Meteorological Measurement Error Analysis based on ANSI/ANS-3.11 (2005)

Kenneth G. Wastrack
Tennessee Valley Authority

NUMUG 2005

Introduction

Accuracy is the primary indicator of meteorological system performance. Observed accuracy must be calculated in a consistent manner to permit comparison with specified values. One of the key changes in ANSI/ANS-3.11 (2005) addresses this issue.

Presentation Topics

- Error Calculation History
- ANSI/ANS-3.11 (2005) Method for Calculating Accuracy
- Example Calculation

Error Calculation History

Safety Guide 1.23, "Onsite Meteorological Programs," 1972

Section 4, "Instrument Accuracy," states plus or minus (±) accuracy values for different meteorological variables, but does not indicate if the accuracy applies just to the sensors or to the entire data channel.

No calculation methodology is defined.

Error Calculation History

Proposed Revision 1 to Regulatory Guide 1.23, "Meteorological Measurement Programs for Nuclear Power Plants," ~1981 (never issued)

Section 3, "System Accuracy":

- System accuracy refers to the composite channel accuracy.
- System accuracy defined as the root sum of the squares.
- For time-averaged values, random errors may be decreased by considering the number of samples.
- The system accuracies similar to Safety Guide 1.23 (1972).

NRC defines calculation methodology.

Error Calculation History

ANSI / ANS-2.5 (1984), "Standard for Determining Meteorological Information at Nuclear Power Sites," 1984

Section 6.1, “System Accuracy”:

- System accuracy refers to the composite accuracy.
- System accuracy defined as the root sum of the squares (*references “Brooks and Caruthers” methods*).
- For time-averaged values, random errors may be decreased by considering the number of samples.
- The system accuracies are similar to those in RG 1.23 (1972) and Proposed Revision 1 to RG 1.23 (1981).

ANSI / ANS-2.5 (1984) fills gap in guidance.

Error Calculation History

NUMUG Presentation, "A Methodology for Calculating Meteorological Channel Accuracies," by Brad Harvey, 1999

Not a guidance document, but provides insight into how ANSI/ANS-2.5 (1984) guidance was interpreted and used.

Section 3, “Potential Sources of Error”:

- System accuracy refers to the composite accuracy.
- Distinguishes between “bias” and “random” errors.

Illustrates implementation of ANSI/ANS-2.5 (1984) and provides example calculations.

Error Calculation History

ANSI/ANS-3.11 (2000), "Determining Meteorological Information at Nuclear Facilities," 2000

Section 7.1, “System Accuracy”:

- Calculation methodology is described as "root-mean-square" (RMS) rather that "root sum of the squares" (RSS).
- Does not clearly state that the calculation methodology has changed--**many users don’t realize the calculation methodology has changed**.
- No longer distinguishes between instantaneous and time-averaged values.

Not certain changes were really intended.

$RSS = \sqrt{(r_1)^2 + (r_2)^2 + \cdots + (r_x)^2}$

Error Calculation History

ANSI / ANS-3.11 (2000), "Determining Meteorological Information at Nuclear Facilities," 2000 (continued)

- **Root-mean-square (RMS)**

$$RMS = \sqrt{\frac{(r_1)^2 + (r_2)^2 + \ldots + (r_x)^2}{x}}$$

- **Root sum of the squares (RSS)**

$$RSS = \sqrt{(r_1)^2 + (r_2)^2 + \ldots + (r_x)^2}$$

$r_1, r_2 \ldots r_x$ *are random error components.*

x *is the number of components.*

Error Calculation History

ANSI/ANS-3.11 (2005), "Determining Meteorological Information at Nuclear Facilities," 2005

Section 7.1, "System Accuracy" has been revised and Exhibit 1, "Method for Calculating System Accuracy" has been added.

- ANSI/ANS-3.11 (2005) is intended as an **official** source of guidance.
- ANSI/ANS-3.11 (2005) defines what is required by including the actual equations and step-by-step instructions to ensure a consistent approach.
- ANSI/ANS-3.11 (2005) reverts back to RSS.
- ANSI/ANS-3.11 (2005) distinguishes between bias errors and random errors.

Error Calculation History

ANSI/ANS-3.11 (2005), "Determining Meteorological Information at Nuclear Facilities," 2005 (continued)

Section 7.1 was principally written by Ken Wastrack.

- Significant input from Paul Fransiloi (SAIC), Brad Harvey (NRC), and Matt Parker (Westinghouse Savannah River).
- Reviewed by about 30 members of the ANS-3.11 working group.
- Comments from Stan Krivo (EPA) and Walt Schalk (NOAA).

Error Calculation History

ANSI/ANS-3.11 (2005), "Determining Meteorological Information at Nuclear Facilities," 2005 (continued)

Section 7.1 - System Accuracy

Accuracy values shall reflect the performance of the total system, and shall be based on the more stringent of the individual facility requirements or the minimum system accuracy and resolution requirements given in Table 1 (which provides values for a monitoring system using typical tower-mounted sensors and digital data processing systems).

System accuracy should be estimated by performing system calibrations, or by calculating the overall accuracy based on the system's individual components. Accuracy tests involve configuring the system near to normal operation, exposing the system to multiple known operating conditions representative of normal operation, and observing results. Data channels may be separated into sequential components, as long as results from each component are directly used as input for the next component in sequence. Exhibit 1 provides a method that should be used to calculate system accuracy from individual component accuracy values.

Method for Calculating System Accuracy [from ANSI/ANS-3.11 (2005) Exhibit 1]

1. Identify the individual components that contribute to system accuracy.
   - Sensor
   - Installation error (e.g., sensor alignment)
   - Operational error (e.g., solar heating of temp. sensors)
   - Data processing equipment
   - Computer (e.g., conversion equations)
   - Calibrations
   - etc.

Method for Calculating System Accuracy [from ANSI/ANS-3.11 (2005) Exhibit 1]

2. Classify the error type for each component.
   - **Bias errors** (b_1, b_2, . . . b_x).

     Bias (or systematic) errors consistently affect the system accuracy in a known manner.

     For example: Solar heating only <u>increases</u> apparent air temperatures during daytime.

   - **Random errors** (r_1, r_2, . . . r_x).

     Random errors are independent and can fluctuate within the range between the extreme maximum and minimum values.

Method for Calculating System Accuracy [from ANSI/ANS-3.11 (2005) Exhibit 1]

3. Estimate the values of the component errors based on engineering analysis, vendor specifications, accuracy tests, or operational experience.
   - If a bias applies to only a portion of the sampling period, multiple calculations of the system accuracy, using different bias values, are necessary.
   - The random errors of the individual components should represent $\pm 2\sigma$ values or 2 times the standard deviation of errors based on component testing (95.5%). Unless otherwise stated, manufacturer's data for random errors can normally be assumed to be $\pm 2\sigma$ values.

Method for Calculating System Accuracy [from ANSI/ANS-3.11 (2005) Exhibit 1]

4. Perform time-average adjustments for each random error component.

$$a = r/(\sqrt{n})$$

Where: r is the unadjusted random error component.
n is the number of samples.
a is the adjusted random error component.

Note: For instantaneous values (where n=1), a = r.

Method for Calculating System Accuracy [from ANSI/ANS-3.11 (2005) Exhibit 1]

5. Calculate "root sum of the squares" (RSS) for the adjusted random error components.

$$RSS = \sqrt{(a_1)^2 + (a_2)^2 + . . . + (a_x)^2}$$

Where: a_1, a_2, . . . a_x are adjusted random error components.

x is the number of components.

Method for Calculating System Accuracy [from ANSI/ANS-3.11 (2005) Exhibit 1]

6. Add bias errors to obtain system accuracy (*SA*).

$$SA = RSS + b_1 + b_2 + . . . + b_x$$

Where: b_1, b_2, . . . b_x are bias error components.
x is the number of components.

Note: **Repeat as necessary with different bias values to determine extreme values.**

Method for Calculating System Accuracy [from ANSI/ANS-3.11 (2005) Exhibit 1]

7. Compare the extreme system accuracy (*SA*) values with applicable requirements to evaluate system performance.
   - Table 1 in ANSI/ANS-3.11 (2005) for most cases.
   - Table 1 values are both system (channel) accuracy and sensor accuracy values.
     - System accuracy encompasses all channel components impacting system accuracy (sensors, data processing equipment, computer, calibrations, etc).
     - Sensor accuracy applies to the manufacturer's instrument specification.

Example Calculation
[Wind Speed – Ultrasonic Sensor]

1. Identify Sources of Error.
   - Sensor
     - Input – Laboratory Standard
     - Input – Transfer Standard
     - Input – Test Position (placement in wind tunnel)
     - Input – Comparison Apparatus
     - Output – Tolerance
   - Sampling (placement in field)
   - Signal Conditioning and Data Logger
     - Final rounding of hourly average value

Example Calculation
[Wind Speed – Ultrasonic Sensor]

2. Classify Error Type.
   - Sensor
     - [Input] Sensor placement is bias
     - [Input] Other sensor components are random
     - [Output] Tolerance is random
   - Sampling (placement) is random
   - Final rounding is random

Example Calculation
[Wind Speed – Ultrasonic Sensor]

3. Estimate the values of the component errors. [0-100 mph range]
   - Input – Laboratory Standard [± 0.20 mph]
   - Input – Transfer Standard [± 0.10 mph]
   - Input – Test Position [± 0.02 mph]
   - Input – Comparison Apparatus [± 0.08 mph]
   - Output – Tolerance [± 0.30 mph]

   - Sampling [± 0.04 mph]
   - Final rounding of hourly average value [± 0.05 mph]

Example Calculation
[Wind Speed – Ultrasonic Sensor]

4. [Sensor only] Perform time-average adjustments for each random error component.

- Only 1 sample is used for calibration
- Adjusted values equal initial values

Example Calculation
[Wind Speed – Ultrasonic Sensor]

5. [Sensor only] Calculate "root sum of the squares" (RSS) for the adjusted random error components.

$$RSS = \sqrt{(0.20)^2 + (0.10)^2 + (0.08)^2 + (0.30)^2} \text{ mph}$$

RSS = ±0.38 mph

Example Calculations
[Wind Speed – Ultrasonic Sensor]

6. [Sensor only] Add bias errors to obtain system accuracy (*SA*).

SA = RSS + b

SA = 0.38 + 0.02 = 0.40 mph

SA = 0.38 – 0.02 = 0.36 mph

SA = **± 0.40 mph**

Example Calculation
[Wind Speed – Ultrasonic Sensor]

4. [Field Measurements] Perform time-average adjustments for each random error component.

- Sensor output is random (time-averaged)

  $$0.03 = 0.40/(\sqrt{180})\ \text{mph}$$

- Sampling is random (time-averaged)

  $$0.00 = 0.04/(\sqrt{180})\ \text{mph}$$

- Rounding is random (1 sample)

  $$0.05 = 0.05/(\sqrt{1})\ \text{mph}$$

Example Calculation
[Wind Speed – Ultrasonic Sensor]

5. [Field Measurements] Calculate "root sum of the squares" (RSS) for the adjusted random error components.

$$RSS = \sqrt{(0.03)^2 + (0.00)^2 + (0.05)^2} \text{ mph}$$

RSS = ±0.06 mph

Example Calculation [Wind Speed – Ultrasonic Sensor]

6. [Field Measurements] Add bias errors to obtain system accuracy (*SA*).

- No bias term:

SA = RSS + b

SA = 0.06 + 0.00 = 0.06 mph

SA = **± 0.06 mph**

Example Calculation [Wind Speed – Ultrasonic Sensor]

7. Compare the extreme system accuracy (*SA*) values with applicable requirements to evaluate system performance.
   - Table 1 specifies WS accuracy as:
     0.2 m/s +5% of observation = 0.45 mph at 0 mph
     5.45 mph at 100 mph
   - Applies to both sensor and channel accuracies.
   - Sensor accuracy of **± 0.40 mph** and channel accuracy of **± 0.06 mph** both meet specification.

Measurements satisfy ANSI/ANS-3.11 (2005).

Final Comments

ANSI/ANS-3.11 (2005) provides specific guidance for calculating meteorological measurements accuracy.

The ANSI/ANS-3.11 (2005) methodology is consistent with past practices--prior to ANSI/ANS-3.11 (2000), so calculations should be comparable with historical information.

Hopefully, ANSI/ANS-3.11 (2005) will be adopted as an **official** source of guidance regarding meteorological measurements accuracy.