Designation: D4430 – 00 (Reapproved 2015)

Standard Practice for Determining the Operational Comparability of Meteorological Measurements[1]

This standard is issued under the fixed designation D4430; the number immediately following the designation indicates the year of original adoption or, in the case of revision, the year of last revision. A number in parentheses indicates the year of last reapproval. A superscript epsilon (ε) indicates an editorial change since the last revision or reapproval.

1. Scope

1.1 Sensor systems used for making meteorological measurements may be tested for laboratory accuracy in environmental chambers or wind tunnels, but natural exposure cannot be fully simulated. Atmospheric quantities are continuously variable in time and space; therefore, repeated measurements of the same quantities as required by Practice E177 to determine precision are not possible. This practice provides standard procedures for exposure, data sampling, and processing to be used with two measuring systems in determining their operational comparability (**1,2**).[2]

1.2 The procedures provided produce measurement samples that can be used for statistical analysis. Comparability is defined in terms of specified statistical parameters. Other statistical parameters may be computed by methods described in other ASTM standards or statistics handbooks (**3**).

1.3 Where the two measuring systems are identical, that is, same make, model, and manufacturer, the operational comparability is called functional precision.

1.4 Meteorological determinations frequently require simultaneous measurements to establish the spatial distribution of atmospheric quantities or periodically repeated measurement to determine the time distribution, or both. In some cases, a number of identical systems may be used, but in others a mixture of instrument systems may be employed. The procedures described herein are used to determine the variability of like or unlike systems for making the same measurement.

1.5 *This standard does not purport to address the safety concerns, if any, associated with its use. It is the responsibility of the user of this standard to establish appropriate safety and health practices and determine the applicability of regulatory limitations prior to use.* (See 8.1 for more specific safety precautionary information.)

2. Referenced Documents

2.1 *ASTM Standards:*[3]

D1356 Terminology Relating to Sampling and Analysis of Atmospheres

E177 Practice for Use of the Terms Precision and Bias in ASTM Test Methods

3. Terminology

3.1 For additional definitions of terms, refer to Terminology D1356.

3.2 *Definitions of Terms Specific to This Standard:*

3.2.1 *difference (D)*—the difference between the systematic difference (d) of a set of samples and the true mean (μ) of the population:

$$D = d - \mu \quad (1)$$

3.2.2 *systematic difference (d)*—the mean of the differences in the measurement by the two systems:

$$d = \frac{1}{N} \sum_{i=1}^{N} \left(X_{ai} - X_{bi} \right) \quad (2)$$

3.2.3 *operational comparability (C)*—the root mean square (rms) of the difference between simultaneous readings from two systems measuring the same quantity in the same environment:

$$C = \pm \sqrt{\frac{1}{N} \sum_{i=1}^{N} \left(X_{ai} - X_{bi} \right)^2} \quad (3)$$

where:

X_{ai} = ith measurement made by one system,
X_{bi} = ith simultaneous measurement made by another system, and
N = number of samples used.

3.2.3.1 *functional precision*—the operational comparability of identical systems.

3.2.4 *estimated standard deviation of the difference (s)*—a measure of the dispersion of a series of differences around their mean.

[1] This practice is under the jurisdiction of ASTM Committee D22 on Air Quality and is the direct responsibility of Subcommittee D22.11 on Meteorology.

Current edition approved April 1, 2015. Published April 2015. Originally approved in 1984. Last previous edition approved in 2010 as D4430 – 00 (2010). DOI: 10.1520/D4430-00R15.

[2] The boldface numbers in parentheses refer to the list of references at the end of this practice.

[3] For referenced ASTM standards, visit the ASTM website, www.astm.org, or contact ASTM Customer Service at service@astm.org. For *Annual Book of ASTM Standards* volume information, refer to the standard's Document Summary page on the ASTM website.

$$s = \pm\sqrt{C^2 - d^2} \quad (4)$$

3.2.5 *skewness (M)*—the symmetry of the distribution (the third moment about the mean).

$$M = \frac{\sum_{i=1}^{N} \left((X_{ai} - X_{bi}) - d \right)^3}{N^3} \quad (5)$$

$M = 0$ for normal distribution.

3.2.6 *kurtosis (K)*—the peakedness of the distribution (the fourth moment about the mean), $K = 3$ for normal distribution.

$$K = \frac{\sum_{i=1}^{N} \left((X_{ai} - X_{bi}) - d \right)^4}{N^4} \quad (6)$$

3.2.7 *response time (T)*—the time required for the change in output of a measuring system to reach 63 % of a step function change in the variable being measured.

3.2.8 *identical systems*—systems of the same make and model produced by the same manufacturer.

3.2.9 *resolution (r)*—the smallest change in an atmospheric variable that is reported as a change in the measurement.

4. Summary of Practice

4.1 The systems to be compared must make measurements within a cylindrical volume of the ambient atmosphere not greater than 10 m in horizontal diameter. The vertical extent of the volume must be the lesser of 1 m or one-tenth *H*, where *H* is the height above the earth's surface of the base of the volume. The sample volume must be selected to ensure homogeneous distribution of the variable being measured.

4.2 For some measurements (for example, visibility) the horizontal distance or the height (for example, cloud height) may be the variable of interest. In the first case, one of the two dimensions of horizontal distance is minimized and may not exceed 10 m while all other criteria remain the same. In the second case, all criteria for position and sampling described in 4.1 remain unchanged and the measured height is treated as if it were an atmospheric variable. The physical dimension of some measuring systems may exceed the spatial limits of 4.1 (for example, a rotating beam ceilometer with a 200-m baseline). In those cases the systems must be installed so that the measurements are obtained from within the volume specified in 4.1.

4.3 Samples are taken in pairs and the time interval between the pairs of samples must be no less than four times the response time (4T) of the measuring systems (**4**).

4.4 The time between members of a pair of measurements must be as small as possible, but must not exceed one tenth the response time.

4.5 The root mean square (rms) of the measurement differences is calculated to provide operational comparability or functional precision of the systems.

4.6 Measurement differences may change with the magnitude of the measurement (for example, the absolute value of the difference in the measurement of wind speed by two systems may be greater or smaller at high-wind speeds than at low-wind speeds). To test the data for such dependence, the range of measurements shall be divided into no less than three class intervals and each class shall have a sufficient number of samples to represent the class. The change in rms difference between classes indicates the dependence of the measurement difference on the magnitude of the measurement.

5. Significance and Use

5.1 This practice provides data needed for selection of instrument systems to measure meteorological quantities and to provide an estimate of the precision of measurements made by such systems.

5.2 This practice is based on the assumption that the repeated measurement of a meteorological quantity by a sensor system will vary randomly about the true value plus an unknowable systematic difference. Given infinite resolution, these measurements will have a Gaussian distribution about the systematic difference as defined by the Central Limit Theorem. If it is known or demonstrated that this assumption is invalid for a particular quantity, conclusions based on the characteristics of a normal distribution must be avoided.

6. Interferences

6.1 Exposure of the systems shall be such as to avoid interference from sources, structures, or other conditions that may produce a gradient in the measurement across the sample volume.

6.2 A mutual interference by systems may produce a systematic difference (*d*) or bias that would not occur if one system were used by itself. That bias is not a part of the comparability and must be reported separately.

6.3 A systematic difference greater than one increment of resolution must be investigated by interchanging the position of the sensors with an equal number of samples taken in each position. If the bias changes sign, it is due to the exposure and must be reported separately.

7. Apparatus

7.1 The apparatus used is the combination of sensor systems for which the operational comparability or functional precision is to be determined plus the data-processing equipment required to extract the data and calculate the statistical parameters.

8. Precautions

8.1 Safety precautions accompanying the sensor systems must be followed.

8.2 *Technical Precautions:*

8.2.1 Measurement-system mutual electrical interference must be minimized.

8.2.2 Use of this practice is based on a statistical analysis of the distribution of differences used to calculate operational comparability. Mean, standard deviation, skewness, and kurtosis of the distribution are reported to facilitate such analysis.

9. Sampling

9.1 Samples are collected in pairs from two sensors sampling the free ambient atmosphere.

9.2 Samples are collected from a cylindrical volume of the free atmosphere as defined in 4.1.

9.3 The distance between sensors should be the smallest distance that avoids sensor interaction but must meet 9.2.

9.4 The time between pairs of samples (X_{ai}, X_{bi}, and $X_{ai} + 1$, $X_{bi} + 1$) must be equal to or greater than four times the response time (4*T*) of the sensor system. The nature of atmospheric data is such that time intervals between pairs of samples as long as an hour or more may be desirable.

9.5 The time between members of a pair of samples (X_{ai} and X_{bi}) must not exceed one tenth of the response time (*T*/10).

9.6 The comparability determined is limited to the range of atmospheric conditions encountered. The number of samples cannot be too large. The minimum number of samples that must be exceeded is found by using the criteria for a 99.7 % or greater confidence interval that the absolute value of the difference (*D*) between the systematic difference (*d*) and the true mean (μ) of the population of all samples is less than or equal to the absolute value of three times the standard deviation (3s) about the mean, divided by the square root of the number of samples in the set of data. To calculate *D* the estimated standard deviation (*s*) is used to provide:

$$D = | d - \mu | \leq \left| \frac{3s}{\sqrt{N}} \right| \quad (7)$$

9.6.1 The sampling is not complete until *D* is less than or equal to one increment of resolution (*r*) of the system being tested. Stated another way, the number of samples needed N_n must be:

$$N_n \geq \left(\frac{3s}{r} \right)^2 \quad (8)$$

10. Preparation

10.1 The systems to be compared must be prepared for operation individually according to manufacturer's instructions.

10.2 Deliberate readjustment to obtain identical simultaneous readings shall be avoided.

11. Procedure

11.1 Install two or more meteorological measuring systems so that they are measuring the free ambient atmosphere from a cylindrical volume as defined in 4.1.

11.2 Record a measurement from each system separated by no more than *T*/10-s time interval.

11.3 Repeat 11.2 at a time interval at least four times the response time (4*T*) of the particular systems being tested. If systems with different response times are being compared, the longest shall be used to determine the minimum allowable time between pairs of samples. The period between the readings may be much larger than four times the response time (4*T*) for practical and operational reasons. It is advisable to choose both the time period between readings and the total period over which the determination is made long enough to include a wide sample of naturally occurring meterological phenomena at the site.

11.4 Continue sampling until at least N_n samples have been obtained where:

$$N_n \geq \left(\frac{3s}{r} \right)^2 \quad (9)$$

11.5 Divide the range of measurement into no less than three class intervals. Continue sampling until the number of samples in each interval (N_i) is:

$$N_i \geq \left(\frac{2s}{r} \right)^2 \quad (10)$$

11.6 Test the data for dependence between the difference measured and the magnitude of the measurement.

11.7 Calculate the skewness (*M*) (see 3.1) and the kurtosis (*K*) (see 3.1) of the frequency distribution of the differences.

12. Reports

12.1 Report *C*, the two-system operational comparability.

12.2 Report *d*, the systematic difference in the measurement by the two systems.

12.3 Report *N*, the number of samples used to calculate *C* and *d*.

12.4 Report *t*, the time interval between pairs of samples.

12.5 Report the range of measurements across which sampling was made.

12.6 Report on the dependence between the sample difference measured and the magnitude of the measurement.

12.7 Report any evidence of system interaction that would affect the systematic difference *d*.

12.8 Report *M*, the skewness of the frequency distribution of the differences.

12.9 Report *K*, the peakedness of the frequency distribution of the differences.

12.10 Report date and time of most recent calibration.

12.11 Report *r*, the resolution of the measurements.

12.12 Report date and time of beginning of data-gathering period.

12.13 Report date and time of end of data-gathering period.

13. Precision and Bias

13.1 Sample sizes have been chosen to assure a 99.7 % confidence level for *C* and *d* within the resolution of the measurements.

14. Keywords

14.1 atmosphere; functional precision; measurement comparisons; meteorological measurements

REFERENCES

(1) Hoehne, W. E., "Standardizing Functional Tests," *IEEE Transactions on Geoscience Electronics*, Vol GE-11, No. 2, April 1973.

(2) Stone, R. J., "National Weather Service Automated Observational Networks and the Test and Evaluation Division Functional Testing Program," *Fourth Symposium on Meteorological Observations and Instrumentation*, Denver, Colorado, April 10–14, 1978.

(3) Natrella, Mary Gibbon, "Experimental Statistics," *National Bureau of Standards Handbook*, Vol 91, August 1, 1963.

(4) Haykin, Simon S., *Communication Systems*, John Wiley & Sons, New York, NY, 1978.