. Additionally, this result also indicates that the number of Class 1 AWS (initial number of references) is key to obtaining a large number of evaluated stations.

6. Summary and Conclusions

This assessment method proposed in this study gives more capability to assess AWS located nearby another station. However, some areas, especially the northwest mountain area (Tây Bắc) and mid-south highland area (Tây nguyên Trung Bộ) cannot have been assessed. It is difficult to locate the reason. One of the reasons may be supposed to be the criteria obtained from AMeDAS. Because the AMeDAS used for the criteria are installed in some small islands in the southern part of Japan where no steep mountains, therefore, a difference in geographical precipitation pattern could not have been covered by this method and the criteria. Additionally, the assessment distance between the reference and candidates had been 20 km temporarily. There remains for discussion.

This assessment method was based on the data of the JMA, but the data of the VNMHA/AMO are surely required for obtaining the proper criteria for this assessment method. Therefore, continuous maintenance on some reference AWSs is yet required for the proper criteria even if this assessment will be conducted ever since.

Supplementary Materials: The JMA observation data used in the assessment are available online at https://www.data.jma.go.jp/gmd/risk/obsdl/index.php. Station data of the JMA are available online at https://www.jma.go.jp/jma/kishou/know/amedas/ame_master.pdf.

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