12A.3 A Quality Control Algorithm for the ASOS Ice Free Wind Sensor

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1. INTRODUCTION

The Vaisala NWS 425 sonic anemometer was first installed on ASOS in late 2005 to replace the Belfort Model 2000 cup and vane anemometer, which had a tendency to freeze during icing weather events. Installation of the Vaisala NWS 425, also known as the Ice Free Wind Sensor (IFWS), continued in earnest during 2006 into 2007. However, problems began to surface in 2007 resulting in numerous missing and erroneous wind reports. Further investigation revealed that the problems were the result of birds landing on the sensor. Additional problems were observed during the 2007-08 winter season due to snow and ice build-up on the sensor. When bird activity or ice build-up occurs, the symptom is similar: the path blockage results in missing or erroneous data.

The most remarkable form that the erroneous data takes is an unrealistically high wind gust report. Bogus wind gust observations in excess of 100 knots are not uncommon. In addition to birds and ice build-up, additional factors may result in missing or erroneous IFWS data such as insects or blowing debris in the sample volume, e.g., leaves or needle grass. Erroneous wind data raises concerns over aircraft operations and safety, the quality of real-time meteorological data used by meteorologists and as input into numerical models, and the integrity of the climate record. To mitigate the generation of erroneous wind observations, meteorologists at the National Weather Service have developed a robust quality control algorithm. The algorithm scrutinizes data from the IFWS at its most fundamental level- the 5-second data. Data that are found to be suspect are flagged and achieved, but are not used in the generation of ASOS wind reports.

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2. BACKGROUND

The Automated Surface Observing System (ASOS) continually monitors important meteorological parameters at almost 1000 locations across the United States and is the nation's primary meteorological observing network. ASOS was deployed during the 1990's and monitors wind, temperature, humidity, visibility, sky condition, atmospheric pressure, precipitation type and precipitation amount.

Figure 1. The Vaisala NWS 425

ASOS was originally equipped with the Belford 2000 wind sensor in order to measure wind speed and direction. The Belford 2000 consists of a three cup anemometer to measure the wind speed and a separate wind vane to measure the direction of the wind. The Belford 2000 performed reliably, however during periods of freezing rain, the cup and vane had a tendency to freeze up. This would result in a loss of wind data until either the ice thawed or was chipped off. Since wind data is critical for aircraft operations, expensive and often hazardous maintenance visits were required to remove the ice from the wind sensor. In the fall of 1995, testing began on a variety of replacement wind sensors with respect to the ability to continue operation under adverse conditions such as freezing rain and snow (National Weather Service, 1998). The decision was made to replace the traditional cup and vane wind sensor with the Vaisala NWS 425 sonic anemometer, also known as the Ice Free Wind Sensor (IFWS). Not only would the

IFWS perform under adverse conditions, but sonic anemometers are inertia free and can measure over very short or very long path lengths (DeFelice, 1998). The lack of mechanical parts also presents a potential reduction in maintenance costs. Deployment of the IFWS began in late 2005 and continued through 2006 into 2007.

Shortly after deployment began, a marked increase in missing wind data and data quality errors was observed. These increases were most prevalent during the summer of 2007 (National Weather Service, 2008). As a result, further deployment of the IFWS was halted. It was determined the large birds roosting on the sensor head were responsible for the problems. While the bulk of the problems occurred during the summer, ice buildup caused problems during the wintertime as well. Ice buildup would occur on the IFWS if either a power interruption or a failure of the heater control circuitry disabled the sensors heaters during periods of freezing rain or heavy snow. These factors contributed to erroneous high wind reports from ASOS sites in Oklahoma, Missouri and Iowa during an ice storm in December 2007(National Weather Service, 2008). Erroneous peak winds of 97 knots were reported at Muskogee, OK and 140 knots at Joplin, MO.

3. ASOS WIND ALGORITHMS

A brief discussion describing the algorithms which ASOS uses to convert raw, high resolution wind sensor data into meteorological observations is needed, since the way in which ASOS processes sensor data is integral to the design and execution of the quality control algorithm. The IFWS utilizes the interference in the frequency of sound pulses sent across a short path length due to wind (DeFelice, 1998). This information is converted into wind speed and direction information by the sensor. The sensor data, along with data from other ASOS sensors, is collected by the data collection package (DCP) and is sent to the ASOS acquisition control unit (ACU). The ACU software contains government furnished algorithms which utilize the raw sensor data sent via the DCP in order to generate meteorological observations.

At the sensor, wind speed and direction measurements are made once per second. Also every second, a running three second average of the wind speed and direction is computed. Every five seconds, the average of the last five one second wind speed (WS5) and direction (WD5) measurements is made. Concurrently, the running three second average with the highest speed over the past five seconds is determined. The speed of which is stored as WS3 and the direction of which is stored as WD3. Every five seconds, WD3, WS3, WD5 and WS5 are sent to the ACU via the DCP. Other information, such as signal quality, the data quality flag and averaging times are also sent.

At the ACU, the most recent 24 five second observations are used to compute the 2 minute average wind speed and direction. The 2 minute average wind is the quantity reported in routine observations such as the METAR. WS3 and WD3 together are known as the three second peak. Three second peak values are stored by ASOS for up to ten minutes for the purposes of determining wind gusts. If a three second peak exceeds 25 knots, it can be stored up to an hour for determining the peak wind. Other ASOS wind algorithms include algorithms for the determination and reporting of squalls, wind shifts and variable wind direction.

4. ALGORITHM DEVELOPMENT

Bird activity, ice accretion and snow accumulation resulted in numerous data quality errors and missing wind reports. Occasionally, erroneous wind reports were disseminated in the observations. Bogus variable wind direction reports and outlandishly high wind gusts and peak wind reports were the hallmarks of these errors. Bogus wind gust reports in excess of 100 knots were not uncommon. The following actual observations illustrate the problem. The first is the result if ice accretion during a winter storm at Joplin, MO. The second is due to the presence of a large hawk roosting on the wind sensor at Marysville, CA:

KJLN 100100Z AUTO 01010G140KT 290V020 M03/M04 A3031

KMYV 200055Z AUTO 09004G79KT 10SM CLR 16/12 A3008

Examination of tainted wind reports revealed that the 2 minute average wind reports were only minimally affected. This was due to the fact that often only a small number of five second samples were affected, too few to have an impact on an observation that averaged 24 samples. At times when many of the samples were bad, the 2 minute average simply went missing. However, gust reports and peak wind reports were particularly susceptible. This was because the maximum 3 second peak wind information was stored for a long period of time and had the capability to corrupt wind observations for up to an hour after the ice had melted away of the bird flew off.

Close examination of high resolution wind data and wildlife camera pictures collected from several ASOS sites across the U.S. revealed the characteristics of contaminated 5 second samples. These characteristics were used in order to develop a simple, yet robust quality control algorithm that is independent of the cause of the problem known as the IFWS QC Algorithm.

The IFWS QC Algorithm analyzes each 5 second sample against 9 criteria. If the sample fails to meet one or more of the following criteria, then the sample is flagged as suspect and is not used in any of the ASOS wind algorithms.

IFWS QC Algorithm Criteria:

Data Quality Flag ≠ F

Signal Quality =< 79

(WS3 – WS5) > -1

IF WS5 >=, THEN |WD5 – WD3| < 30

IF WS5 >=, THEN WS3 < (2.5 * WS2Min)

IF WS5 < 12, THEN WS3 < 30

IF WS2Min <= 6 AND WS3 > 6, THEN WS3 < (2.5 * WS2Min)

WS5 < 165 AND WS3 < 165

WT5 = 5 AND WT3 = 3*

**Note: WT5 and WT3 are the averaging times for the five second average and three second peak, respectively.*

In addition to the actual samples, the pattern of rejected samples is also used. If 7 or more of the preceding 24 samples does not meet all 9 criteria (known as the 75% rule), all subsequent samples will be flagged as suspect until 18 *consecutive* samples that meet all 9 criteria are observed.

Description of criteria

The first criterion makes use of the sensors built in data quality flag. If the sensor determines that the sample is bad, it will transmit a data quality flag of F. The second criterion utilizes the signal quality sent by the sensor. Signal quality ranges from -1 to 99, with 99 the best -1 being the worst. Examination of wind data during ice events or bird episodes reveals that the signal quality will fall below

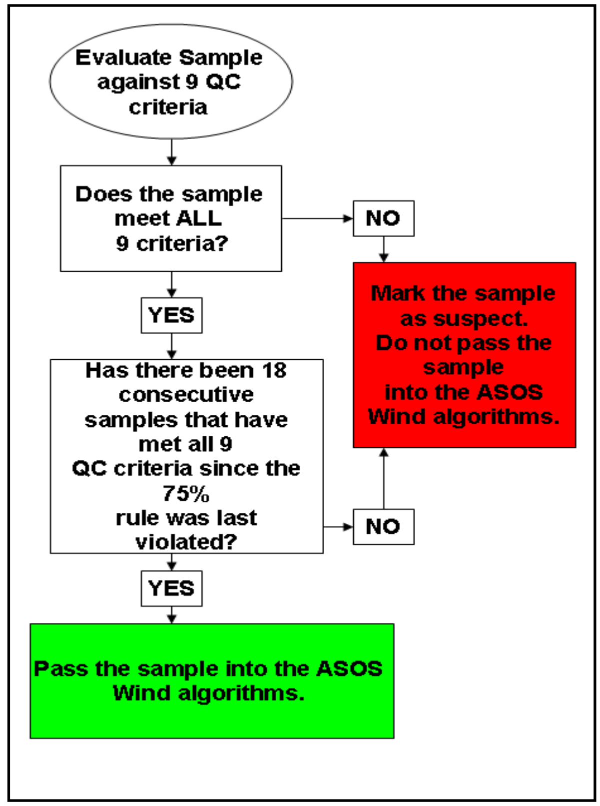

Figure 2. IFWS QC Algorithm Logic

79, but is almost always 99 when no problems are present. Thus, a signal quality of al least 79 is required.

One characteristic of a contaminated 5 second sample is a marked difference between WD3 and WD5 at higher wind speeds. While large differences are common at low wind speeds, differences exceeding 30 degrees are rare when the wind is greater than 12 knots. Contaminated samples often will have a value for WS5 that is considerable larger than WS3. A characteristic of a bird contaminated sample is the tendency for a high peak wind corresponding to a low 5 second average and/or 2 minute average.

Objects on the sensor are not the only cause of contaminated 5 second samples. Occasionally, a variety of external factors can result in a garbled transmission of data between the DCP and the ACU. A characteristic of a garbled transmission is often an out of bound wind speed or direction report (WD3 = -1079 degrees or WS5 = 2415672.9 knots, for example). Another are incorrect averaging times, which are always 3 and 5. Thus, the last two criterion help to prevent corrupted or garbled data from being used by the ASOS algorithms.

5. TESTING METHODS AND RESULTS

The IFWS QC Algorithm was tested using over 4000 hours worth of 5 second samples collected from 40 ASOS sites across the U.S. during real meteorological events. Roughly half of the data was clean, while the other half was collected during bird episodes (as validated from wildlife cameras installed at select locations) and ice events which resulted in wind data problems. Parameters analyzed included how many good 5 second samples were incorrectly rejected by the algorithm (good data rejected), how many samples containing bogus peak winds/gusts were rejected by the algorithm and how many bogus peak winds/gusts slipped past the QC algorithm. The results were compared with the existing ASOS QC for wind data, which is minimal by comparison to the IFWS QC Algorithm.

The results were broken down by the magnitude of the bogus wind observation. While removing all bogus wind data is important, the ones with the highest magnitude are most important. More than 96% of all bogus wind gusts (14 knots and higher) were filtered, compared with only 2.3% from the existing ASOS QC. Over 99% of bogus peak winds (25 knots or higher) were filtered.

	Current ASOS QC	IFWS QC Algorithm
Good Data Rejected	0	0.17%
Bogus 14 – 24 knot gusts caught	2.7%	96.2%
Bogus 24 – 49 knot gusts caught	1.0%	99.1%
Bogus 50+ knot gusts caught	0	100%
All bogus peaks caught (25+ kts)	0.7%	99.2%
All bogus gusts caught (14+ kts)	2.3%	96.9%

The one tradeoff is that some good data samples will be wrongfully rejected by the algorithm. The IFWS QC Algorithm incorrectly rejected 0.17% of the data tested. This translates into an average of about 14 hours per year. It is worth noting that not all samples are of equal operational value. On April 11, 2008 a severe thunderstorm produced a peak wind of 52 knots in Topeka, KS. The sample containing the 52 knot wind gust was rejected by the algorithm, although close examination revealed that the wind report was accurate. The second highest peak was 45 knots contained in the 5 second sample after the one containing the 52 knot peak. The sample containing the 45 knot peak was accepted. While the raw data will be preserved and made available, it will be flagged as suspect. In addition, the METAR observation would produce a peak wind of 45 knots, as opposed to 52 knots.

One final note regarding the testing of the IFWS QC algorithm: while the algorithm was tested under a wide variety of meteorological conditions, data for sustained high wind events was of insufficient quantity. Therefore, the IFWS QC Algorithm is suspended whenever the 2 minute average wind speed exceeds 35 knots. Collection of more high wind data and further testing may result in use of the algorithm at high winds in the future.

6. CONCLUSION

The IFWS QC Algorithm is a simple, yet robust method for filtering contaminated wind data sent from the IFWS to the ASOS ACU. The algorithm is also independent of the cause of the problem, a key design goal. The IFWS QC Algorithm filters more than 99% of bogus peak wind sand nearly 97% of all bogus gust reports. However, it does result in a minimal rejection of good data, some of which may be operationally significant.

7. ACKNOWLEDGEMENTS

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The views expressed are those of the author and do not necessarily represent those of the National Oceanic and Atmospheric Administration.

8. REFERENCES

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