INCORRECT WIND MEASUREMENT

DUE TO ICING ON HEATED ULTRASONIC ANEMOMETER

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Abstract: In cold climates, ultrasonic anemometers sometimes measure extraordinary higher winds compared with the mean values during the respective periods of measurement. The problem is that these irregular readings are below the ultimate maximum wind speed, which cannot be eliminated from the series of record in some theoretical manner. Field measurements indicated that these cases occurred accompanied by precipitation and temperature below or just above freezing. In order to know what may cause the irregulars, icing wind tunnel tests were conducted. It turned out that ice accretion with a gap between the transducer surface of the ultrasonic anemometer and the inner surface of the ice deposit would be the cause of the incidence. The *secondary icing*, due to refreezing of the molten water generated by a heater installed in the transducer, may be another reason for incorrect measurement in snowy conditions as well.

1. INTRODUCTION

Ultrasonic anemometers have been widely used for wind measurement. However, in cold climates, irregular signals were transmitted. They can be translated as extraordinary higher wind speed compared with the mean values in a period of measurement. The recent measurement conducted in winter indicates that icing or snowing must be the reason for the irregulars. Hence icing wind tunnel tests were carried out to find out the mechanism of this phenomenon.

2. RESULTS AND DISCUSSION

Figure 1 shows the effect of the change of ice structure artificially made on a transducer of Vaisala's ultrasonic anemometer on wind speed measurement. From the picture in the figure there is a gap between an ice deposit and the transducer surface, which may cause the irregular reflection of ultrasonic wave from the transducer, namely the extraordinary high wind speed.

An ice deposit on a heated transducer produced by snow through the secondary icing process is shown in Figure 2. Even in a snowy condition, ice accretes on the heated anemometer through the following process: snow accretion – melting by heat – refreezing.

It can be suggested that for icing prevention, namely prevention of incorrect wind measurement, heating is carefully considered in terms of the capacity of the heating element and the extent of heated area.

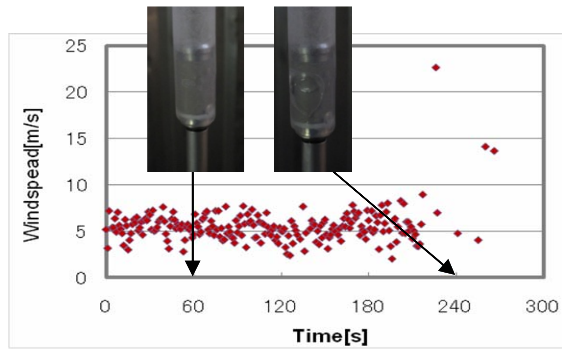

Figure 1: Effect of change of ice structure by heat on measurement

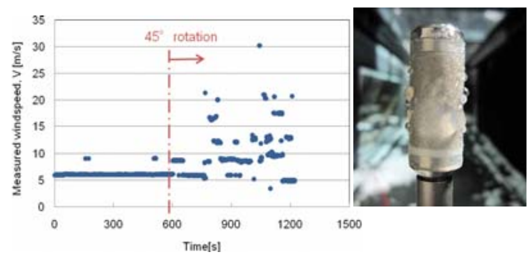

Figure 2: Incorrect measured wind speeds by the secondary icing on the transducer of the ultrasonic anemometer

3. CONCLUSION

By conducting the icing wind tunnel tests using Vaisala's heated ultrasonic anemometer, it turned out that ice accretion due to collision of supercooled water droplets with the transducer surfaces of the anemometer in the in-cloud icing conditions would cause incorrect wind measurement. Moreover, under the snowy conditions, the secondary icing caused by refreezing of melted snow on unheated areas of the transducer may be another reason for transmissions of irregular signals meaning extraordinary high wind speed.

4. REFERENCES

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***Abstract* - In cold climates, ultrasonic anemometers sometimes measure extraordinary higher winds compared with the mean values during the respective periods of measurement. The problem is that these irregular readings are below the ultimate maximum wind speed, which cannot be eliminated from the series of record in some theoretical manner. Field measurements indicated that these cases occurred accompanied by precipitation and temperature below or just above freezing. In order to know what may cause the irregulars, icing wind tunnel tests were conducted. It turned out that ice accretion with a gap between the transducer surface of the ultrasonic anemometer and the inner surface of the ice deposit would be the cause of the incidence. The *secondary icing*, due to refreezing of the molten water generated by a heater installed in the transducer, may be another reason for incorrect measurement in snowy conditions as well.**

Keywords: Icing, Snowing, Ultrasonic Anemometer, Icing wind tunnel, Wind measurement

I. INTRODUCTION

The observation of wind is not limited to mere gathering meteorological data but it also plays a vital role in disaster prevention (regulation of traffic and natural disasters), structural design, as well as exploitation of renewable energy (wind and solar). Observations are performed using an anemometer. Mainstream anemometers were and continue to be the propeller and cup types, but nowadays expectations are mounting for ultrasonic anemometers (abbreviated as “US”). Aside of course from its high accuracy another advantage of the US is the ease for maintenance and inspection, since it has no rotating components. On the other hand, the fact that birds at times land on wind velocity measurement section of anemometers or abnormal values sometimes are output during the cold season bringing about problems, which appears to be the case when the use of US is shunned for measurements that must be regulated using threshold values. The “abnormal” value mentioned here refers to cases when the values of about 40 m/s are output (discretely) as instantaneous values, in spite of the fact that the average wind velocity for the measurement period is about 5 m/s. Although such a value as 40 m/s has significance of its own as wind velocity value, it is considered reasonable to conclude that such results are derived from an erroneous measurement of the meteorological environment at the time of observation. However, no appropriate method has been established to process such abnormal values, as they are indeed significant wind velocity values and most of all since the occurrence of such abnormal values cannot be prevented they are considered to be causes damaging the advantage of this measuring device in the current condition. This research considers the formulation of measures that must be implemented in perspective and sets the clarification of the mechanism for the occurrence of such an abnormal value output during the cold season, in order to realize such actions. Furthermore, the impact of birds landing, as described earlier, was excluded from the scope of this research.

II. METHOD OF RESEARCH

The research sought to clarify the mechanism for the occurrence of abnormal values through the following steps.

A. Analysis of abnormal value occurrence case examples during field observations

The results of wind velocity measurements taken throughout the year (using Vaisala WXT510, etc.) in fiscal 2009 were investigated [1]. The occurrence of abnormal values were, as described later, considered to be caused by the accretion of ice and/or snow on the transducer (hereinafter abbreviated as “TD”), since the results of our analysis indicated that such abnormal values occurred when the air temperature was in the vicinity or lower than the freezing, at the time precipitation and wind were present. Tests were conducted with this condition in mind, once this relationship was discovered.

B. Reproduction tests for occurrence of abnormal values in ice accretion wind tunnel

A US (Vaisala WS425/F) anemometer was installed at the outlet section of the ice wind tunnel at the Kanagawa Institute of Technology. The ambient temperature was set at -12ºC while the mean airstream velocity was set at 6 m/s in the wind tunnel outlet. After exposing the unheated anemometer to the icing environment for a certain period of time, a heater was activated while the wind velocity was maintained. In reality, many US instruments said to contain cold climate specifications have a certain threshold value with ice accretion prevented through the operation of an internal heating device (electric heater). Furthermore, the threshold also changes when the air temperature drops and when the temperature rises, to ensure that the heater operation can provide for hysteresis. For example, the control method would involve a repeating history with the heater being turned on whenever when the overall air temperature dropped and sank below +2ºC, whereas the heater operation was suspended at +7ºC whenever the temperature rose. Therefore, not operating a heater under an ice accretion environment and starting the application of heat after the occurrence of the ice accretion is the reproduction of a sort of a situation that hardly ever occurs. Since the purpose of this test was not aimed at staying in line with the actual conditions to verify whether or not the accretion of ice and snow occurs while the heater is operating and reproducing erroneous measurements, but rather it was instead intended to determine whether any erroneous measurements occurred under any circumstances, thereby confirming that there was no need to pursue the justification for validity of the test itself. Furthermore, since the authors have gained knowledge through experiences with ice accretion tests conducted thus far, which indicate that ice accretion can occur at the locations subjected to this test even with instruments that have heating capabilities, depending on the conditions, such as the range to which heat is applied or the amount of heat being applied, it was decided that there is sufficient significance for investigating the impact of change in the condition of ice accretion by applying heat to the ice accretion prepared previously.

C. Reproduction test through artificial and simulated ice accretion

Clarification of the mechanism for the occurrence of erroneous measurements was sought through an understanding of the conditions when abnormal values occur, by taking measurements after ice forms on the TD of the US used in Section 2-3, artificially or through simulation. This simplified ice accretion, a reproduction of which was sought in the ice accretion wind tunnel test described in the previous section, made it possible to quantitatively and qualitatively evaluate it in order to clarify the causal relationship between the ice accretion conditions and erroneous measurements. A cylinder was placed over the TD under a constant temperature, then water was poured in and left to stand for several hours while ice formed, after which the cylinder was removed. The application of heat to the TD section started thereafter and chronological observations were made on the changes in the ice and wind velocity measurements were taken.

Information regarding the heating method for the TD section of the WS425F, which was used in this test, was not available. An investigation on the range of the heating section was therefore conducted ahead of the test, by observing the heating condition using a thermograph instrument (TVS-500 manufactured by Nippon Avionics). It was discovered that the heater was integrated inside at the center of the TD section, which is long in a vertical direction, in practically a semi-circular shape (with the front side the mid point between the two facing TDs).

D. Evaluation test on impact of snow accretion

In order to determine the possibility of erroneous measurements with the US during a snowfall, wind velocity measurements were taken under an artificial snowfall environment. The test was conducted inside the wind tunnel belonging to the Cryosperic Environment Simulator (CES), located inside the Shinjo Branch of the Snow and Ice Research Center of the National Research Institute for Earth Science and Disaster Prevention. An image inside the CES is shown in Fig.1, whereas a typical display of the test is shown in Fig.2. A snowfall machine was installed on the ceiling of the wind tunnel measuring section to supply snow inside the wind tunnel. The snowfall condition depended on the wind velocity inside the wind tunnel. For this reason, a position at which the most appropriate snowfall could be applied on the US was determined in advance and in line with the prescribed wind velocity. The environment in which the test was conducted is summarized in Table 1, whereas the anemometer used in the test is summarized in Table 2. Since the purpose of the test was to determine the snow accumulation and ice accretion condition on the US when erroneous measurements occurred, the test was conducted in a set environment, wherein the snowfall was reproduced and measurements of the wind velocity taken, with observations made of the changes in values.

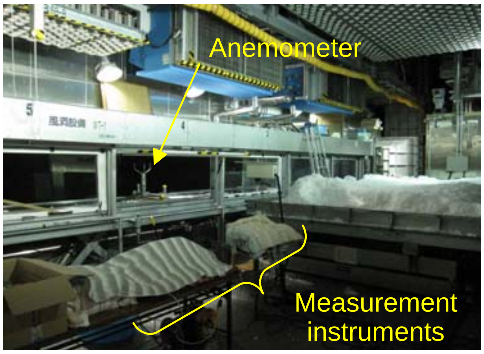

Fig.1 Cryosperic Environment Simulator and the ultrasonic anemometer placed in the test section

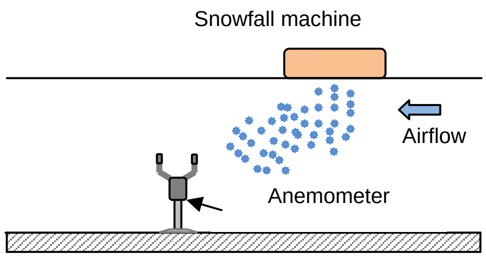

Fig.2 Snowfall machine and anemometer

Table 1. Test conditions

Airstream speed (m/s)	0, 1, 2, 6
Ambient temperature (Cel)	-2, -12

Table 2. Tested ultrasonic anemometers

Vaisala OY	WS 425
	WS 425F
GILL instruments	Wind Observer II

Furthermore, obtained data was expressed by categorizing it into the following four types:

Normal values: Wind velocity values of normal measurement readings.

Abnormal values: Significant wind velocity values that are determined to be chronologically abnormal.

Invalid values: Values output without measurements taken for some reason (for example "999").

Missing values: When the output of values did not occur from the measuring instruments.

III. Results and Discussion

A. Analysis of abnormal value occurrence case examples during field observations

The results of the wind velocity measurements taken on February 1, 2009, are shown in Fig.3. An intermittent downpour starting from 15:00 on the day resulted in an output with a significant abnormal value. Considering that the air temperature was below the freezing point and the downpour was actually snow or a supercooled mist, the accretion of snow on the US was anticipated under the conditions with a high wind velocity, even though the instrument was heating. The ice and snow accretion on the US started to melt once the downpour diminished, which is considered to have led to the output of the abnormal value.

B. Reproduction tests for occurrence of abnormal values in ice accretion wind tunnel

The output results from the US during the ice accretion wind tunnel test are shown in Fig.4. The ice accretion formed on the US was melted by heating the TD and wind velocity measurements were then taken. Even though the conditions were different, the fact that the output of abnormal values ceased at the point where ice accretion on the TD section was eliminated, confirmed more or less an identical output as the results obtained through the field observations. As described previously, although it is definitely possible to eliminate invalid values from the output, the processing output of the wind velocity measurements during actual measurements becomes difficult at 50 m/s or below, as shown in the figure. It is only when the average wind velocity is a known figure, as was the case with wind tunnel tests conducted, that it is possible to positively determine when output values are abnormal.

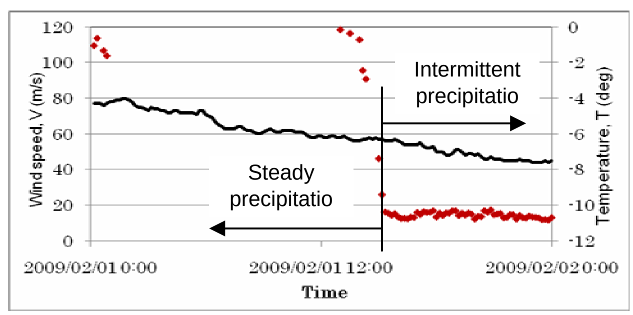

Fig.3 Result from the field measurement

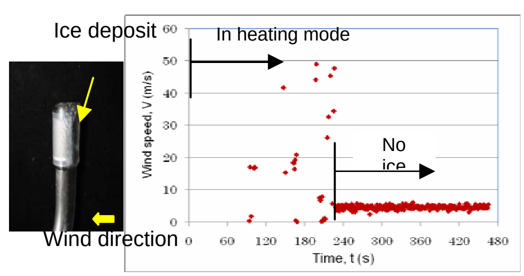

Fig.4 Result of icing wind tunnel test in KAIT

C. Reproduction test through artificial and simulated ice accretion

For this test ice accretion was artificially formed (ice thickness of 0.9mm) on the TD section of the US, set in the ice accretion wind tunnel, in order to investigate the impact on the measurement from ice accretion alone. When ice accretion was closely attached to the TD section and its shape was flat, it was determined that no abnormal values occurred even when some fluctuations in the wind velocity took place (this test was planned in such a manner), similar to the results obtained from a simplified test that involved the use of an ultrasonic range meter, as described in the previous section.

Next, the relationship between the condition of the ice and the wind velocity measurements was investigated by applying heat to TD with an artificially formed ice accretion. Abnormal values were output approximately four minutes after starting the heat application, as shown in Fig.5. Prior to that the ice on the surface of the TD section had already started melting and was trapped inside ice in a liquid state, as shown in the photograph on the left side of the figure, however the measurements taken were normal. Once approximately four minutes had elapsed, the surface layer of the ice accretion melted and water drained out, leaving the ice interior with an air pocket (as shown in the photograph on the right side of the figure) and this condition is understood to have caused the problem with the measurement.

D. Evaluation test on impact of snow accretion

Three types of ultrasonic anemometers were installed at the wind tunnel measuring section and tests were conducted under prescribed environmental conditions. No significant abnormal values were output under any of the conditions. The wind tunnel tests in question did differ from the actual snow accretion environment, due to the stability of the test conditions. For this reason and with WS425F only, the change in the wind direction was simulated by rotating the instrument 45 degrees in a counterclockwise direction after snowfall for ten minutes (snowfall flow rate of 8.53g/m^{2}s), after which snowfall was continued for another ten minutes. An output of abnormal values was recorded starting immediately after the rotation, as shown in Fig.6. The wind tunnel internal wind velocity was 6m/s, but the measurement values of up to a maximum of 30m/s were detected, with a frequent occurrence of numerical values of about 20m/s. An image of the TD section immediately after the test is shown in Fig.7. Since a feedback circuit was integrated into the TD section, it is considered to be designed to maintain this section at about 30 degrees Celsius (based on tests implemented separately). For this reason, a secondary ice accretion was being formed by the melting of the ice accretion and then freezing it at the TD section. Furthermore, the formation of a secondary ice accretion from snowfall was confirmed in a narrow range on the front side of the TD section, the ice accretion range appeared to have broadened due to the rotation of the anemometer intended to simulate the change in wind direction, which is considered to have become an obstruction for the transmission and reception of ultrasonic waves.

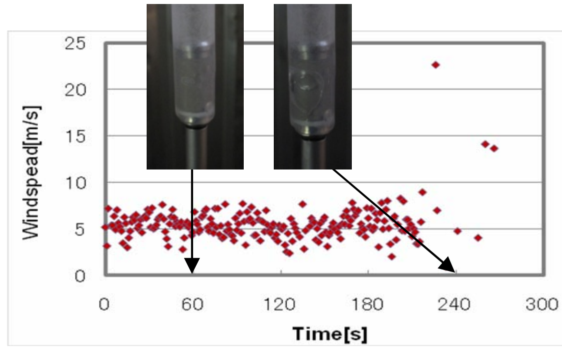

Fig.5 Change of ice by surface heating

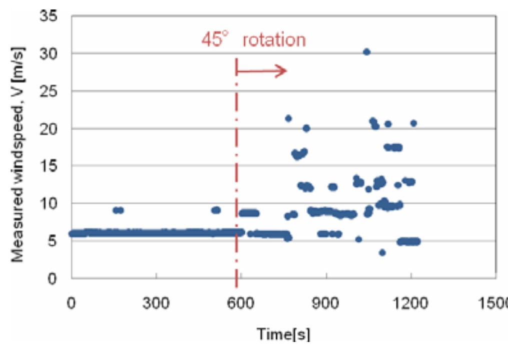

Fig.6 Incorrect wind speed measurement


Fig.7 Ice accretion on the transducer

Furthermore, snow accumulation on the US was observed in a no wind condition. Snow accumulation occurred with WS425 only on the arm section and when the upper section of the main unit of the US was not being heated (Fig.8). Although snow accretion can be melted by heating the section with WS425F and the Wind Observer, which is heated in the TD section, the sedimentation of snow continues for a certain length of time. Once the amount of sedimentation reached a certain level, the snow dropped off and no impact on the measurement was apparent. The snow accumulation on WS425 was continued further (Fig.9(a)) and snowfall was suspended when the values were missing, then the amount of shielding provided by the accumulation of snow on the TD section was changed to see the change in the output of the TD. When the length of snow accumulation in the up wind direction of the TD on the downstream side was 5cm, the

Fig.8 Snow accumulation on WS425

(a) (b) (c)

Fig. 9 Reduction of snow covering the transducer

values continued to be missing (Fig.9(b)), whereas when the shielding was completely removed (Fig.9(c)), abnormal values were output. In this case the three TD sections had not been shielded by snow and thus mutual transmissions and receptions were possible, therefore the output for the wind velocity of 0m/s, which certainly was different from what had been anticipated, was quite interesting. No further investigations were conducted beyond this, however, the conjecture was that the ultrasonic wave could have been reflected by the surface of the snow that spreads in the lower section of the TD, which may have caused the erroneous measurements to be made. Confirmation for this, however, will be left to future research.

IV. Concluding remarks

A speculation was made that the accretion of ice and snow on the ultrasonic wave transmission and reception section was the cause of the erroneous measurement, when it was revealed through the analysis of data on the wind observed during the cold season, the air temperatures at or below freezing point, the existence of wind and rainfall were deeply related to the output of abnormal values from ultrasonic anemometers. Based on this, ice accretion wind tunnel tests and wind observation tests using simulated ice accretion on an ultrasonic range meter and heated ultrasonic anemometer were conducted. It was then deduced that when ice accretion was occurring, it was not the ice accretion itself, but rather, the melting of ice on the surface of the ultrasonic wave transmission and reception section, as well as the subsequent draining of melted water that created an air pocket inside the ice accretion and these were the principal causes for the occurrence of abnormal values. The snow accretion wind tunnel tests revealed that abnormal values occurred when secondary ice accretion took place over a wide range of ultrasonic wave transmissions and the reception section due to changes in the direction of the wind. Furthermore, it was also revealed that no secondary ice accretion occurred when the ultrasonic wave transmission and reception section was small and when all its surface was being heated, resulting in the lower probability of erroneous measurements taking place. In the case of a snowfall without a wind condition, when the upper section and arm section of the ultrasonic anemometer were not heated and when the accumulation of snow covered the upper section of the ultrasonic anemometer, or when the transmission and reception section was the only section that was not under accumulated snow, then non-recording of data (missing data) or the output of abnormal values were observed. When both sections were heated, then no accumulation of snow occurred and in this manner the necessity to apply heat to these sections was revealed. Based on these findings, it was concluded that the occurrence of secondary ice accretion can be prevented with heated ultrasonic anemometers, by properly setting the level of heating as well as the size of the ultrasonic wave transmission and reception section. Furthermore, it was also pointed out that in order to prevent the accumulation of snow, it is also necessary to heat the upper section of the main body of the anemometer, as well as its arm section.

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