15.5 VISIBILITY SENSOR ACCURACY: WHAT'S REALISTIC?

John D. Crosby*
EnviroTech Sensors, Inc. Clarksville, Maryland

1. INTRODUCTION

Improvements in forward scatter-type visibility sensors in the past decade have resulted in a growing interest in automating this important meteorological parameter. Applications for visibility sensing include airport weather systems (synoptic and runway visual range), road weather systems, air quality studies, and fog warning networks.

Visibility sensing differs from many of the typical meteorological parameters because of the complex nature of the measurement. No standard test methods or measurement practices are available for visibility. Other sensors, however, are held to rigorous standards. For example, a temperature sensor is tested to the American Society for Testing and Materials (ASTM) E644-98 Standard Test Methods for Testing Industrial Resistance Thermometers, implemented with ASTM D6176M-97 Standard Practice for Measuring Surface Atmospheric Temperature with Electrical Resistance Temperature Sensors (Metric) and traceable to standards at the National Institute of Science and Technology (NIST).

The lack of industry standards for visibility leads to several problems, including misunderstandings of how to prepare sensor specifications and requirements on the part of the buyer and how to specify accuracy and key parameters on the data sheet on the part of the seller. Being a savvy user of visibility sensors and data begins with understanding what is realistic.

This paper will examine several key areas in an attempt to help define the accuracy of visibility sensors. First, a review of the accuracy believed achievable by leading meteorological organizations and the visibility accuracy requirements of several weather systems in use today will be presented. Second, sensor manufacturer statements and claims about their own sensor accuracy will be compared. Third, test data from organizations including the World Meteorological Organization (WMO), Federal Aviation Administration (FAA), National Weather Service (NWS), and Canadian Atmospheric Environment Service (AES) will illustrate real world results. Fourth, other factors effecting the measurement including the psycho-physical nature of the measurement by humans and the inherent inaccuracies of the reference sensors will be discussed. Using these four key areas, the author will propose a reasonable level of accuracy you can expect from electro-optical visibility sensors and the need for standardization in their testing and reporting.

2. THE QUESTION OF VISIBILITY ACCURACY

Understanding visibility accuracy does not require studying the history or theory of visibility sensing since this information is not needed to specify or make use of the sensor. Visibility sensors have been tested for decades, especially in support of the aviation community. In general, the needs of the aviation community are more stringent than the needs of the typical road weather information system (RWIS) user. Airports must land aircraft loaded with hundreds of people in all weather conditions, so visibility is of critical importance to them. Therefore, we can transfer their knowledge and apply it to the road weather field and other applications with confidence.

Visibility accuracy is a term misunderstood by many, even those who specify and use visibility sensors. However, the measurement of visibility need not be a confusing subject. Being savvy regarding visibility data begins with understanding what is realistic. To define accurate visibility, we will look at several key points.

- The results believed achievable by leading meteorological organizations and the accuracy requirements of several weather systems in use today
- Sensor manufacturer statements and claims about their own sensor accuracy
- Real word test results
- Other factors effecting the measurement

Finally, using these four key points, the author will suggest the accuracy you can reasonably expect from electro-optical visibility sensors.

2.1 Visibility Accuracy According to Major Meteorological Organizations and Programs

The major meteorological organizations and systems in use around the world have defined the accuracy of visibility measurements. Below is a list of several of these organizations and applicable publications from the WMO and International Civil Aviation Organization (ICAO). Each specifies the attainable or desirable accuracy of visibility observations. Also included are the requirements for visibility accuracy in automated weather systems. These systems, such as Automated Weather Observing Systems (AWOS) and Automated Surface Observing systems (ASOS), have thousands of sensors operational around the world.

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* *corresponding author address:* John D. Crosby, EnviroTech Sensors, Inc, P.O. Box 794, Clarksville, MD 21029; e-mail jcrosby@envirotechsensors.com

WMO Guide to Meteorological Instruments and Methods of Observations

Achievable operational accuracy:

- +/- 10-20% over the field range

ICAO Manual of Aeronautical Meteorological Practice

Currently attainable accuracy:

- +/- 100m up to 1000m
- +/- 200m between 1000m and 2000m
- +/- 20% between 2000 m and 10 km

ICAO Manual of Runway Visual Range Observing and Reporting Practices

Operationally desirable accuracies:

- +/- 25m up to 150m
- +/- 50m between 150 and 500m
- +/- 100m between 500 and 1000m
- +/- 200m above 1000m

FAA New Generation Runway Visual Range (NGRVR) System

- 15% Root Mean Square Error (RMSE) up to 300m
- 20% RMSE between 300m and 2000m

Automated Weather Systems including:

FAA Automated Weather Observing System (AWOS)
FAA Automated Weather Sensors System (AWSS)
NWS/FAA Automated Surface Observing System (ASOS)
U.S. Air Force Observing System – 21^{st} Century (OS-21)

At least 80% of the visibility data shall be within these limits:

- +/- 400m up to 2km
- + 400/- 800m between 2.4 and 2.8km
- +/- 800m between 3.2 and 4km
- + 800m/- 1.6km between 4.8 and 5.6
- +/- 1 Reportable visibility Increments (RI) between 6.4 and 16km

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Table 2.2-1 Sensor Manufacturer Specifications

Manufacturer	Sensor	Accuracy	Range	Notes
Aanderaa Instruments A/S	Model 3340	<20%	20m to 3 km	
Belfort Instrument	Model 6000	+/- 10%	20 ft to 10 miles	
	Model 6100	+/- 10%	20 ft to 10 miles	
	Model 6230	+/- 10%	17 ft to 30 miles	
Biral, LTD	Model VF-500	+/- 5%	3m to 16 km	1
EnviroTech Sensors	Model SVS1	+/- 10%	20m to 16 km	
Optical Scientific, Inc	Model OWI-130	+/- 20%	1m to 3 km	
Qualimetrics, Inc.	Model 6364-E	+/- 10%	10m to 32 km	
Vaisala, Inc.	Model FD12	Not stated	10 to 50,000m	2
	Model PWD11	Not stated	10 to 2000m	2
	Model PWD21	+/- 10%	10m to 10 km	
		+/- 15%	10 km to 20 km range	

Notes: 1) Biral, LTD now manufacturers the HSS VR-301 sensor discussed in Section 4.
2) Vaisala originally published a four-page brochure on the FD12 that stated *"As a result, the FD12 measured a visibility figure with more than 80% of the measuring points within +/- 20% of the transmissometer's readings."* Now, Vaisala does not specify accuracy for the FD12 and PDW11 sensors. They instead use ambiguous terms like "+/- 4% *variability between units*" or "+/- 5% *optical measurement consistency*."

2.2 Visibility Accuracy According to Sensor Manufacturer Specifications

The manufacturers of some the most common forward scatter visibility sensors in use today are listed in Table 2.2-1 above in alphabetical order. Model number, stated accuracy, range, and applicable notes are included. The specifications in the table were obtained from printed and electronic sources available to the public.

2.3. Real World Visibility Test Results

Data from several published visibility studies is included in this section. All sensors are of the forward scatter type and are currently in use today. Two general observations can be made from the graphs.

First, the overall linearity of the data is quite good. Second, there is significant scatter in the data. The data is presented in this section is directly as it was published. Various graphing techniques such as scatter diagrams and box plots are used. Units of measure vary from kilometers to miles. And both linear and log formats are used. These factors make it particularly difficult for inexperienced users to analyze the data.

Example from Vaisala testing of the FD12 (data from their FD12 brochure):

Note: The X & Y axes are plotted from maximum (20 km) to minimum values (MOR is 'meteorological optical range'). Other graphs provided in this paper show data with increasing values rather than decreasing values.

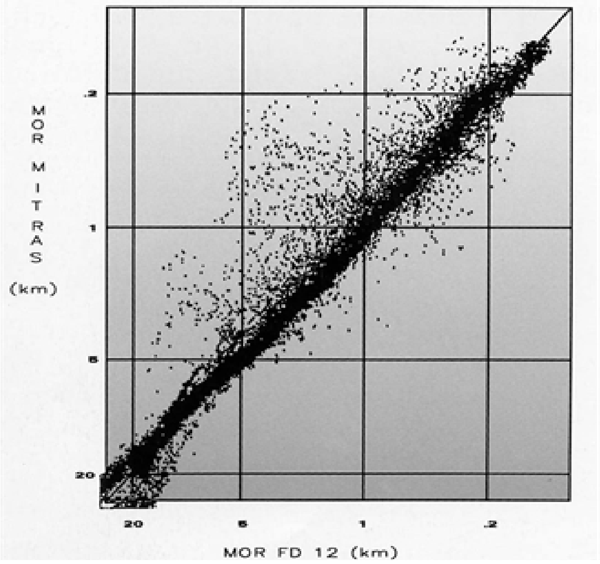

Figure 2.3-1 Vaisala FD12 sensor compared to one Vaisala MITRAS Transmissometer

Example from Canada AES testing of HSS (now Biral) VR-301 sensor:

Note: This data graph uses a log scale instead of a linear graph. The log scale helps to illustrate the data over a wide dynamic range and tends to reduce the appearance of data scatter.

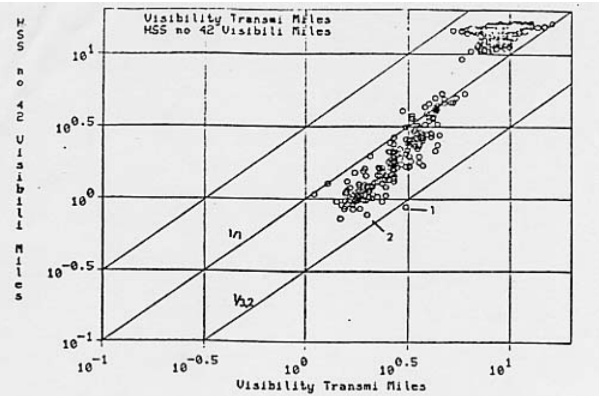

Figure 2.3-2 HSS VR-301 sensor compared to one Transmissometer

Example from NWS ASOS testing of Belfort ASOS sensor:

Note: Data plotted as X-Y graph in units of miles. The numbers in the grid spaces represent the number of data points (10 minute average) that was in each particular grid increment.

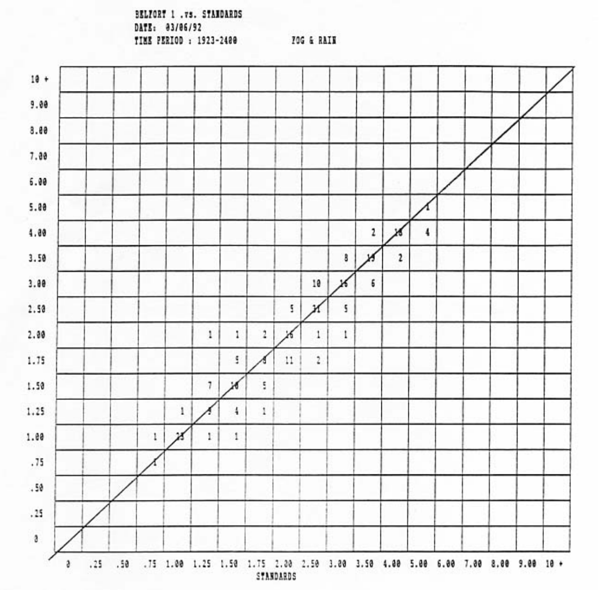

Figure 2.3-3 Belfort 6200 Series compared to two IR Transmissometers for visibility < 1¼ and two Visible Light Transmissometers for visibility > 1¼ miles

Example from EnviroTech Sensors, Inc. testing of the Sentry™ sensor:

Note: Data plotted as X-Y graph in units of miles.

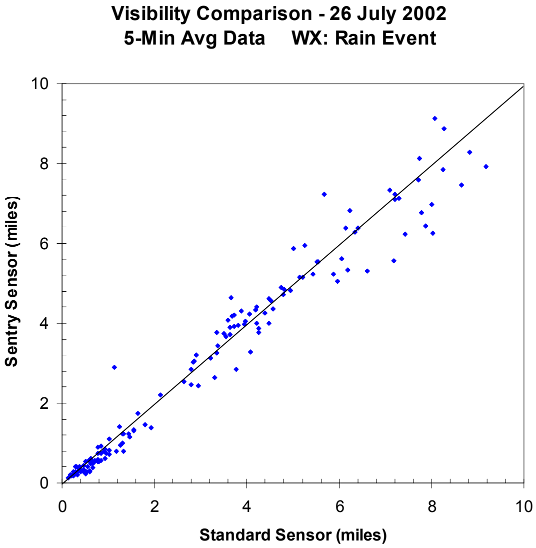

Figure 2.3-4 EnviroTech Sentry™ sensor compared to one Belfort 6200 Series ASOS sensor in fog and haze

Example from WMO Sponsored Visibility Intercomparison testing of Qualimetrics 8360 sensor:

Note: Box plots are used in the WMO analysis. Data are placed into bins of MOR based on the measurement of a reference sensor. The data are plotted as a ratio of test sensor visibility divided by reference sensor visibility. Graphically, an "X" is plotted at the median of the distribution and a box is drawn around the 25th – 75th percentiles. Lines (whiskers) are projected from the boxes indicating the 5th and 95th percentiles. The vertical axis of the data graphs are plotted as MOR where 10^3 = 1000m. The horizontal axis of the WMO data graphs is plotted as a MOR ratio.

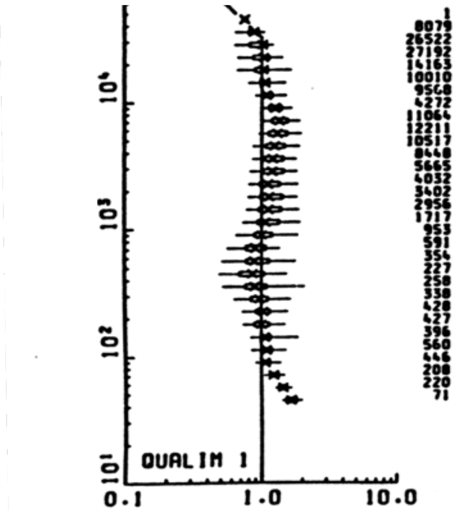

Figure 2.3-5 WMO test of Qualimetrics sensor compared to the average of 2 transmissometers

Example from FAA testing of Handar (Vaisala) RVR sensor:

Note: Box plots are used in the FAA analysis. Data are placed into bins of MOR based on the measurement of a reference sensor. The data are plotted as a ratio of test sensor visibility divided by reference sensor visibility. Graphically, an "X" is plotted at the median of the distribution and a box is drawn around the 25th – 75th percentiles. Lines (whiskers) are projected from the boxes indicating the 5th and 95th percentiles, effectively encompassing 90% of the data points. The vertical axis of the data graphs are plotted as log MOR where 3000m is represented by "1", 100m represented by "2", etc. The horizontal axis of the FAA data graphs is plotted as log MOR ratio.

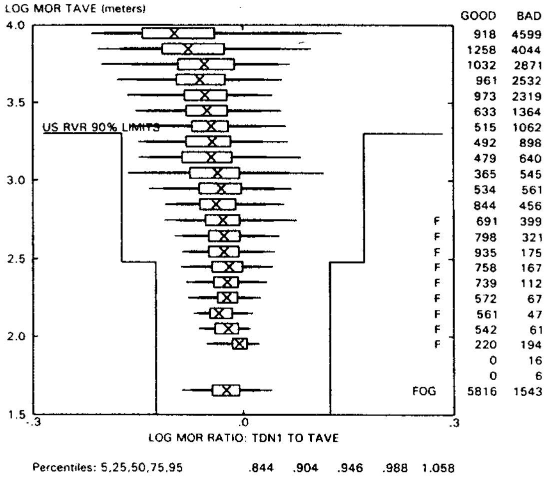

Figure 2.3-6 FAA testing of Handar RVR sensor compared to the average of 2 transmisometers

2.4. Other Factors Affecting Visibility Test Results

Determining the accuracy of visibility sensors is further complicated by the fact that the reference transmissometers used as reference standards may disagree by as much as 10% and still be acceptable. For a sensor vendor to claim 5% visibility accuracy when the test references can vary by 10% is preposterous. Add to this the various systematic and random errors inherent in electro-optic sensors as well as the uncontrolled nature of testing outdoors. The WMO and FAA have suggested further study of forward scatter angle, particle size, source wavelength, and site climatology.

The WMO Visibility Intercomparison stated that in rain and snow, "forward scatter sensors were relatively unchanged in their correspondence with STANDARD, particularly the BELFORTs." However, after several years of testing of the Belfort sensor by the NWS, they implemented precipitation corrections to the reported visibility (+10% rain and -10% snow). This finding clearly demonstrates that there are a number of unanswered questions about visibility testing.

Adding a weather observer to the measurement mix does not necessarily improve testing accuracy. Typically, he/she will only add to the data scatter since each human interprets visibility differently. The Office of the Federal Coordinator for Meteorology (OFCM) lists several uncertainties with human observers including site limitations, target characteristics, contrast and illumination thresholds, dark adaptation of the eye, and observer training. A human observer can help resolve test ambiguities but because of variations in perception, he/she is not a quantitative resource.

3. CONCLUSIONS

Based on the published data presented in this paper and personal experience, the author agrees with the findings of the WMO and other agencies that 10-20% RSME visibility error is realistic and achievable. The test data presented in Section 2.3 clearly show real world results with accuracies within this range, and in some cases, worse.

Testing of the same sensor by different organizations may result in differences as shown by comparing results from WMO and NWS testing. These differences in test results are not caused by test sensor differences but more likely by differences in the reference standards, local atmospheric conditions, data interpretation, and on human factors.

In the world of optical visibility sensing, a vendor that claims visibility accuracy to less than 10% is probably not telling the whole story.

4. RECOMMENDATIONS

The meteorological community should begin the process of writing ASTM style standard test methods and practices. Standardization would identify what sensor parameters are most important and establish reasonable levels of performance for each. Using these standards, recognized visibility test beds like Otis AFB or NWS Sterling could provide test results with 3rd party objectivity.

For the sensor buyer or user:

- Be realistic and specify a visibility sensor with 10-20% RSME error. Overly stringent accuracy specification demands may result in vendors manipulating data to be compliant with the specification.
- Ask the vendor for supporting test data in various weather conditions. Make sure you know what sensor(s) is being used as a reference. The report should contain hundreds of hours of data.
- Be wary of sensor data sheets that disguise accuracy with specifications like “consistency” or “variability.” Sensor consistency is a useful parameter but is not a substitute for defining a sensors ability to make accurate measurements in real world conditions.

5. REFERENCES

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