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Design and Data Analysis of a New Type of Antifreezing Cup-Type Wind Velocity Sensor

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Abstract

In most areas of China, affected by the environment of low temperature and high humidity, the wind speed sensor and wind direction sensor are frozen and cannot output data in autumn, winter or the alternation of winter and spring. In order to solve the freezing situation of the wind sensor, this paper designs a new type of antifreeze wind speed sensor. After meteorology performance testing and field observation tests, the correlation coefficient of the observation data is demonstrated, and the data curve is fitted. The result shows the sensor is stable, and has a good antifreeze effect, the data output is reliable.

Keywords

Automatic Weather Station, Wind Speed Sensor, Wind Direction Sensor, Freeze, Cold-Resistant Technology

1. Introduction

The measurement of wind elements is one of the important elements of meteorological ground observation. Wind is a three-dimensional vector superimposed on large-scale regular air flow by many small-scale pulsations that vary randomly in time and space [1] [2]. Because in most areas of China, autumn, winter or the alternation of winter and spring, affected by low temperature and high humidity environment, wind speed and direction sensor easily freeze and are unable to output sensor data. Once the wind sensor is frozen, the wind measurement data in the region will be missing. If the fault cannot be removed in time, it will inevitably have a serious impact on the forecast and meteorological service [3].

At present, the most effective measures to solve the frozen wind sensors are as follows: maintenance personnel go to the site, put down the wind pole or climb the wind tower for detection [4]. Especially in winter, the tower is covered with thin ice, and climbing the tower for troubleshooting causes certain safety risks, and the troubleshooting and maintenance of automatic weather stations in remote areas are more inconvenient. In order to cope with the freezing phenomenon of wind sensors, many scholars have conducted in-depth studies and proposed sensor heating devices to solve the freezing problem of wind sensors. However, the experimental results are not satisfactory. Due to the increase of uncertainty introduced by heating devices [5], the maintenance cost and difficulty have been increased.

By analyzing the frozen position of the wind speed sensor and considering the drainage angle, velocity and fluid dynamics [6], this paper proposes an anti-freezing cup-type wind speed sensor based on mechanical principle. After passing through the 40 m/s wind tunnel laboratory, The measurement performance meets the requirements of *Verification Regulations for Wind Direction and Speed Sensors of Automatic Weather Stations* (*JJG* (*Meteorological*) 004-2011) [7]. Subsequently, field experiments are carried out in Zhangjiakou and Chengde of Hebei Province, and the experimental results are good.

2. Design Principle

The cup-type wind speed sensor is an instrument used to measure the wind speed and convert it into an electrical pulse signal. It has a wide range of applications, such as meteorological stations, ships, oil platforms, environmental protection, etc [8]. The antifreeze sensor designed in this paper is composed of the components of the wind cup, the shell and the socket. The protective cover arranged at the upper end of the working part, the connecting shaft arranged in the working part and running through the protective cover, and the induction element in the connecting shaft constitute the key components of the equipment [9]. Its external structure is shown in **Figure 1**.

Both the input and output of the sensor adopt transient suppression diodes for overload protection, as shown in **Figure 2**. Wind speed measurement uses a low-inertia wind cup component as the sensing component, which rotates with the wind and drives the wind speed code disc to carry out photoelectric scanning

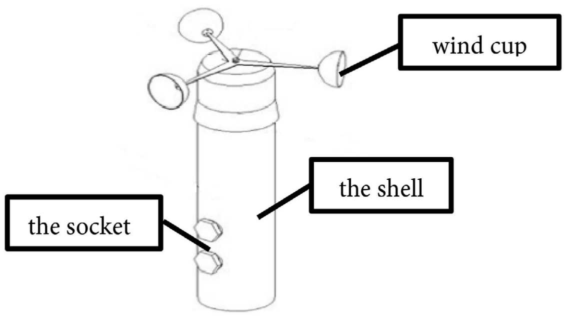


Figure 1. Appearance structure diagram.

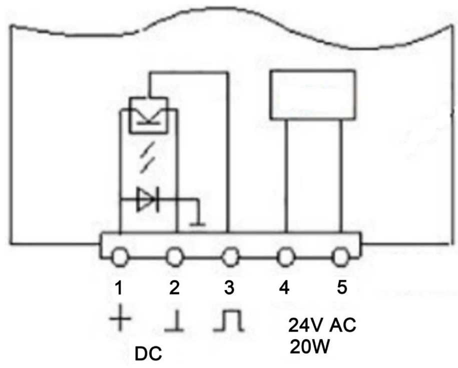


Figure 2. Schematic circuit design.

and output the corresponding electrical pulse signal [10] [11]. The external protective cover is made of corrosion-resistant materials and protected by spraying layer. The seal uses a labyrinth structure and O-rings to protect the sensitive elements inside the instrument from harsh environments [3].

3. Measurement Performance Test

The designed wind speed sensor has the following parameter requirements, as shown in Table 1.

3.1. Test Condition

3.1.1. Verification Using Measuring Standard Devices

Standard Name: First class compensatory micropressure gauge standard device.

Measurement Range: (0 - ±1500) Pa.

Accuracy Level: First Class.

3.1.2. Antifreeze Type Wind Speed Sensor

Unit Type: EL15.

Measurement Range: 0 m/s - 40 m/s.

3.1.3. Environmental Conditions

Temperature: 15˚C - 30˚C.

Humidity: 30% RH - 70% RH.

Atmospheric Pressure: 900 hPa - 1100 hPa.

Selection of Experimental Points: Starting Wind Speed, 1 m/s, 2 m/s, 5 m/s, 10 m/s, 15 m/s, 20 m/s, 25 m/s, 30 m/s.

3.2. Start-Up Wind Speed Test

When the wind speed sensor can overcome the friction torque and air resistance moment on the rotation axis, the speed at which rotation begins is the starting wind speed. The starting wind speed of the whole experiment section (0 m/s - 40 m/s) is less than 0.5 m/s, which meets the requirements of the Verification Regulations of Wind Direction and Speed Sensors of Automatic Weather Stations (JJG (Meteorological) 004-2011).

Table 1. Parameter specifications.

environmental conditions	−40˚C - 60˚C 0% - 100% RH
working voltage	DC5V
weight	1 kg
boundary dimension	319 mm × 225 mm
measurement range	0 m/s - 60 m/s
maximum permissible errors	±(0.5 + 0.03 V) m/s (Note: V is the indicated wind speed)
start-up wind speed	0.5 m/s
resolving ability	0.1 m/s
wind velocity output	0 Hz - 1221 Hz
intensity of draft	75 m/s

3.3. Wind Speed Comparison Experiment

Two ordinary cup-type wind speed sensors and two new anti-freezing cup-type wind speed sensors were selected for experimental analysis and comparison.

Instrument Model: EL15-1C;

Instrument Number: 14110761756;

Experimental Result: For details, see **Table 2**.

According to the error of comparison experiment, the error curve of indication value is drawn, as shown in **Figure 3**.

The anti-freezing wind speed sensor is 77.8% better than the ordinary wind speed sensor. This may mean that the function of the anti-freezing wind speed sensor is more reliable and the measurement of wind speed is more accurate.

Instrument Model: EL15-1A;

Instrument Number: 13120721887;

Experimental Result: For details, see **Table 3**.

According to the error of comparison experiment, the error curve of indication value is drawn, as shown in **Figure 4**.

The anti-freezing wind speed sensor was optimized by 66.7% compared with the ordinary wind speed sensor. When compared with ordinary sensors, certain aspects of the frost-resistant sensor have been optimized. This may refer to possible improvements such as cost reduction.

Instrument Model: EL15-1E;

Instrument Number: 17040770049;

Experimental Result: For details, see **Table 4**.

According to the error of comparison experiment, the error curve of indication value is drawn, as shown in **Figure 5**.

The anti-freezing wind speed sensor was optimized by 88.9% compared with the ordinary wind speed sensor.

Through the comparison of the laboratory data of the above three models, the new antifreeze wind speed sensor has different degrees of optimization than the

Table 2. Wind tunnel test data (1C).

Micromanometer indicating value (Pa)	Standardized wind speed V indicating value (m/s)	Normal wind speed (V1)	Antifreeze typewind speedsensor (V2)	Indication error (ΔV1)	Indication error (ΔV2)
0.05	0.30	0.35	0.34	0.05	0.04
0.46	0.91	1.06	1.04	0.15	0.13
2.49	2.11	2.16	2.13	0.05	0.02
13.56	4.93	5.02	5.03	0.09	0.10
54.85	9.92	10.31	10.29	0.39	0.37
125.51	15.00	15.59	15.50	0.59	0.50
223.15	20.00	20.55	20.61	0.55	0.61
348.45	25.00	25.89	25.87	0.89	0.87
504.66	30.08	31.04	31.01	0.96	0.93

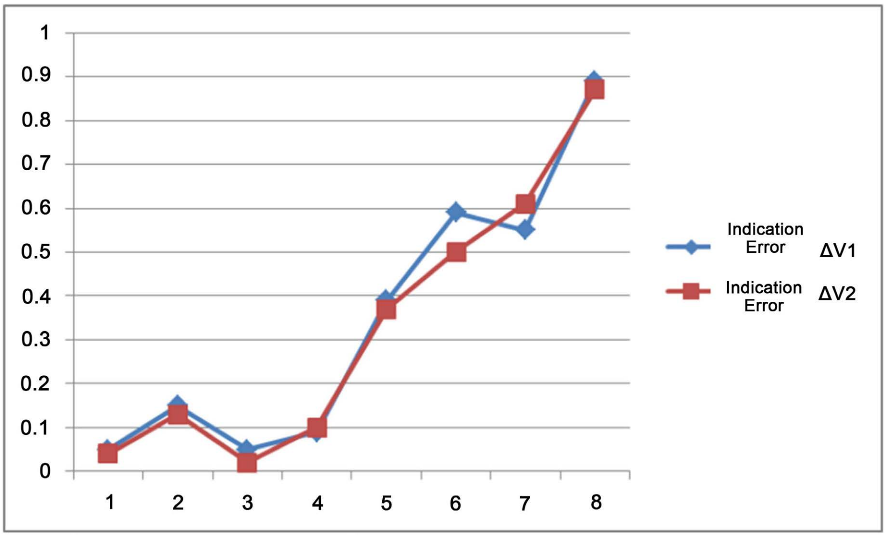


Figure 3. The error curve (1C).

Table 3. Wind tunnel test data (1A).

Micromanometer indicating value (Pa)	Standardized wind speed V indicating value (m/s)	Normal wind speed (V1)	Antifreeze typewind speedsensor (V2)	Indication error (ΔV1)	Indication error (ΔV2)
0.03	0.23	0.42	0.32	0.19	0.09
0.53	0.97	1.08	1.08	0.11	0.11
2.47	2.10	2.09	2.16	-0.01	0.06
14.16	5.02	4.95	5.02	-0.07	0.00
56.34	10.01	10.18	10.03	0.17	0.02
127.56	15.06	15.55	15.56	0.49	0.50

Continued

225.06	20.00	20.66	20.54	0.66	0.54
354.24	25.09	25.67	25.64	0.58	0.55
505.85	29.98	30.80	30.82	0.82	0.84

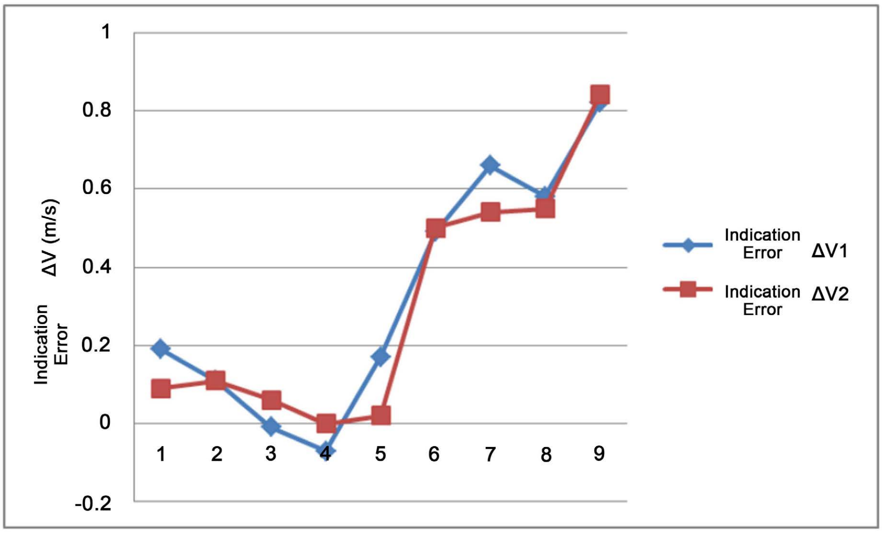


Figure 4. Error curve (1A).

Table 4. Wind tunnel test data (1E).

Micromanometer indicating value (Pa)	Standardized wind speed V indicating value (m/s)	Normal wind speed (V1)	Antifreeze typewind speedsensor (V2)	Indication error (ΔV1)	Indication error (ΔV2)
0.04	0.27	0.10	0.20	−0.17	−0.07
0.53	0.98	0.80	0.85	−0.18	−0.13
2.52	2.13	1.90	1.90	−0.23	−0.23
13.61	4.94	4.70	4.80	−0.24	−0.14
54.72	9.91	10.10	10.10	0.19	0.19
123.45	14.89	15.30	15.40	0.41	0.51
223.99	20.06	20.90	20.80	0.84	0.74
346.29	24.94	25.90	25.89	0.96	0.95
503.73	30.08	31.40	31.38	1.32	1.30

ordinary wind speed sensor, and its indication error result has obvious advantages, which is closer to the real measurement value.

4. Observation Field Test

4.1. Trial Site

The preliminary pilot test was carried out in Zhangbei County Meteorological

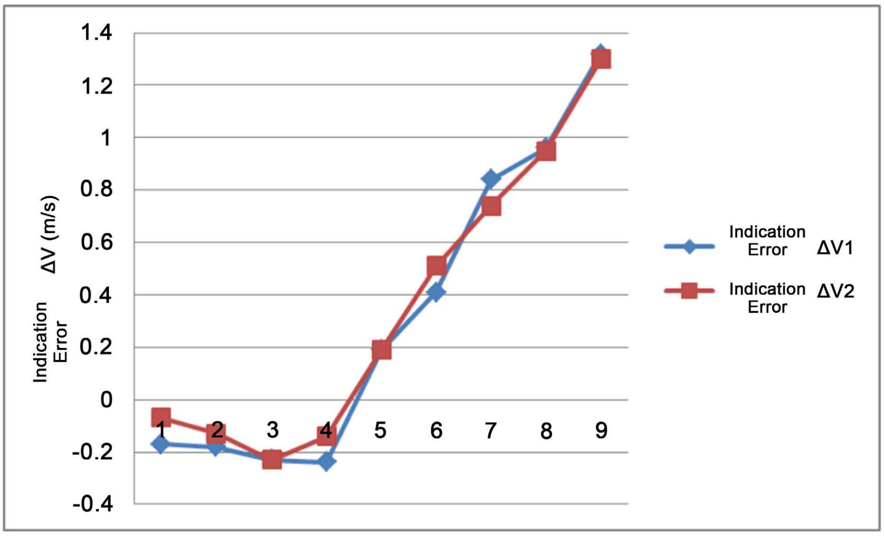


Figure 5. Error curve (1E).

Bureau, Guyuan County Meteorological Bureau, Chengde Longhua County Meteorological Bureau and Luanping County Meteorological Bureau. The trial will run from September 1 to November 30, 2021.

4.2. Test Content

The test instrument was installed in the position of the existing wind speed sensor in the backup station, the existing wind speed sensor was replaced, and the data of the wind speed sensor in the active main station was compared.

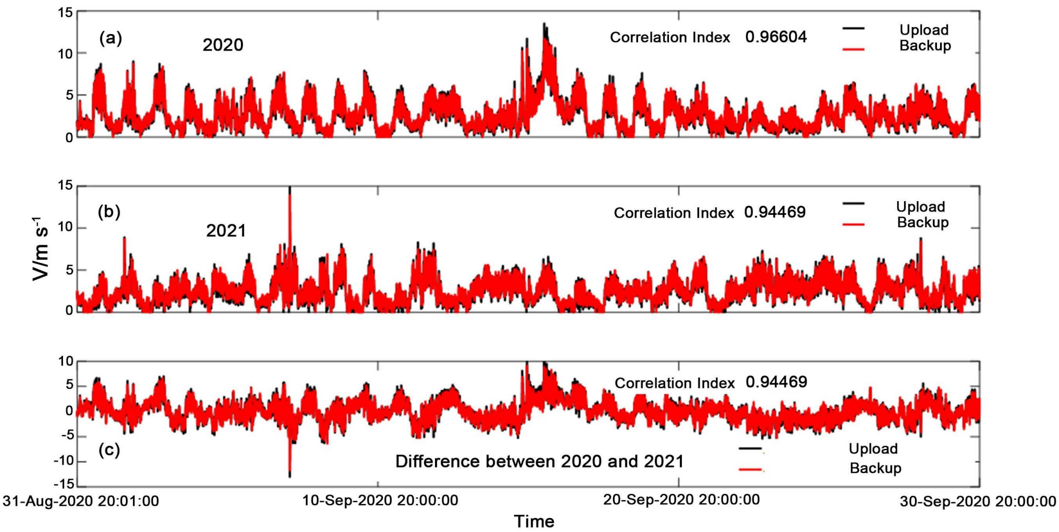
4.3. Test Results

Based on the wind speed observation data of Zhangbei County, Guyuan County, Longhua County, Luanping County Meteorological Bureau in September 2020 and September 2021, the wind speed data of upload station and backup station were processed, and the wind speed changes of traditional wind speed sensor and anti-freezing wind speed sensor in the same month in different years were analyzed in detail.

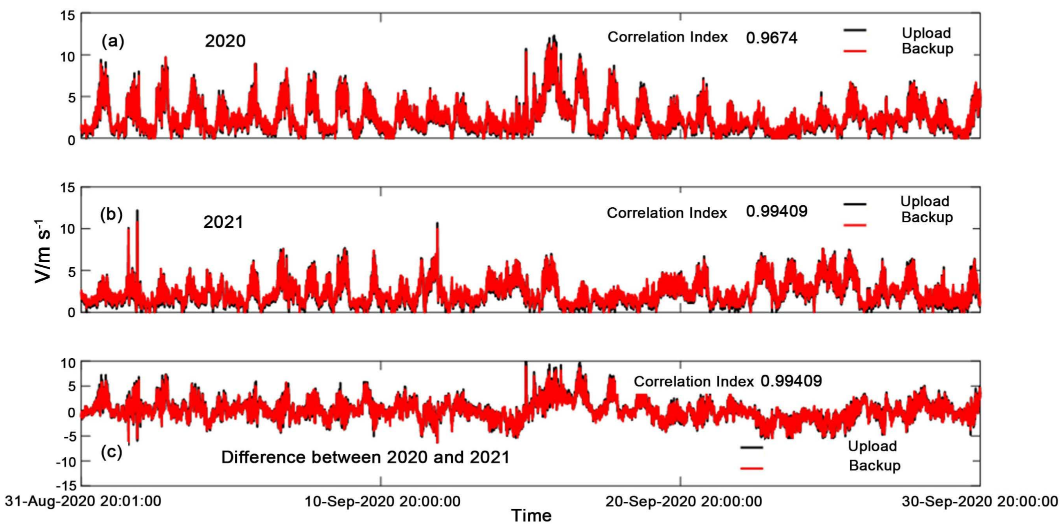
Based on the wind speed data of the four test sites, the wind speed changes and correlation coefficients of the upload station and backup station in 2020, the wind speed curves and correlation coefficients of the upload station and backup station in 2021, the difference between the upload station and 2021, and the difference between the backup station and 2020 are respectively compared, as shown in Figure 6.

In general, in September 2020 and mid-September 2021, the change trend of wind speed at the upload station and backup station over time is basically the same, with good consistency.

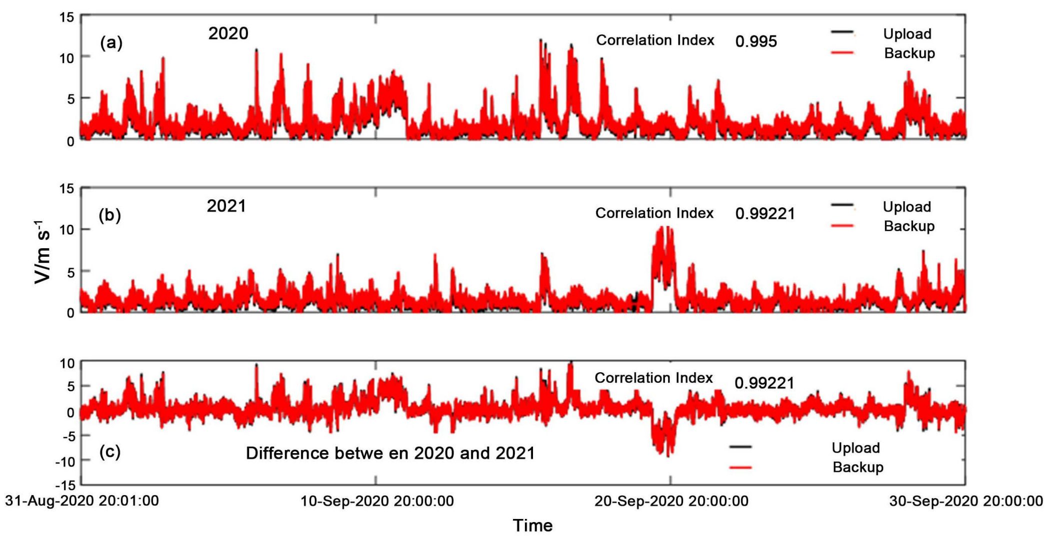
From Figure 6(B) of the four test sites, it can be seen that compared with the traditional wind speed sensor of the upload station, the wind speed evolution trend of the anti-freezing wind speed sensor of the backup station in September



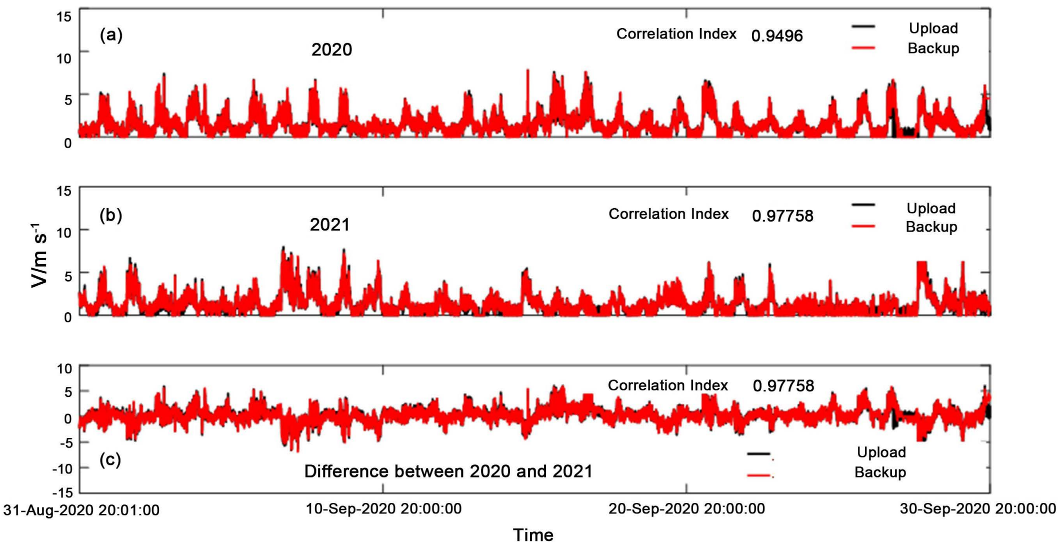
(A) Zhangbei



(B) Guyuan



(C) Longhua



(D) Luanping

Figure 6. Comparison of wind speed changes in 2020 and 2021 between upload stations (traditional wind speed sensors) and backup stations (antifreeze wind speed sensors) at the four test sites of Zhangbei, Guyuan, Longhua and Luanping ((a) Comparison of wind speed changes of upload station and backup station in 2020; (b) Comparison of wind speed changes of upload station and backup station in 2021; (c) Comparison of changes in wind speed difference between upload station and backup station in 2021 and 2020).

2021 is basically the same with time, and has a good correlation. It is worth noting that the correlation coefficient of the wind speed data of the upload station and the backup station in Guyuan and Luanping in 2021 even increased slightly.

5. Conclusion

In summary, the antifreeze cup-type wind speed sensor has excellent performance in the measurement performance experiment and observation field test. In the comparison of ordinary wind speed sensors, the average optimization rate of metrology performance reached 77.8%. In the field test, the antifreeze wind speed sensor had a good correlation with the ordinary wind speed sensor, and even slightly improved than the previous data.

Conflicts of Interest

The authors declare no conflicts of interest regarding the publication of this paper.

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