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Installation and Operation of Ultrasonic Anemometers in JMA

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Abstract

The Japan Meteorological Agency (JMA) has run ultrasonic anemometers as part of its nationwide AMeDAS Automatic Weather Station (AWS) network since 2021, replacing the previous conventional windmill-type models. As of April 2024, these are in operation at 433 of the organization's 687 AWSs. Here we outline their background, evaluation and quality control, with coverage of the history of wind observation since 1875, challenges associated with the old windmill-type, testing to address climatic issues (such as missing data due to snow and ice accretion) and measurement accuracy during typhoons, heavy wind and heavy rain. There's also an overview of quality control for observation data and that for equipment based on ultrasonic anemometer status information in JMA.

1. Introduction

1.1. JMA wind observation

JMA began official wind observation at the Tokyo Meteorological Observatory (the organization's predecessor) in 1875, when anemometer operation involved only four-cup types and wind vanes. Three-cup types were introduced in 1961 for more accurate wind speed evaluation. However, as these did not record data automatically or continuously, the AWS system was launched in 1974, and windmill-type anemometers were introduced in 1976 for automation. These were subsequently changed from metal to polycarbonate for compactness and lightness, and heated models were introduced in 2011 to prevent freezing (Fig. 1).

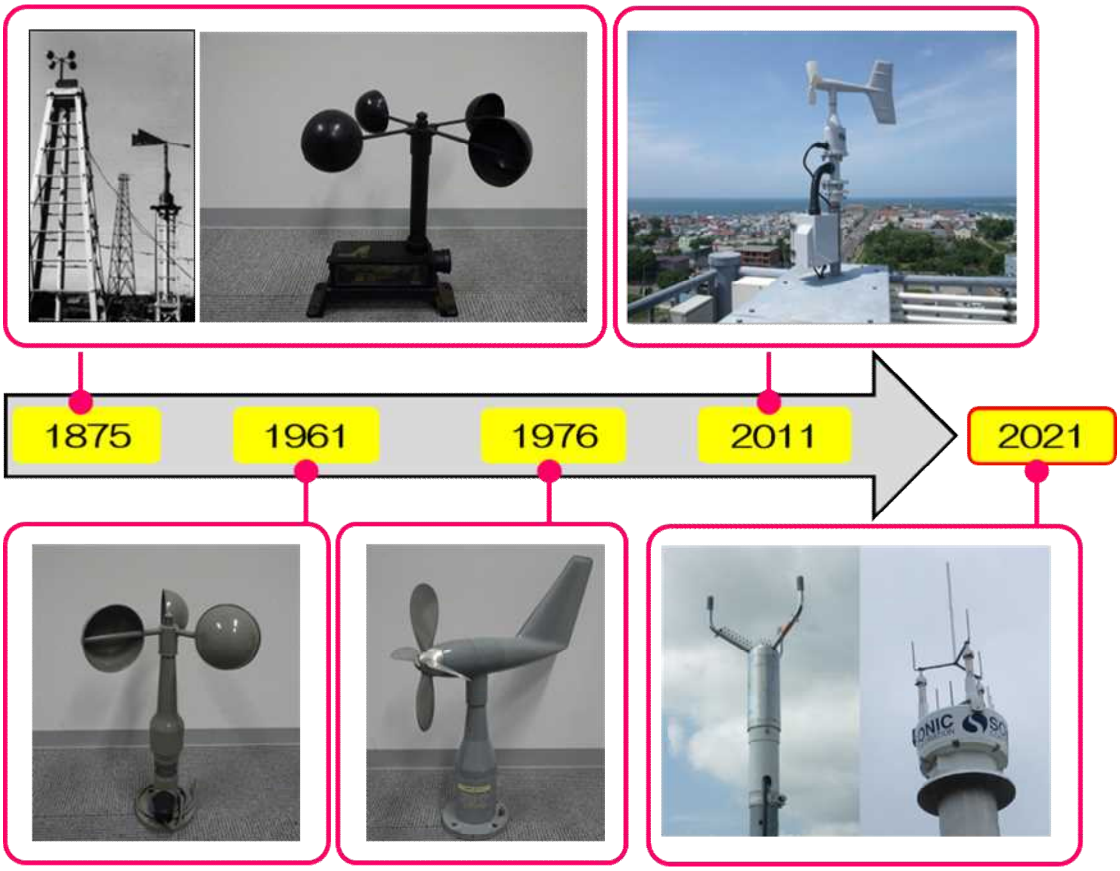

Figure 1: History of JMA anemometers: four-cup type and wind vane, three-cup type, windmill-type in AWS, windmill-type with anti-icing, ultrasonic

1.2. Issues with windmill-type anemometers, and ultrasonic adoption

The moving parts in windmill-type anemometers (such as propellers and unit parts) need to be periodically replaced and reinspected. In winter, snow and ice can impair wind speed/direction analysis (Fig. 2).

Conversely, ultrasonic anemometers have no moving parts, thereby facilitating maintenance and the cost of work at high elevations (Fig. 3). With these benefits, ultrasonic anemometers were considered in conjunction with instrument updates.

Figure 2: Frozen windmill-type anemometer

Figure 3: AWS and inspection at high altitude

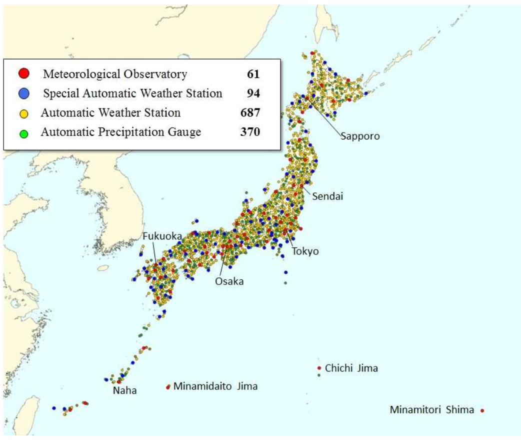

Figure 4: Distribution of weather stations (April 2024)

JMA runs anemometers at around 840 locations at intervals of about 21 km in its Meteorological Observatory and Special Automatic Weather Station and AWS system (Fig. 4). Japan has a long north-south distribution, with winter snowfall in northern parts and frequent typhoons in central and southern regions. Accordingly, anemometers must withstand operation during periods of snowfall and wind speeds of up to 90 m/s.

2. Ultrasonic anemometer testing

2.1. Challenges

The following needed to be addressed for the capacity of ultrasonic anemometers in Japan’s AWS system:

(1) Normal observation in rain storm and snow

(2) Elimination of avian influence on observation data, and prevention from related instrument damage

JMA’s avoidance of abnormal data has included three models (A, B and C; Fig. 5) for high potential against various external effects, and indoor/field tests have been conducted.

Model A	Model B	Model C	Windmill type
Sensor count: 3	Sensor count: 3	Sensor count: 4	
Shape caging an entire area	Upward-facing metal rod on top of each sensor and on the top surface of the main unit	Upward-facing wire at the top of each sensor	

Figure 5: Birdproof ultrasonic anemometers (left) and observatory windmill-type (right)

2.2. Testing

2.2.1. Indoor

Wind tunnel facilities at JMA's Meteorological Instrument Center were used to verify that accurate basic wind direction/speed performance met the specified accuracy with bird repellence. Accuracy is within 0.3 m/s at 6 m/s or less, and 5% or less otherwise. As these units have three or four ultrasonic sensors, checking was also performed to verify whether wind speed was affected by direction and any effects from bird shields (Fig. 6).

Figure 6: Wind-tunnel analysis (Model A)

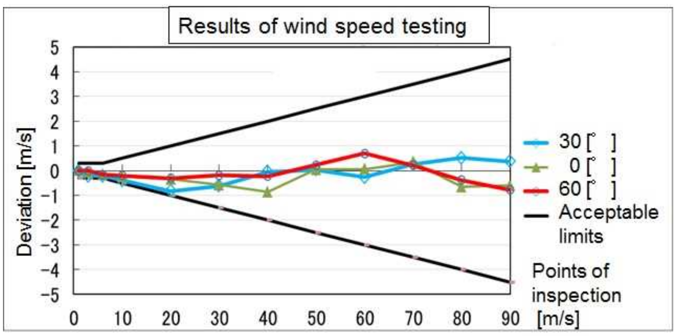

Figure 7: Test results for wind speeds of 1 – 90 m/s (Model B)

Instrumental deviation was checked with bird shields to verify orientation standards at 0 (north), 30 and 60 degrees with wind-tunnel speeds ranging from 1 to 90 m/s (Fig. 7).

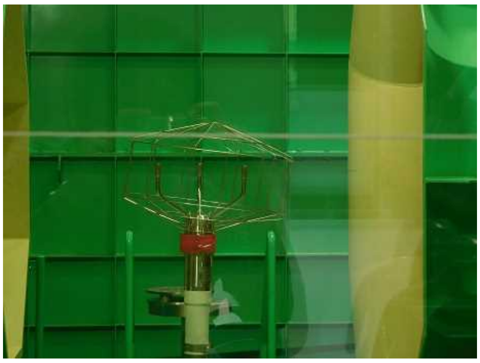

Figure 8: Bird protection during testing at a wind speed of 90 m/s (Model A)

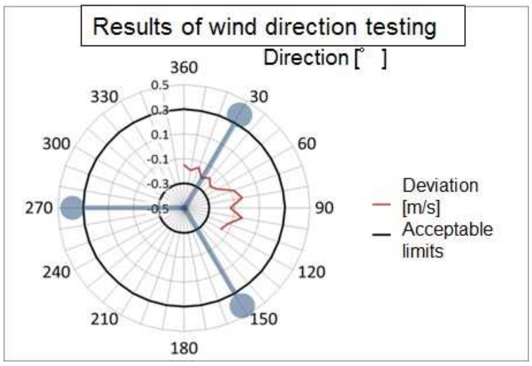

Figure 9: Test results at orientations of 0 – 120 degrees (Model B)

Model A with birdcage-type protection exhibited extensive missing data at 90 m/s due to tilting from strong wind, which caused turbulence near the ultrasonic sensor relating to the self-diagnostic function (Fig. 8). Model C also produced many values outside acceptable criteria in a phenomenon thought to be due to firmware. There were no issues with Model B wind speed data.

The reference wind speed was fixed at 6 m/s, with checking of orientation every 10 degrees from 0 to 120 to verify standard instrumental error. The results were within the standard for Models A and B (Fig. 9).

2.2.2. Field

Tests were conducted as follows (Fig. 10):

(1) Data from the typhoon-prone Ishigakijima District Meteorological Observatory in southwestern Japan were used to examine storm conditions.
(2) Data from the snow-prone Aomori District Meteorological Observatory in northern Japan were examined.
(3) Data from the Tsukuba Meteorological Instrument Center were used to analyze avian damage.

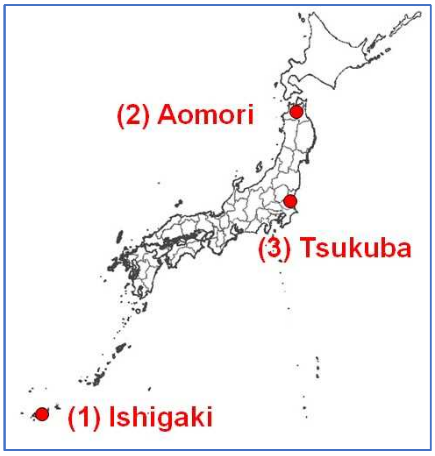

Figure 10: Field testing sites

Testing included comparison of wind direction and speed data from windmill-type anemometers. To check for avian damage, intermittent photography was used to evaluate the timing of presence, effects on wind speed and instrument damage at Tsukuba.

(1) Rain storm testing

Noise and missing data were analyzed with 1-minute values for all models (see Fig. 11 for comparison based on windmill-type modeling for a typhoon approach). Despite some missing data, comparative overall observation accuracy is seen in wind direction and speed.

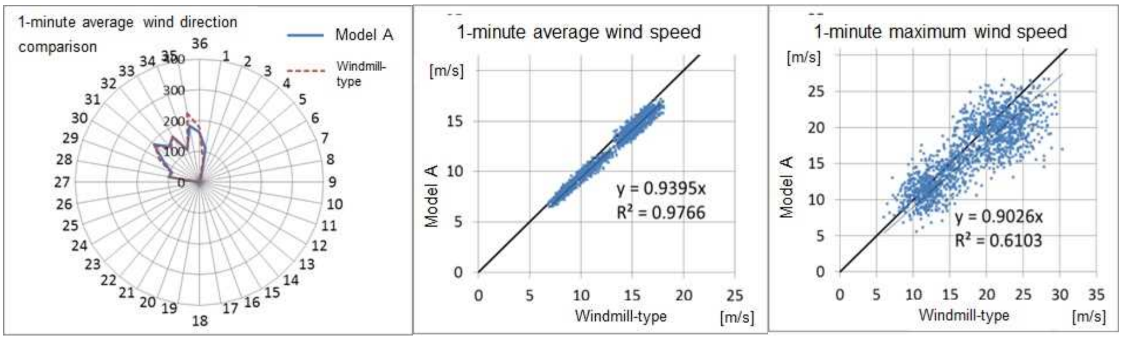

Figure 11: Comparison for an approaching typhoon (T1718, Sept. 13, 2017)

(2) Snowfall testing

For each model, spike noise occurred multiple times in snowfall data due to water droplets from melting snow on sensors. Model A exhibited snow on the bird protection part.

(3) Bird damage testing

Crows often sat for long periods on anemometers. Few ultrasonic sensors were damaged, but in one case a Model C wire was bent, indicating potential issues with the shape and strength of avian protection measures (Fig. 12).

Figure 12: Left: Crows on anemometers; right: bent bird protection wires

2.2.3. Manufacturer testing

Manufacturers conducted their own snow and ice/wind-tunnel and field testing for Models A and B, and made improvements based on the results.

2.2.4. Summary

Models A and B are expected to show required basic performance with the following considerations:

・Birdcage-type protection is associated with increased turbulence and missing data with higher wind speed. Birds tend to remain, and snow accumulates on the cage. This may not be optimal.

・Water droplets from melting snow and ice around ultrasonic sensors may disturb data waveforms and impair accurate wind speed analysis. Software needs to be improved for normal analysis even with waveform disturbance, and if this is not possible, data should be marked as missing.

Related liaison with the manufacturer was made.

2.3. Maintenance, inspection and cost advantages

JMA's annual inspections to analyze differences from the replacement of windmill-type anemometers with ultrasonic types suggest that work at high observatory elevations is no longer required. As older anemometers have moving parts, the operator must climb a 10-m pole for manual checking to avoid improper spinning and abnormal sounds. The more modern ones have no moving parts, thus removing the need for inspection at high altitude for items such as appropriate orientation and visible damage/deformation.

Moving parts in windmill-type anemometers also need to be replaced every five years or so, requiring disassembly at JMA's Meteorological Instrument Center. Ultrasonic anemometers require no such work.

Cost comparison shows that the ultrasonic type is more expensive, with high power consumption associated with heater usage to prevent snow and ice accretion. However, maintenance and periodic replacement are cheaper, and there are no costs associated with working at high altitudes. As a result, overall costs are reduced.

2.4. Installation

Based on the test results, the manufacturer modified the ultrasonic anemometer bird protection and software (Fig. 13), providing observation with accuracy and frequency similar to those of the windmill type. The ultrasonic type has many advantages over the windmill type in terms of maintenance and cost. Accordingly, these units have been gradually introduced since 2021, with planning for installation at all 687 AWS locations.

Figure 13: Ultrasonic anemometers

3. Observation data/instrument quality control

3.1. JMA data

Observation data quality involves both automatic and human control (AQC and HQC, respectively; Fig. 14).

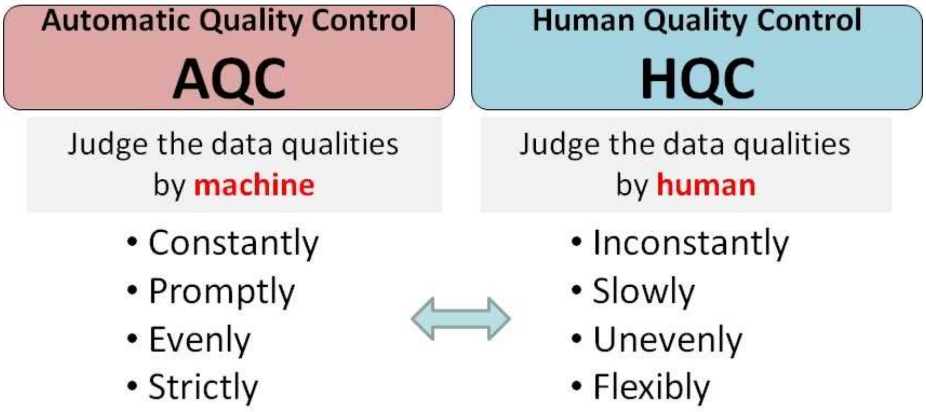

Figure 14: AQC and HQC

AQC simply involves machine determination of data validity, while HQC involves judgment by actual people.

Table 1 shows AQC for wind direction and speed data to identify questionable values.

Table 1: Valid ranges

Element	Limit values
Wind direction	≤ 1 to 360°
Wind speed	≤ 0 to 90 m/s

HQC is more of a comprehensive judgment based on meteorological expertise. In conjunction with AQC, it supports quality control with tools such as diagrams and graphs (see Figs. 15 and 16 for wind direction frequency data with a windmill-type anemometer at a certain AWS). Figure 15 shows wind direction opposite to that of the east-west direction compared to the past two years due to an error in system settings, while Fig. 16 shows an overall absence of east-direction data since August 2021 (red) due to instrument failure.

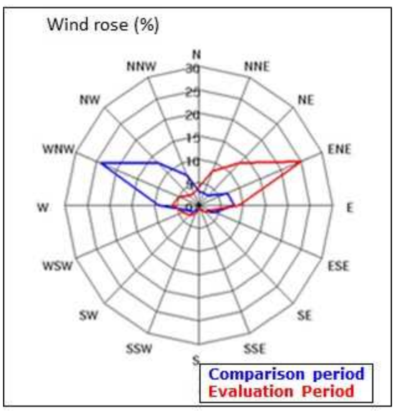

Figure 15: Single station wind direction (compared to the previous two years for August 2012)

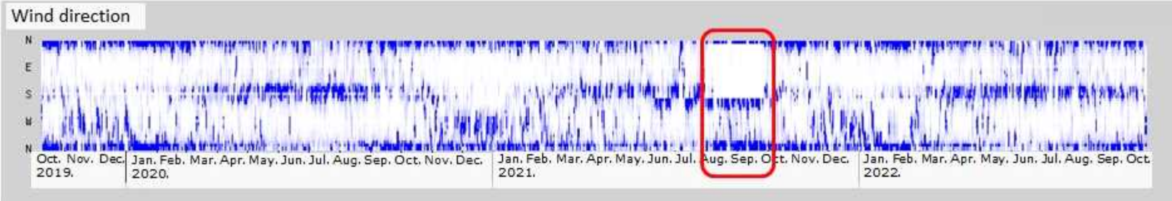

Figure 16: Chronological wind direction

Incorrect wind direction data are often caused by anemometer freezing or malfunction, or by installation or setting errors at the time of replacement. Such erroneous data are determined via HQC, rather than by AQC.

3.2. Ultrasonic anemometer quality control

Ultrasonic anemometers allow early detection of malfunctions and abnormalities without human intervention, simply from status information output. Although there are no moving parts that might cause deterioration, sensor impairments can result in missing data. Early detection of such issues prevents long periods of missing data via JMA AWS status information covering every 10 seconds over the past year from processing equipment, enabling issue analysis (Fig. 17). Results show the onset of

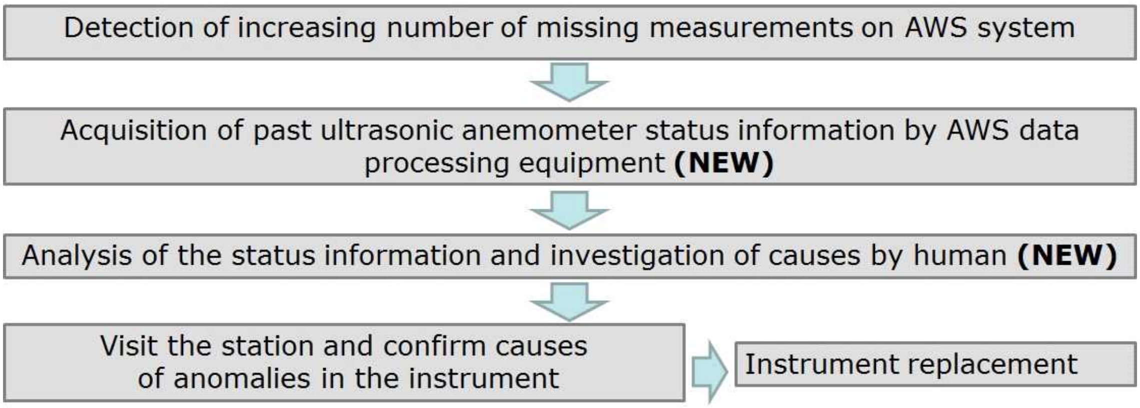

Figure 17: Quality control for ultrasonic anemometers

ultrasonic sensor deterioration at a certain point, indicating an issue, and on-site inspection revealed avian damage (Fig. 18). This example illustrates how more detailed instrument information can be obtained. Other advantages include identification of anomaly timing, detection of non-apparent anomalies, and remote analysis of issues.

Figure 18: Avian damage to silicone sensor rubber

4. Summary

JMA's modern ultrasonic AWS anemometer units replace the conventional windmill-type.

Testing for installation showed issues with ultrasonic anemometer, with results used to improve avian protection and software.

The new quality control also supports more accurate identification of issues.

The initial costs of installation are offset by the lower expense of ongoing periodic maintenance, resulting in cheaper overall operation.

5. References

JMA Website

Historical documents, research materials, training content, inspection procedures, and instrument failure reports in JMA