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FIELD COMPARISON BETWEEN SLING PSYCHROMETER AND METEOROLOGICAL MEASURING SET AN/TMQ-22

By

RONALD W. WAITE

August 1971

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ABSTRACT

During the Service Check Test of Meteorological Measuring Set AN/TMQ-22, a discrepancy in dew point temperature readings was noted between it and the ML-224 Sling Psychrometer. From a series of independent tests designed to minimize error it was concluded that the AN/TMQ-22 yielded a more accurate dew point reading. The average relative humidity error using the sling psychrometer was +9% while the AN/TMQ-22 had a ±2% error. Even with cautious measurement the sling yielded a +4% error.

CONTENTS

INTRODUCTION

The Meteorological Measuring Set AN/TMQ-22 (Figure 1) is a small, portable, surface weather observation set which is capable of sensing air temperature, pressure, wind speed and direction, precipitation and dew point temperature. The latter is sensed with a device following the established theory of Regnault [1]. A Peltier (thermo-electric) cooler is activated until a visible formation of dew occurs on a flat surface. The temperature of the dew-layered surface is then stabilized and sensed to obtain the dew point temperature.

The US Army artillery's present standard method of obtaining relative humidity for rawinsonde flight operations is the use of a sling psychrometer (Figure 2). Basically, psychrometers utilize the physical principle of the cooling of a temperature sensor by evaporation of water into the air. Numerous theories have been proposed concerning the particular processes involved; however, none has found complete acceptance. Nevertheless, empirical formulae for the determination of humidity from this phenomenon have been evolved.

Using the sling psychrometer as a standard during the service testing of the AN/TMQ-22, a discrepancy was noted between the dew point readings from the two devices. This report will attempt to explain the possible reasons for this discrepancy and to compare the accuracy of the two methods of hygrometry.

DISCUSSION

Service Check Test - Discovery of Discrepancy

During the Service Check Tests of Meteorological Measuring Set AN/TMQ-22(XE-4) a disagreement was noted between the AN/TMQ-22 dew point readings and the test comparison standard sling psychrometer (ML-224).

To determine if the discrepancy could be attributed to a single cause, a list of possible sources of error was compiled (Table 1).

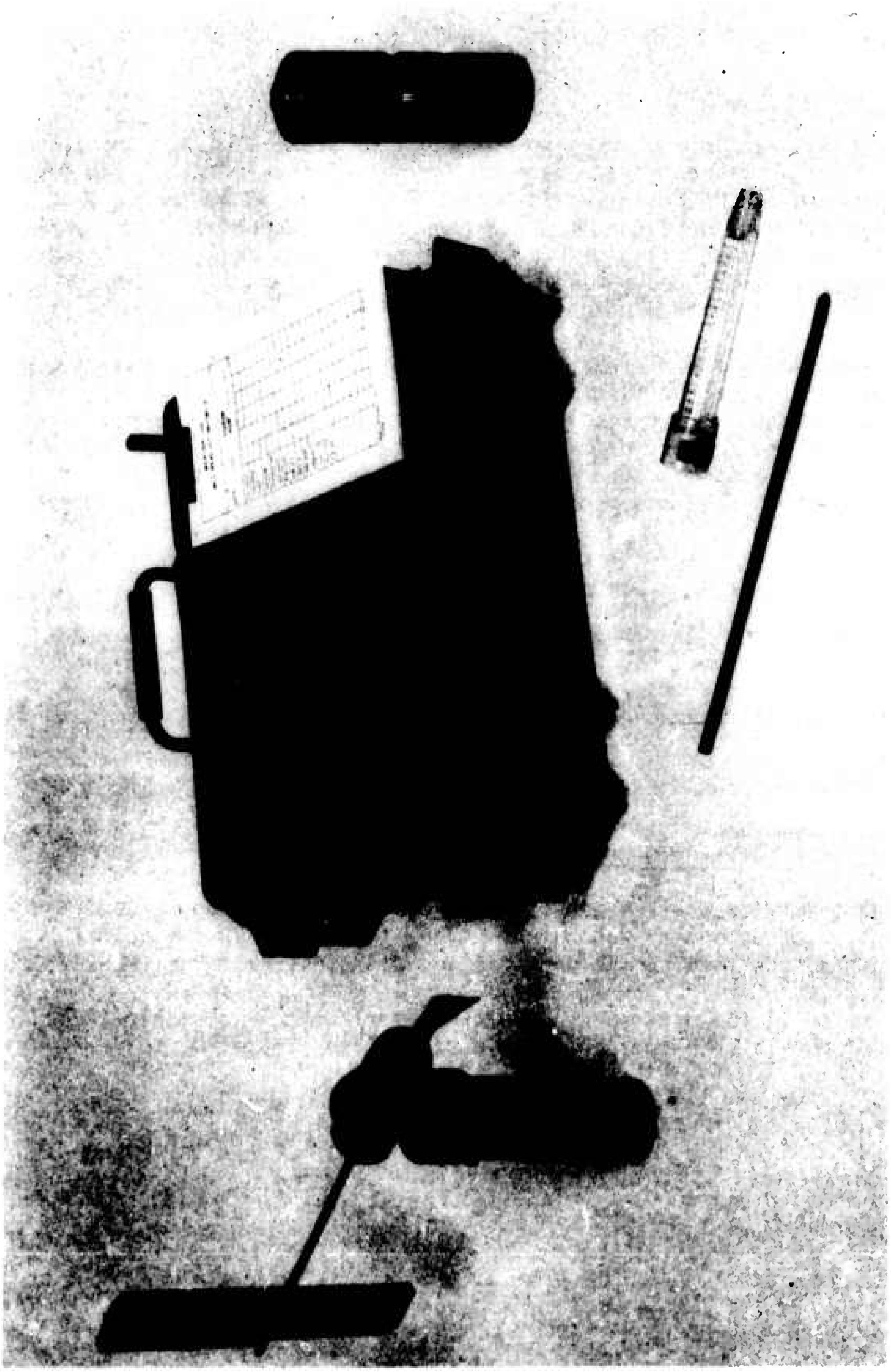


Figure 1. Meteorological Measuring Set AN/TMQ-22.

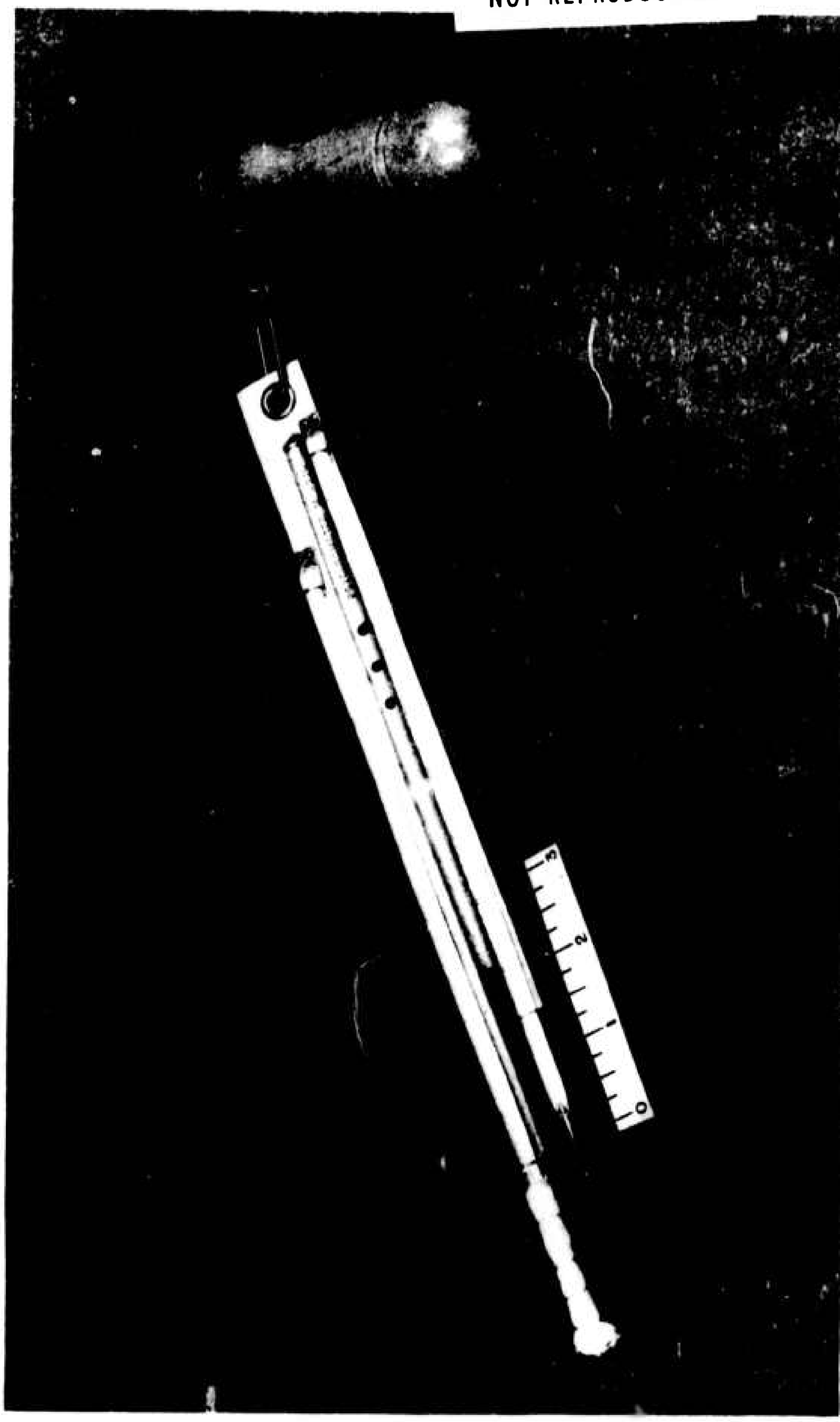


Figure 2. Sling Psychrometer ML-224.

TABLE I

POSSIBLE SOURCES OF ERROR IN HUMIDITY MEASUREMENT

1. Sling Psychrometer

    a. Improper ventilation (2.5 m/sec)
    b. Dirty or mineralized water on wicks
    c. Inaccurate or unmatched thermometers
    d. Radiation effects
    e. Thermometer readings not stabilized
    f. Reading taken at improper time (after wet-bulb reading starts to rise or before it has reached its lowest point)
    g. Improper or inaccurate transcription and reduction of reading

2. AN/TMQ-22

    a. Aspiration rate too low or too high
    b. Measurement bridge inaccurate
    c. Thermistors inaccurate
    d. Radiation effects
    e. Dew point sensor improperly balanced
    f. Improper operation while taking reading - sensor and circuits not stabilized
    g. Improper reading of T-DP dial
    h. Inaccurate transcription of data

3. Relation Between Sensors

    a. Sensors not measuring same air sample - must be reading at same place, same time, under same conditions - extraneous heat sources must be absent
    b. Time and space variability of actual air sample indicates that the response time of the instruments can affect reading - sling psychrometer has longer response time than AN/TMQ-22
    c. Operator involvement - an accurate reading depends upon proper procedures faithfully followed.

Investigative Testing

A series of four independent tests was initiated to investigate this discrepancy. The two tests (#1 and #3) performed by the author were carefully controlled to eliminate as many of the error sources as possible.

Test #1

This test was performed by the author at the Service Check Test (SCT) site under conditions similar to those encountered during the SCT. The devices subjected to the test were three each AN/TMQ-22's and three sling psychrometers. Error eliminating efforts included new wicking, distilled water, shading from the sun, etc. As an immediate check the readings were compared to those taken concurrently with two Assman type psychrometers which had been checked by the contractors who had fabricated the AN/TMQ-22's. Although it was unknown at the time the readings from the #6 AN/TMQ-22 were to be used as the standard for the reduction of the data.

Test #2

This test was also performed at the Service Check Test site. The test was made by SCT personnel using the same equipment as test #1, with close supervision although not as closely controlled as test #1. The standard used for data reduction, again not known at the time of the testing, was #6 AN/TMQ-22.

Test #3

This test was made by the author under more stringently controlled conditions. Most of the test was performed in a closed room in which the air had been mixed to avoid strata and boundary conditions as much as possible. The test was performed using the #6 AN/TMQ-22, an ML-224 sling psychrometer and an Assman type psychrometer all of whose temperature sensors had been calibrated. The objective of the test was to minimize the possible errors and to obtain readings over the full range of humidities. A minimum number of separate readings was taken during this test. Again the standard for data reduction was the #6 AN/TMQ-22 (for dew point readings).

Test #4

This test was relatively uncontrolled and was taken by personnel as an included duty to their normal hourly surface weather observations. The devices tested were a sling psychrometer and #4 AN/TMQ-22. The sensors were housed in a standard meteorological shelter until measurements were taken. Again the data reduction standard was the #6 AN/TMQ-22 for the dew point readings. This was accomplished by comparing the #6 and #4 sensor readings at various dew points and constructing a calibration curve from these. The temperature sensors of the sling and the #4 AN/TMQ-22 were calibrated as described in the next section.

ASL Calibration

Since the sling psychrometers obtain wet- and dry-bulb temperature readings, and the AN/TMQ-22 obtains "dry-bulb" and dew point readings, computations are required to convert the sling reading to dew point or relative humidity, or the AN/TMQ-22 readings to relative humidity. This means that to compare the two instruments some temperature correction or correlation between them is required. Therefore, a temperature calibration was performed on the #6 AN/TMQ-22 at ASL in mid-September 1969 so that data taken during the Service Check Test and the investigative tests could be correlated to a set standard by intermediate use of the #6 unit readings. The calibration consisted of immersing the temperature sensors in a controlled bath, with a calibrated platinum resistance thermometer as the standard, utilizing a Mueller bridge arrangement as a readout.

The sensors tested were: four thermometers from a pair of Assman psychrometers; two thermometers from an ML-224 sling psychrometer, and the temperature thermistor from both the NBS dew point tested #6 AN/TMQ-22 sensor and an AN/TMQ-22 which had been used in test #4. Calibration points were every 5°F from 35°F to 105°F.

The Assman psychrometer thermometers with most closely matching readings were paired so as to reduce error. The maximum observed deviation of one Assman thermometer from its mate was about 0.1°F, while the observed deviation of the sling thermometers was 0.5°C. Since the choice of psychrometers was random it can be assumed that a similar error could occur in any other sling psychrometer.

NBS Calibration

One of the AN/TMQ-22 models (#6) check-tested at Fort Sill was delivered unadjusted to NBS in June 1969 for a calibration check. Results of the testing indicated that the AN/TMQ-22 model was inaccurate by no more than -0.6°C over the range of points checked. Table II lists the positive temperature portion of the test results from NBS.

TABLE II

CHECK OF DEW POINT HYGROMETER ML-616/TMQ-22(XE-4)

NBS Dew Point °C	ML-616 Error °C
- 0.2	-0.5
+13.8	-0.4
+24.1	-0.6
+21.5	-0.5
+ 9.6	-0.1
- 0.2	-0.2

Correlation of Calibrated and Raw Data

Because the data had been obtained from five different sources (three tests from SCT site, two from ASL), it was necessary to determine the accuracy of the readings with regard to a common standard. Since the #6 AN/TMQ-22 had been tested by NBS, it was decided that all dew point accuracies be referred to the NBS standard reading. Only six readings had been taken; thus, it was necessary to construct an interpolated correction curve for all the applicable dew points. While this procedure introduces an uncertainty into the correction, it is believed that this is preferable to correlation with a standard of completely unknown accuracy. The same procedure was used with the temperature accuracies; however, since check readings were taken every 5°F on the #6 unit, no appreciable error should exist between the true temperature and the assumed standard temperature.

DATA PRESENTATION

Relative Humidity Ranges

The data sets were separated into groupings of four relative humidity ranges, generally corresponding to high (100-65%), medium high (65-50%), medium (50-35%), and low (35-0%) humidities. This was done for two reasons. First, these groups were considered to be more readily identifiable to the readers of this report in a physical experience sense. Secondly, the dew point or wet-bulb depression below ambient temperature varies inversely as the humidity; it is apparent, then, that a larger span between dry and wet temperatures will be conducive to a larger error in humidity calculation. The readings were partitioned so that the possible large errors at the low humidities would not overwhelm the undetermined errors at the other humidities when obtaining the mean and standard deviations.

Dew Point Error Comparisons

Tables III, IV, and V give the number of readings taken, the average error and the standard deviation of the dew point reading, for all five data sources for the AN/TMQ-22 models and the sling psychrometers.

Figures 3 through 6 graphically depict the average error and the standard deviation of each source for the individual humidity ranges. (Standard deviation means that 68% of all the readings should lie within the limits imposed, in this case between E + σ and E - σ, where E is the average error and σ is the standard deviation.)

Figure 7 presents a plot of the average dew point error of each source for the various humidity ranges. Figure 8 is a plot of the average error of all the sources for the various humidity ranges. Superimposed on these averages are the weighted average standard deviations (weighted by the number of readings).

TABLE III

DEW POINT ERROR COMPARISONS (SERVICE CHECK TEST SITE)

Data Source / Relative Humidity Range	AN/TMQ-22's			Sling Psychrometers		
	no. of readings	avg. error (°C)	standard deviation (°C)	no. of readings	avg. error (°C)	standard deviation (°C)
Service Check Test						
100 - 65%	221	+0.3	0.9	148	+1.5	0.9
65 - 50%	86	-0.3	1.4	82	+1.6	1.6
50 - 35%	57	-0.4	0.9	55	+2.2	1.8
35 - 0%	66	-0.2	1.5	58	+4.6	2.4
Test #1						
100 - 65%	33	-0.1	0.3	33	+0.9	0.6
65 - 50%	63	-0.2	0.3	56	+0.9	0.6
50 - 35%	46	-0.2	0.2	22	+1.8	0.8
35 - 0%	----	----	----	----	----	----
Test #2						
100 - 65%	----	----	----	----	----	----
65 - 50%	13	-0.3	0.2	5	+3.8	1.6
50 - 35%	27	-0.2	0.4	22	+4.4	1.8
35 - 0%	55	-0.4	0.4	65	+4.9	2.1

TABLE IV

DEW POINT ERROR COMPARISON
TEST #3

Relative Humidity Range	Assman Psychrometer (Electric)			AN/TMQ-22(XE-4) #6			Sling Psychrometer ML-224		
	no. of readings	avg. error (°C)	standard deviation (°C)	no. of readings	avg. error (°C)	standard deviation (°C)	no. of readings	avg. error (°C)	standard deviation (°C)
100 - 65%	3	0.0	0.1	5	-0.1	0.2	5	+0.7	0.4
65 - 50%	4	-0.1	0.1	6	-0.1	1.4	6	+0.5	1.4
50 - 35%	----	----	----	2	+0.5	0.1	2	+2.4	0.1
35 - 0%	7	-0.2	0.4	7	+3.7	2.6	7	+3.8	1.5

Notes: 1. Spring-wound Assman psychrometer used as standard.
2. All data based on corrected observation data.

TABLE V

DEW POINT ERROR COMPARISON
TEST #4

Relative Humidity Range	AN/TMQ-22(XE-3) #4			Sling Psychrometer		
	no. of readings	avg. error (°C)	standard deviation (°C)	no. of readings	avg. error (°C)	standard deviation (°C)
100 - 65%	170	-0.2	0.1	172	+1.8	1.9
65 - 50%	86	-0.3	0.1	86	+3.3	2.3
50 - 35%	57	-0.3	0.1	57	+4.5	2.3
35 - 0%	28	-0.4	0.0	27	+9.5	4.0

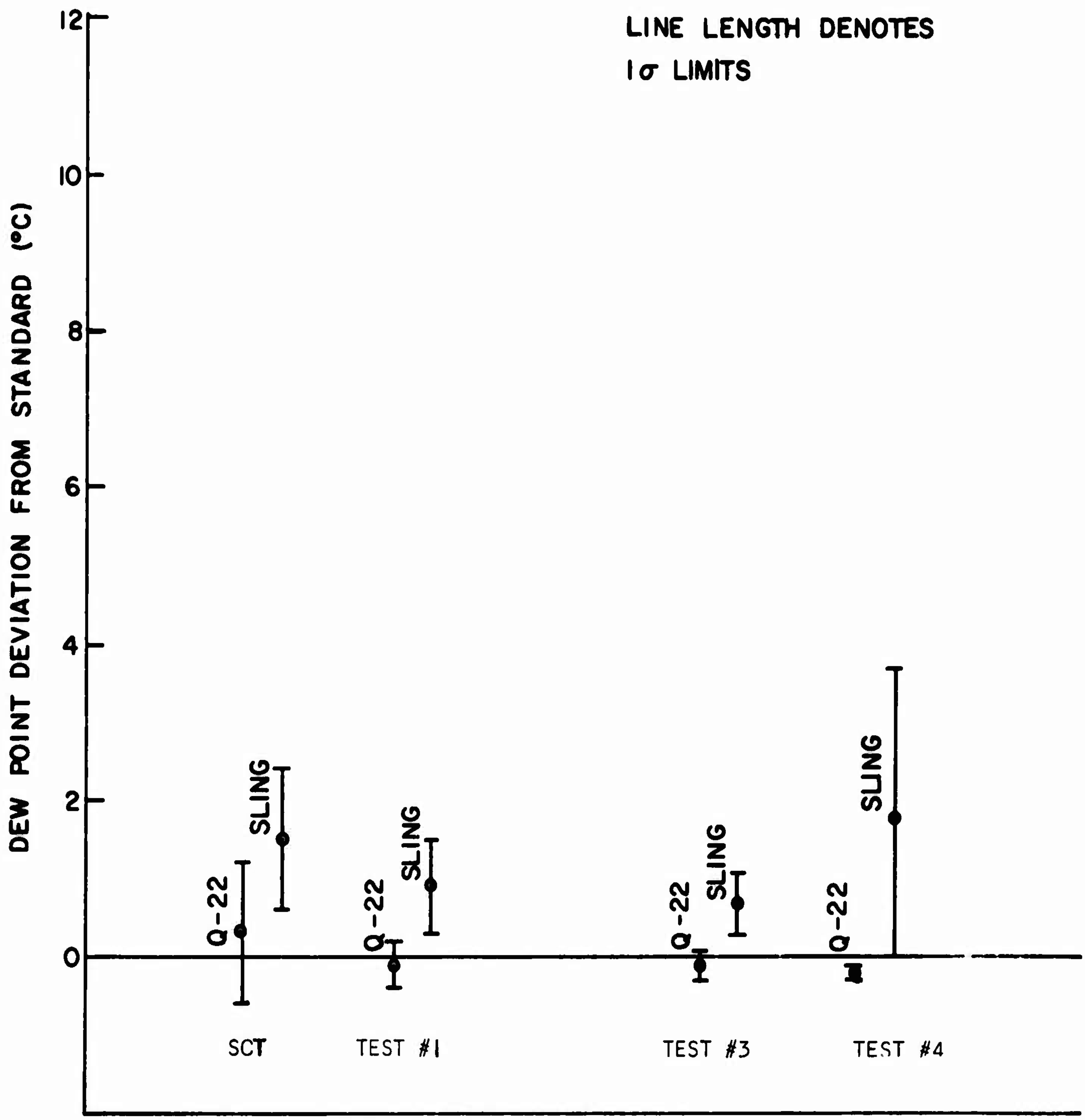


FIG. 3
DEW POINT ERROR COMPARISON
100-65% RELATIVE HUMIDITY RANGE

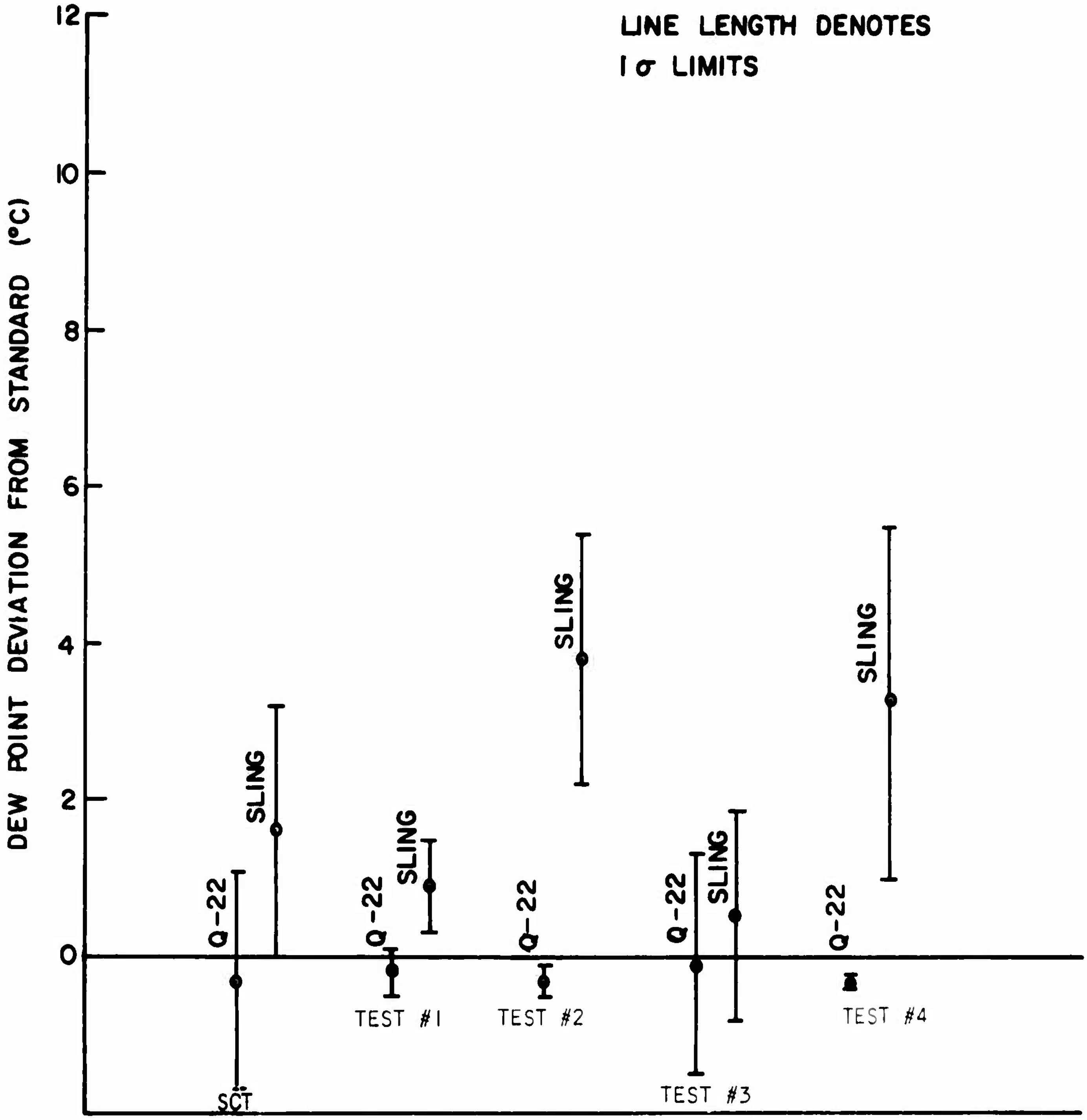


FIG. 4
DEW POINT ERROR COMPARISON
65-50% RELATIVE HUMIDITY RANGE

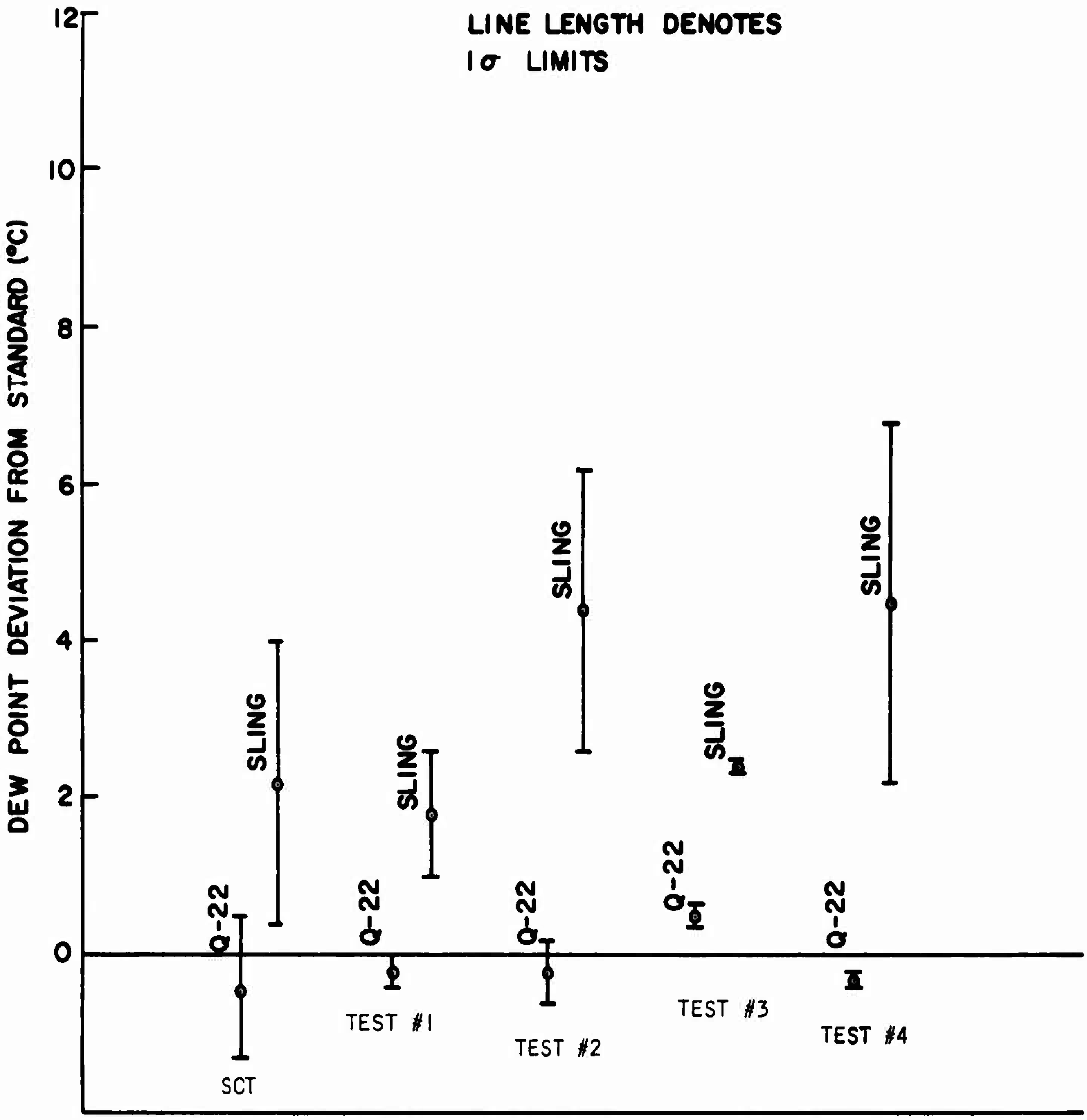


FIG. 5
DEW POINT ERROR COMPARISON
50-35% RELATIVE HUMIDITY RANGE

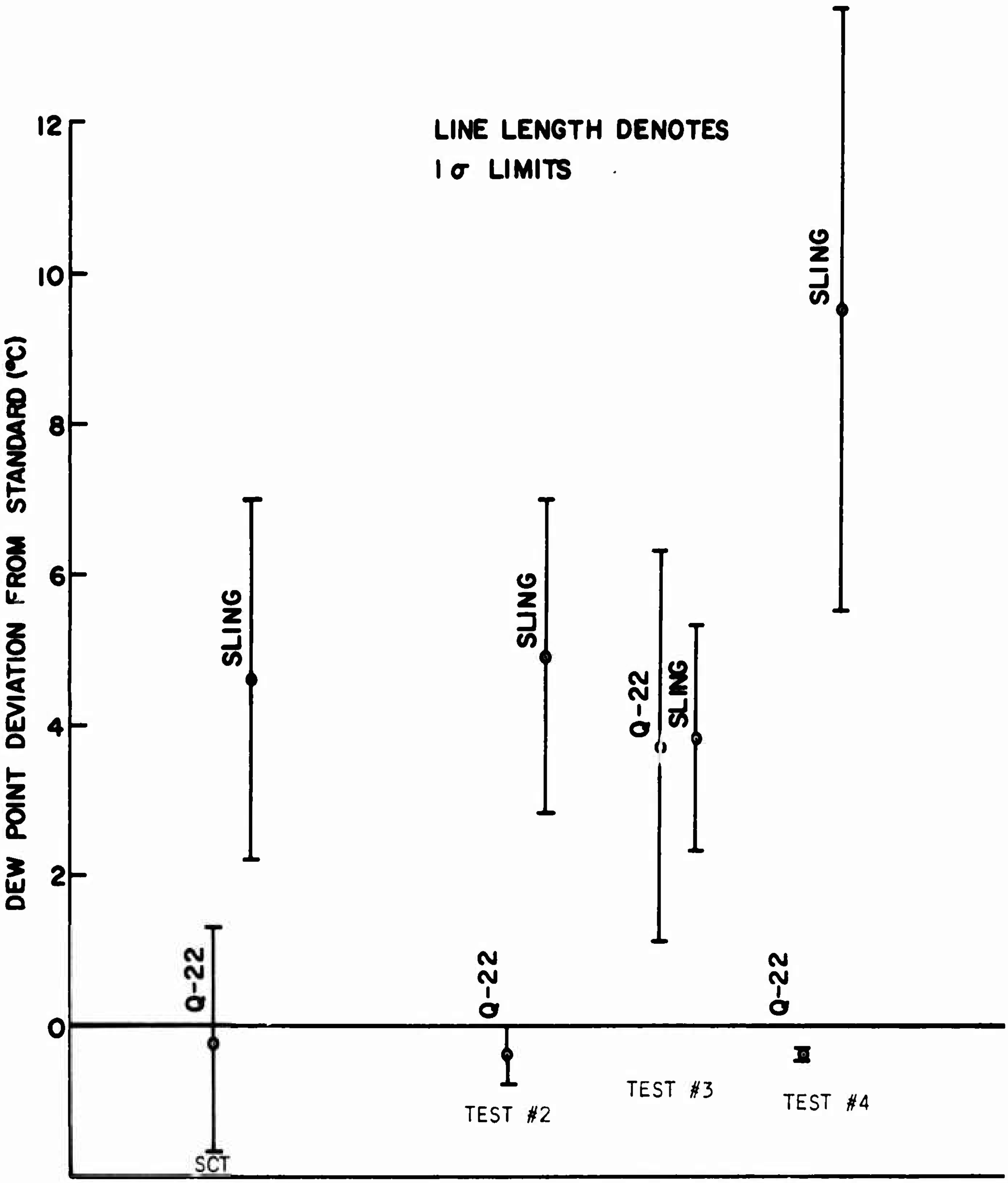
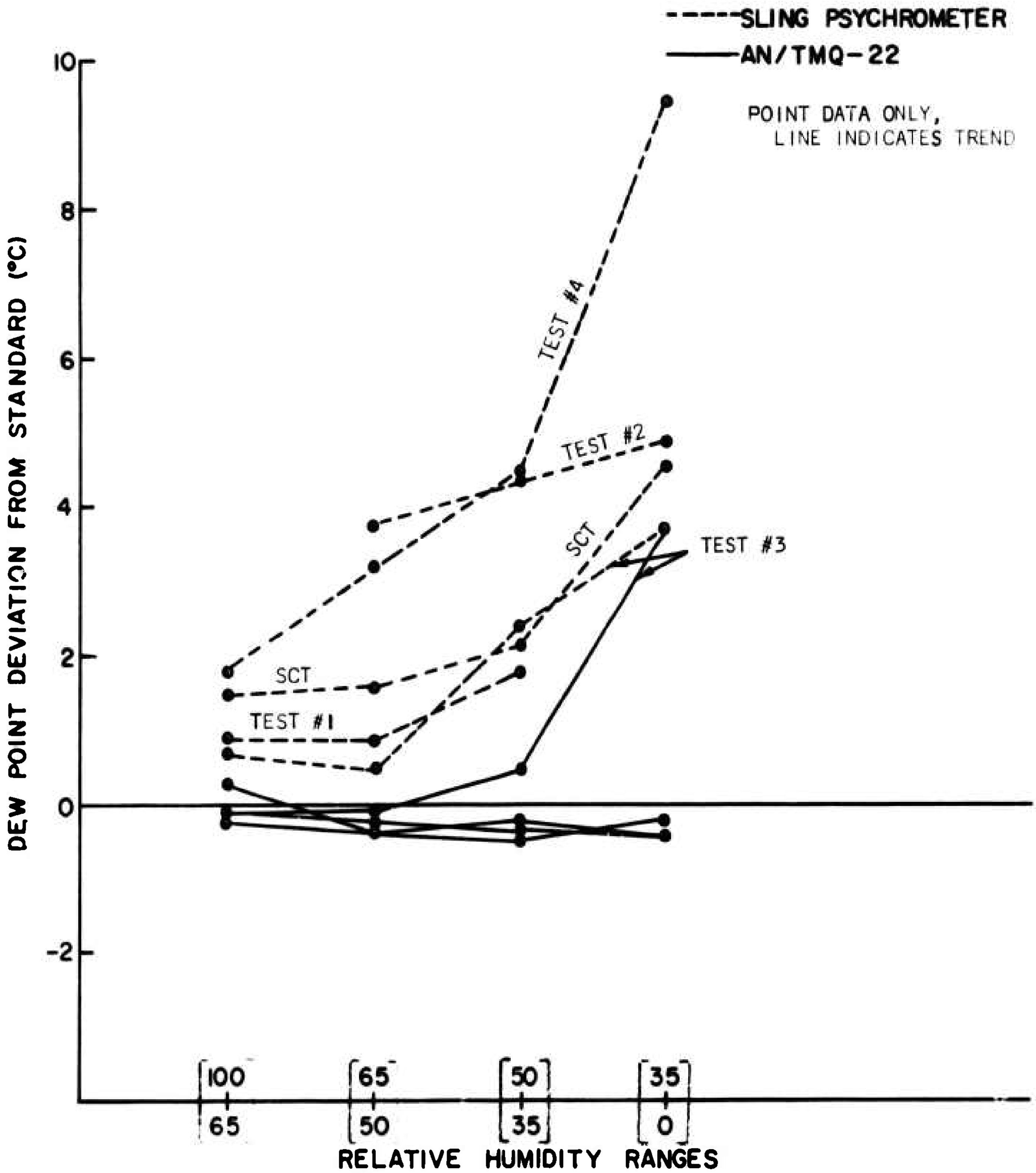
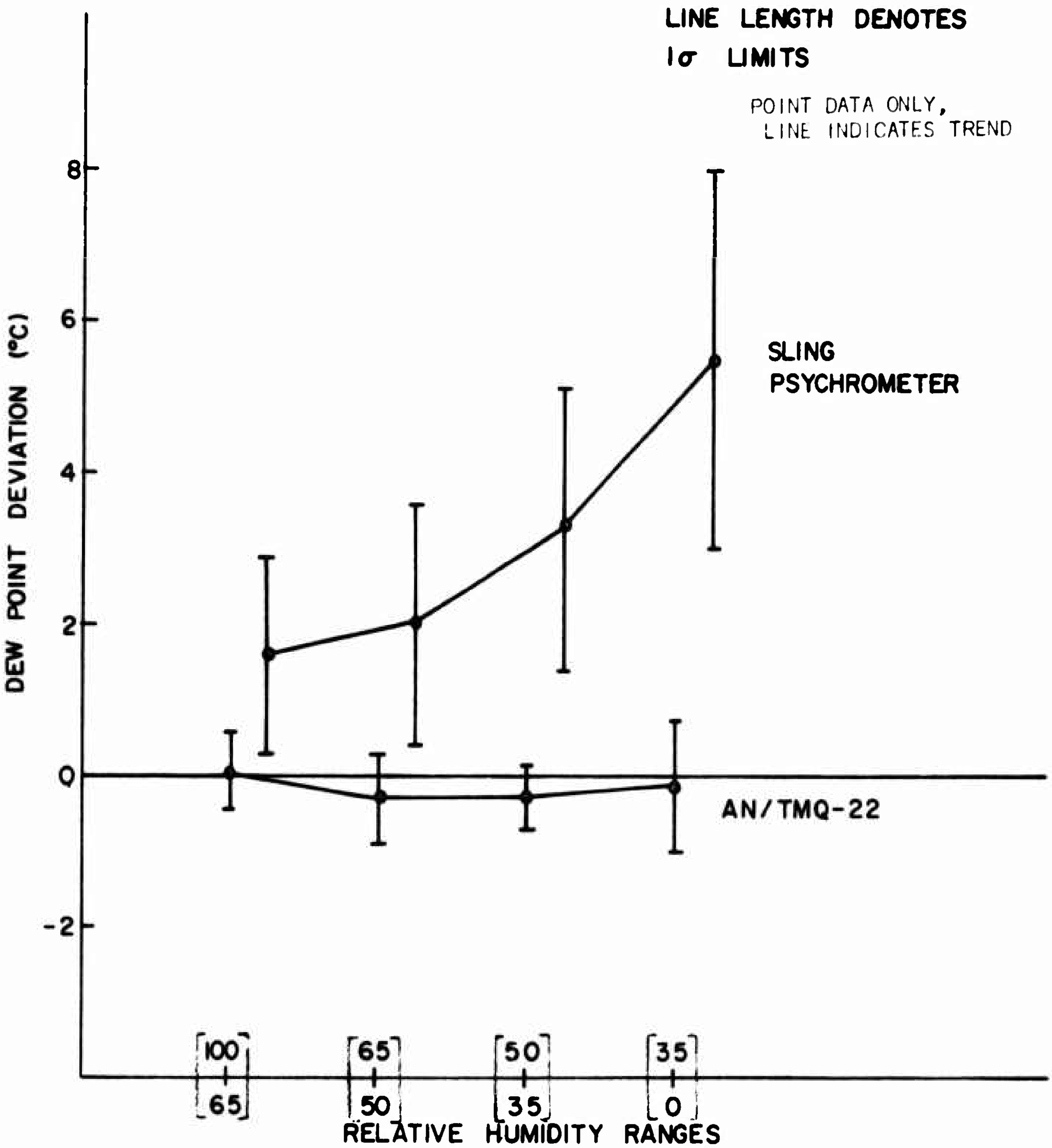


FIG. 6
DEW POINT ERROR COMPARISON
35-0% RELATIVE HUMIDITY RANGE



DEW POINT ERROR COMPARISON
ALL HUMIDITY RANGES
FIG.7



DEW POINT ERROR COMPARISON
FIG. 8

Relative Humidity Error Comparisons

Tables VI and VII compare the relative humidity errors between the sling psychrometers and the AN/TMQ-22's, giving the number of readings, the average error from a standard and the standard deviation for each data source.

Figures 9-12 graphically depict the average error and the standard deviation for each data source for the individual humidity ranges. Figure 13 is a plot of the average relative humidity error of each data source for the various humidity ranges, while Figure 14 is a plot of the average error of all the data sources for the various humidity ranges. Superimposed on these averages are the weighted average standard deviations.

TABLE VI

RELATIVE HUMIDITY ERROR COMPARISONS
SERVICE CHECK TEST SITE

Data Source / Relative Humidity Range	AN/TMQ-22's			Sling Psychrometers		
	no. of readings	avg. error	standard deviation	no. of readings	avg. error	standard deviation
Service Check Test						
100 - 65%	221	+2.1	5.7	148	+10.9	5.6
65 - 50%	86	-0.8	7.3	82	+ 8.9	8.2
50 - 35%	57	-0.6	5.5	55	+ 9.6	7.9
35 - 0%	66	+0.5	4.1	58	+13.6	9.1
Test #1						
100 - 65%	33	-0.5	2.5	33	+3.8	3.7
65 - 50%	63	+0.3	2.4	56	+3.2	2.2
50 - 35%	46	+0.1	0.7	22	+5.2	2.3
35 - 0%	----	----	----	----	----	----
Test #2						
100 - 65%	----	----	----	----	----	----
65 - 50%	13	-0.8	1.7	5	+18.5	8.6
50 - 35%	27	-0.0	1.9	22	+16.6	7.0
35 - 0%	55	-0.6	1.1	65	+10.9	3.5

NOTE: Average error and standard deviation in percent.

TABLE VII

RELATIVE HUMIDITY ERROR COMPARISON
TEST #3

Relative Humidity Range	Assman Psychrometer (Electric)			AN/TMQ-22(XE-4) #6			Sling Psychrometer ML-224		
	no. of readings	avg. error	standard deviation	no. of readings	avg. error	standard deviation	no. of readings	avg. error	standard deviation
100 - 65%	3	+0.3	0.6	5	-2.6	2.7	5	+2.0	2.9
65 - 50%	4	-0.5	0.3	6	-1.1	3.9	6	+2.1	6.8
50 - 35%	----	----	----	2	+0.1	0.9	2	+7.8	0.4
35 - 0%	7	-0.5	0.5	7	+3.7	1.5	7	+4.3	2.0

NOTE: 1. Spring-wound Assman psychrometer used as standard.
2. All data are corrected values.
3. Average error and standard deviation in percent.

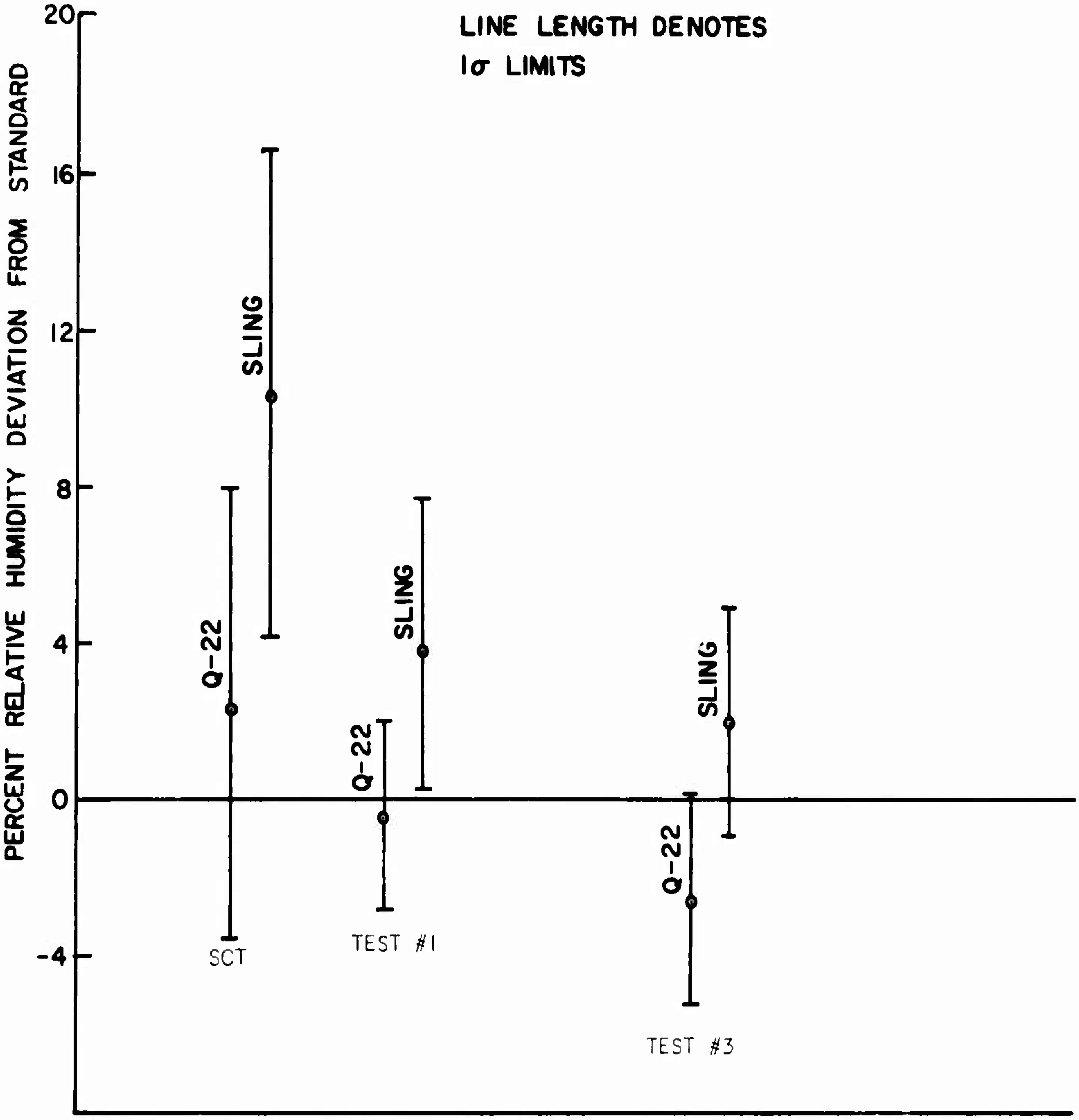


FIG. 9
RELATIVE HUMIDITY ERROR COMPARISON
100-65% RANGE

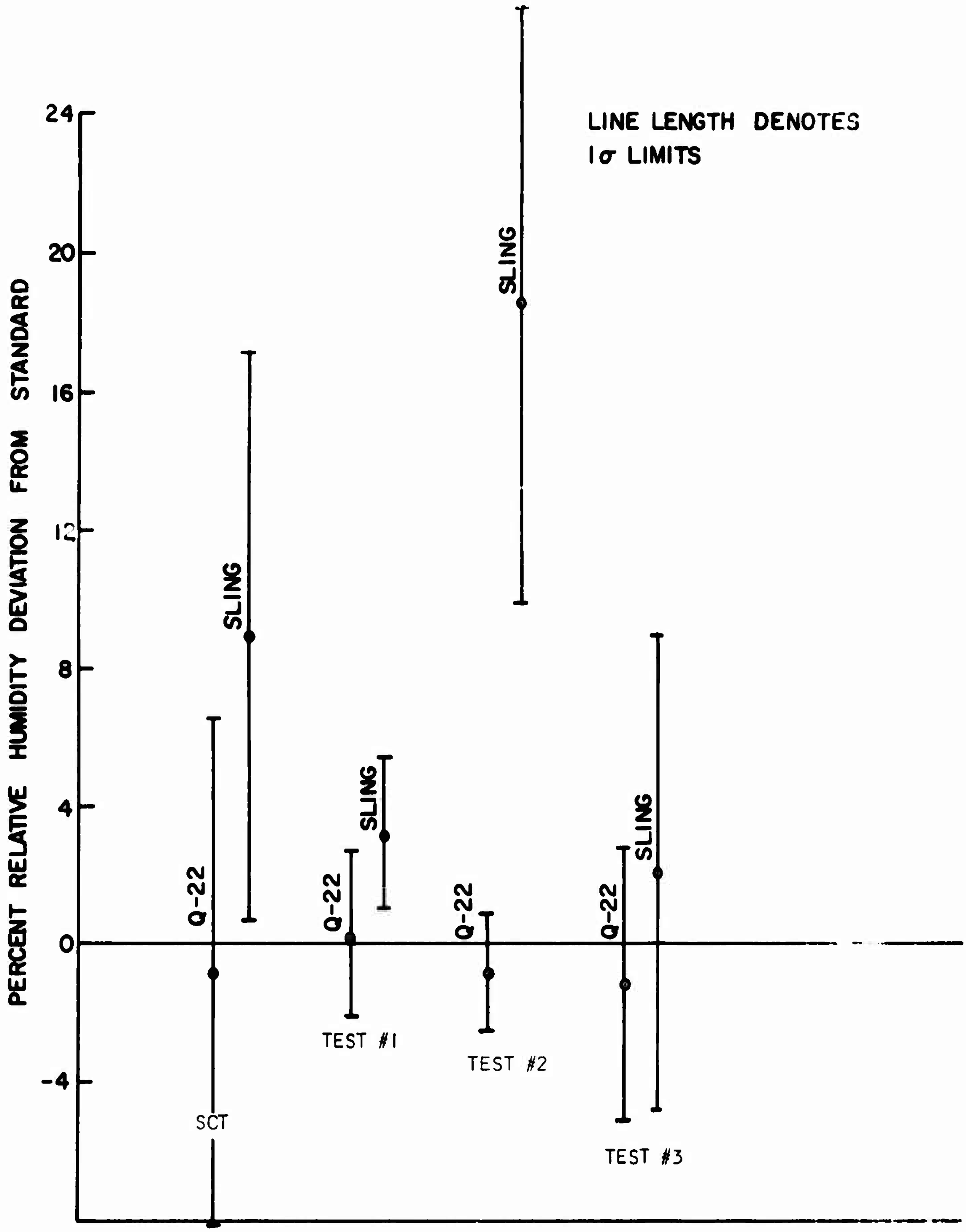


FIG. 10
RELATIVE HUMIDITY ERROR COMPARISON
65-50% RANGE

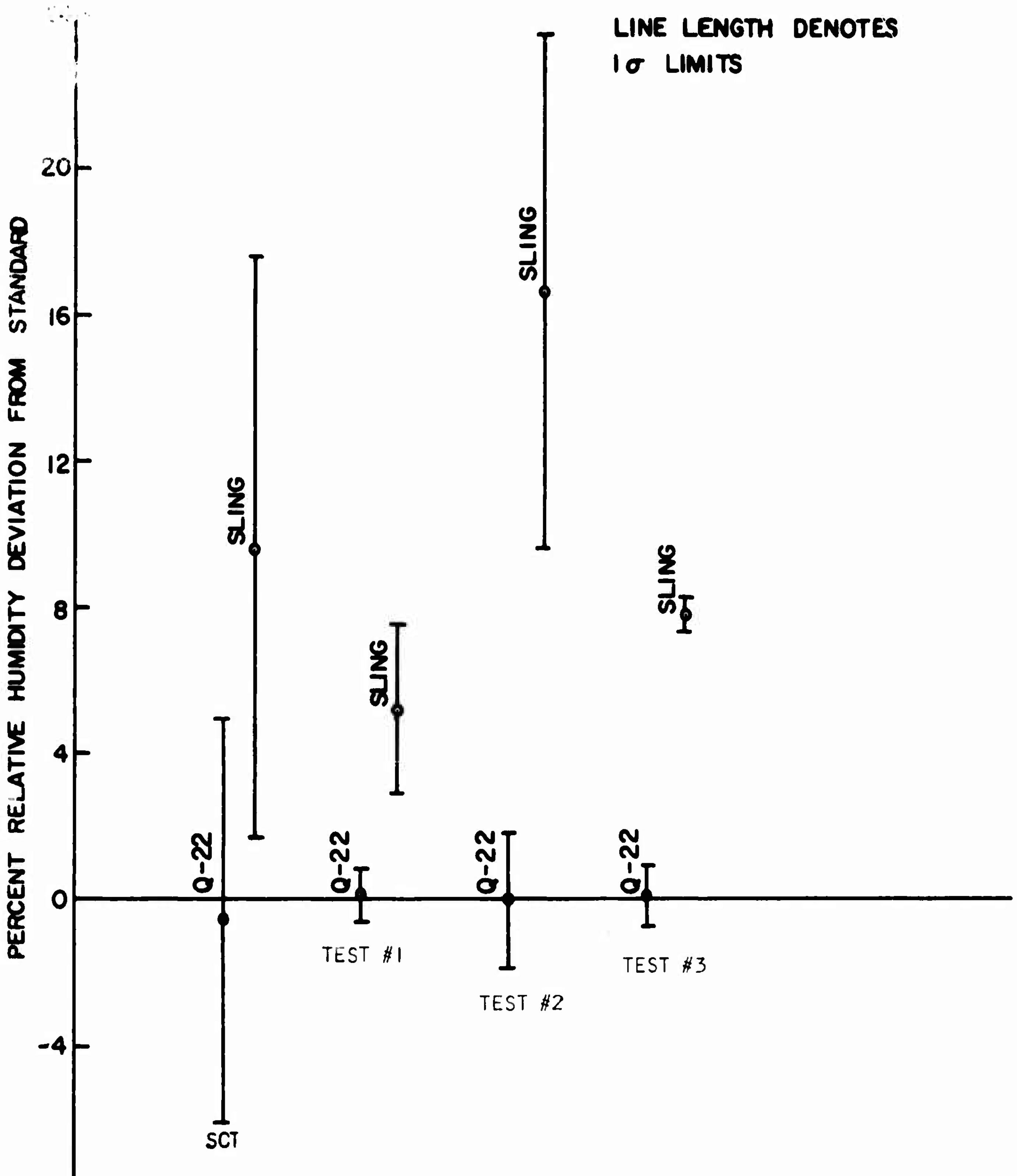


FIG. 11
RELATIVE HUMIDITY ERROR COMPARISON
50 - 35% RANGE

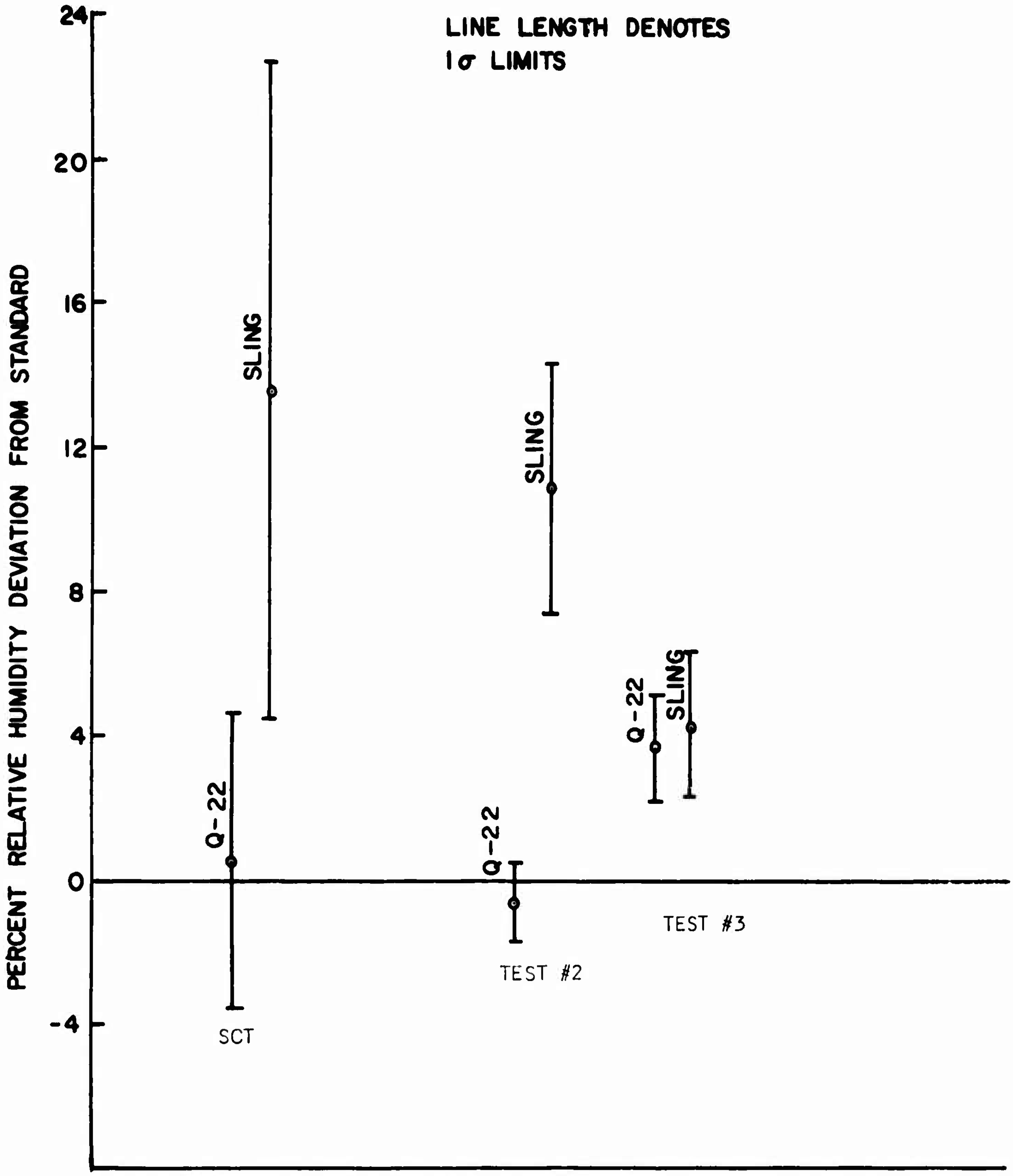
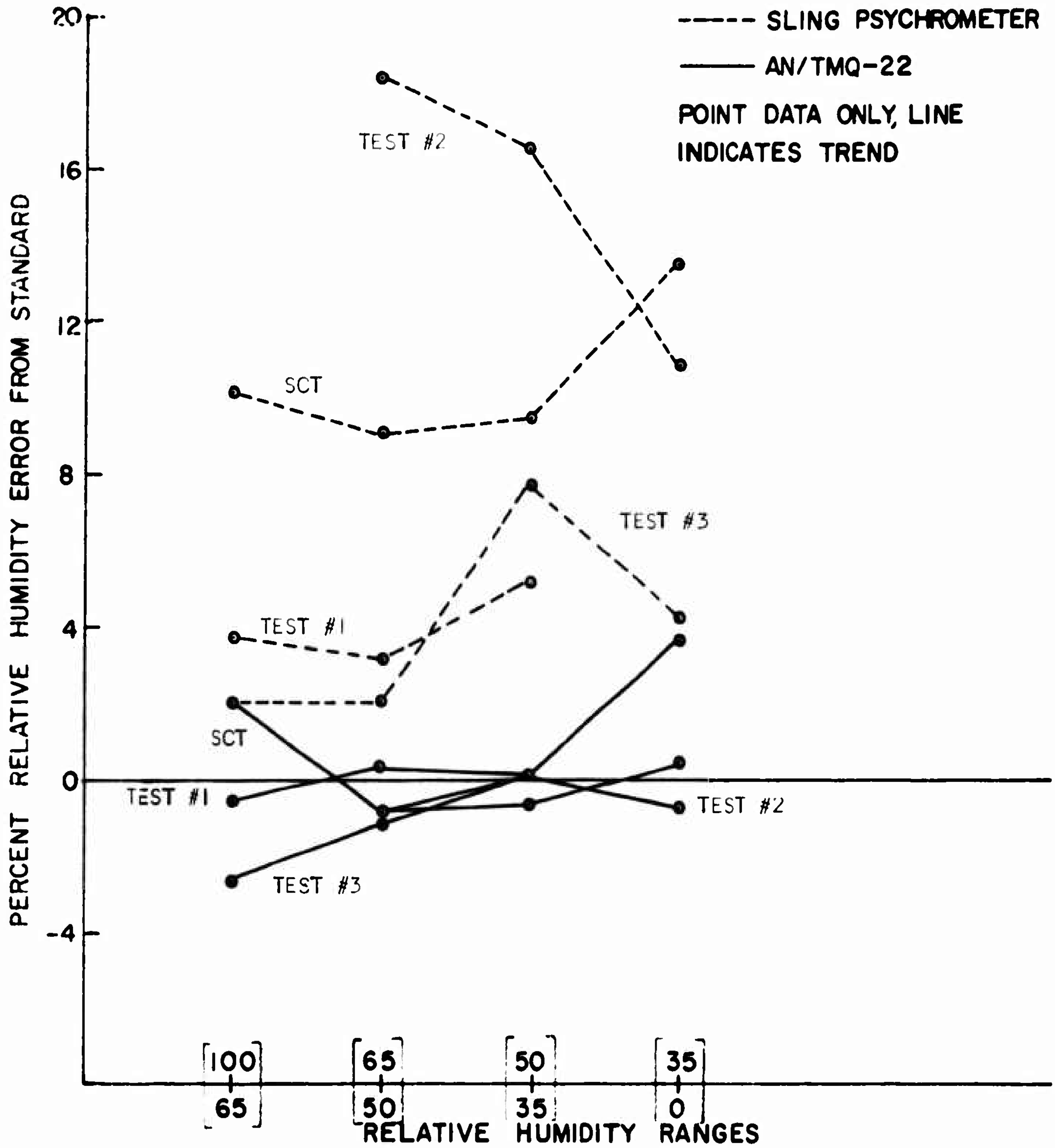
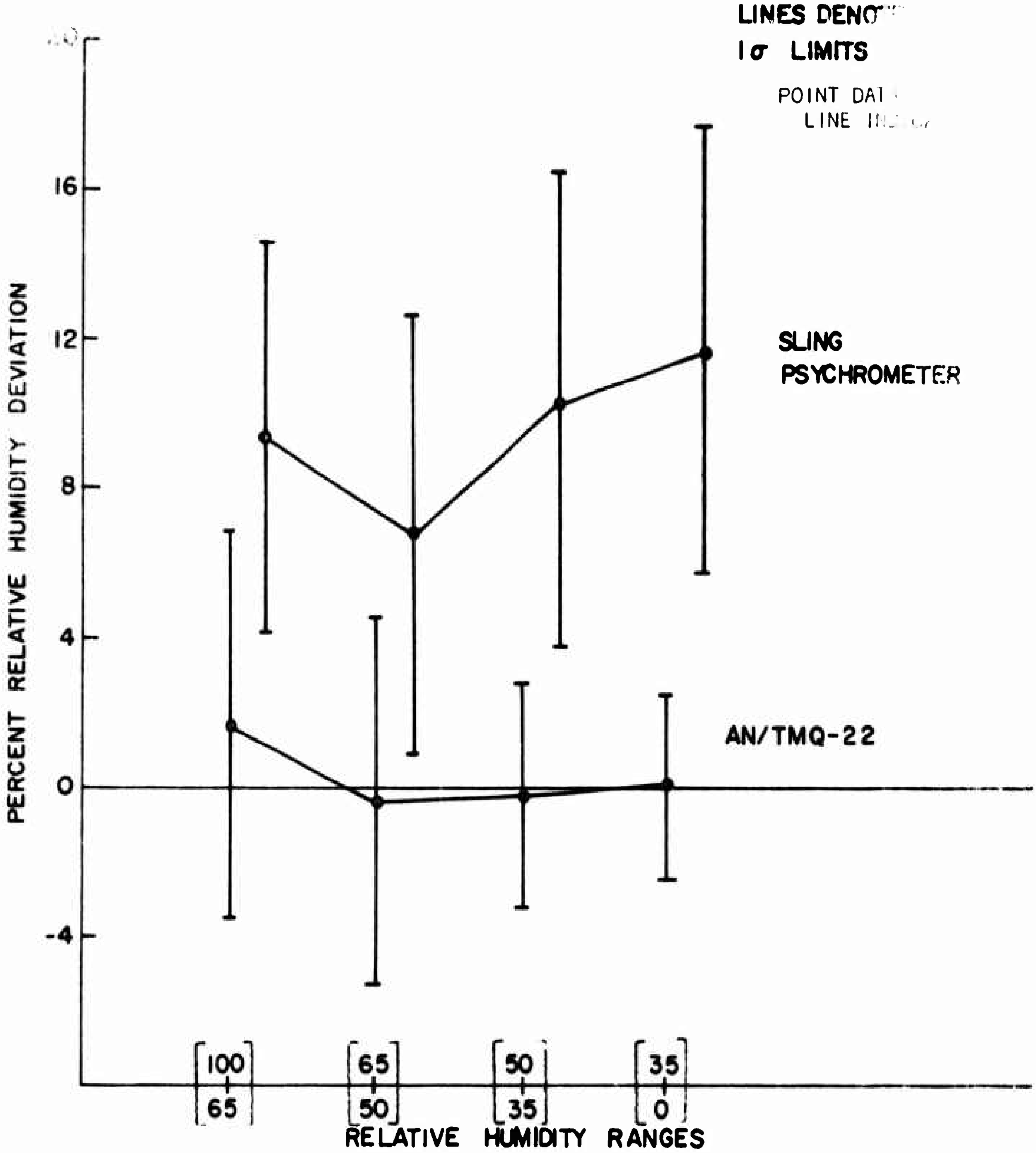


FIG. 12
RELATIVE HUMIDITY ERROR COMPARISON
35-0% RANGE



RELATIVE HUMIDITY ERROR COMPARISON COMPOSITE-
ALL RANGES

FIG.13



RELATIVE HUMIDITY ERROR COMPARISON
FIG. 14

RESULTS

Comments in this section will deal only with the results of the data and the results of the reduction of those data, the main body of which is presented in the figures cited previously. The results of the data reduction have been separately charted as error comparisons in relative humidity and also error comparisons in dew point temperature for two reasons. First many users may be principally interested in one but not the other parameter. The second and more important reason, with regard to this report, is that the magnitude of the error inherent in the measurement of each parameter is maximized at either extreme of humidity.

Measurement Error

Effect on Calculated Relative Humidity

	Relative Humidity	
	30%	90%
1° DP error	2.7%	6%
1° Temp. error	2%	6%

Measurement Error

Effect on Calculated Dew Point

	Relative Humidity	
	30%	90%
5% RH error	2.2°C	0.8°C

From the above tabulations, it can be seen that, theoretically, the least accurate readings in relative humidity will occur at high humidities, while conversely the least accurate dew point readings, calculated from relative humidity (or wet- and dry-bulb readings), will occur at low humidities. Thus, if one wished to observe the data at their worst, so to speak, he should look at the relative humidity errors at high humidities and the dew point errors at low humidities. Examination of Figures 3, 6, 9, and 12 reveals that the above holds true, in general. An exception may be noted in Figure 12, which shows that the sling psychrometer errors are still very high for the Service Check Test (SCT) data source.

[illegible], as deduced from the Figures 5-14, are listed below.

1. In every case for every data source, the dew point and relative humidity average errors of the sling psychrometer were greater than those of the AN/TMQ-22.

2. In every case for every source, the dew point and relative humidity error standard deviations of the sling psychrometer were equal to or greater than the deviations of the AN/TMQ-22.

3. [illegible] error and deviation readings can be ascribed to lack of [illegible] data. See Figure 13 listing the composite relative humidity error. The SCT data in the 65-50% RH range were composed of [illegible] data sets; the test #1 data in the same range were composed of [illegible] data sets. The SCT and the test #1 data were, therefore, essentially equal in the number of observations made. The test #1 data for the sling psychrometer were in error by about 4% RH while the SCT data were in error by about 9%. In both bases, the data taken with the AN/TMQ-22's were approximately equal (0% RH error).

4. Again referring to Figure 13, the test #3 data in the 50-35% relative humidity range were in error by 8% RH; however, this could be ascribed to the fact that only two data points were in that range.

5. When all sources and all humidity ranges were combined, the results were as tabulated below.

Dew Point Error

Sensor	No. of Readings	Average Error	Standard Deviation
AN/TMQ-22	1,028	0.0°C	0.9°C
Sling Psychrometer	908	+2.7°C	2.6°C

Relative Humidity Error

Sensor	No. of Readings	Average Error	Standard Deviation
AN/TMQ-22	687	+0.5%	4.9%
Sling Psychrometer	566	+9.4%	7.2%

6. a. In every case for every data source, the relative humidity average error for the AN/TMQ-22 was less than ±4%.

b. In every case for every source, the dew point average error for the AN/TMQ-22 was less than or equal to ±1°C.

c. In all cases, the author's readings of the sling psychrometer for relative humidity were the only ones having an error of less than 9% R.H.

CONCLUSIONS

Accuracy Comparison

1. The AN/TMQ-22, on the average, will yield more accurate dew point and relative humidity data than will a standard sling psychrometer no matter what operator is using the set. This is apparent in every charted figure.

2. If care is taken in making the measurements with the AN/TMQ-22, it appears that relative humidity data can be accurate to within ±1 to 2% RH on the average; the dew point data can be accurate to ±1°C on the average.

3. If care is taken in making measurements with the sling psychrometer, the relative humidity error can be accurate to ±4% RH; the dew point readings can be accurate to ±1 to 2°C on the average.

4. From reviewing the data taken by all operator personnel it appears that the sling psychrometer readings will be in error by at least +9% Relative Humidity.

Reasons for Discrepancy Between the Sling Psychrometer and AN/TMQ-22

From the data taken and the accuracy tests made on the equipment, and the various psychrometer errors cited in Appendix B, it is apparent that the Meteorological Measuring Set AN/TMQ-22 is a more accurate hygrometric device than the sling psychrometer.

The reasons for the inaccuracies in the sling psychrometer readings can be ascribed to any one or any combination of the error sources cited in Table I; however, it is the author's opinion that, primarily, the errors can be ascribed to the following:

1. Too low a ventilation rate and time, a combination effect. From observation it appears that generally the operator will rotate the sling initially at the proper speed (~ 2 m/sec), but that in many cases, due to arm fatigue, the rotation will slow down and the operator will take a reading earlier than he should. This results in a higher than actual wet-bulb reading and a higher calculated relative humidity.

2. Inaccurate thermometers. Usually the operational procedure is to use either the thermometers supplied with the sling or the spare thermometers that most closely agree as the measuring device. In either case, any error in the thermometer(s) is transferred to an error in the calculated relative humidity.

3. Radiation effects. Depending upon conditions of use, the thermometers are sensitive to any source of radiant heat whether directly from the sun's rays, sun rays reflected from a surface, or from the thermometer being too close to a body which has stored heat energy. For example, between readings the sling psychrometer was placed on a table directly in the sun's rays. The thermometer and the sling, having absorbed heat, gave a higher than actual reading. As a further example, even the proximity of the observer's hand to the thermometer bulb produced a reading a few tenths of a degree higher than actual.

4. Time and space variability. In the measurements made during these tests, a single operator first manipulated either the sling or the AN/TMQ-22 and then the other. In periods of partly cloudy and gusty weather, the temperature measured varied erratically over a small range (1-2°). The very fact that the two readings were taken at different times would then make apparent the fact that a close correlation is not possible.

5. Operator Involvement. In the opinion of the author, this is the most serious and significant source of error. If this could be eliminated, many of the other error sources would become less significant. Briefly, operator involvement means that the operator shall exercise care in taking the measurements and shall have some knowledge of and appreciation for causes of error in his measurement. Even though instructions are given in the use of the sling psychrometer, the constant, repetitious nature of the measurement can dull the enthusiasm even of one who is interested in the final outcome of the testing. Some observers will, of course, take data more carefully than others. Therefore, during normal field usage, operator involvement will be present and no corrective actions will be effective.

In each of these instances, errors can enter into the calculations. Thus, it is concluded that the "tightening up" of instructions would not significantly affect the overall accuracy of the measurements over a period of time. Therefore, if the sling psychrometer is utilized in a field environment, a relative humidity error of at least +9% should, in general, be expected; however, as was shown, with a properly calibrated AN/TMQ-22, used by any operator, a relative humidity error of about 1% can be expected if the temperature correction factors are known.

Two appendices have been added to this report. Appendix A has been written to assess, for various army field operations, the effect of the above judged 9% relative humidity error in sling psychrometer readings. Appendix B has been included to provide a very brief historical note on the development of the two humidity measuring devices and also to point out what a very few other investigators have determined concerning psychrometric errors.

APPENDIX A

EFFECTS OF RELATIVE HUMIDITY ERROR

The effect of relative humidity error on Army field operations can be illustrated by the three examples which follow. The assumption made is that the sling psychrometer is utilized and yields a relative humidity that is 9% higher than the actual value. For simplicity, it will be assumed that the error occurs only in the wet-bulb thermometer, not the dry-bulb. Errors are attributable to both; however, the end result of the calculations will be approximately the same.

The examples chosen are the effect on (1) density altitude; (2) temperature-humidity index (THI); and (3) an artillery shell trajectory.

Density Altitude

The density altitude reading is important as a means of assessing proper loading with respect to the lift ability of an aircraft.

To determine the effect of RH error, four typical sites were chosen, and, based upon data from a Natick Laboratory report [2], reasonable maximum temperatures and dew points were chosen for each site. The density altitude was then calculated for this set of readings and then for a second set of readings where the dew point represented an error of +9% in relative humidity. The calculated density altitudes and errors are shown below.

Location	Station Height (Feet)	Typical Density Alt. (Feet)	9% Adjusted Density Alt. (Feet)	Error in Density Alt. (Feet)
Saigon, S. Vn.	30	2715	2779	64
Taipingsze, China	1640	4981	5054	73
Madrid, Spain	2188	6177	6289	112
Meshed, Iran	3104	6764	6850	86

Thus, the error in relative humidity results in a density altitude 50 to 100 feet higher than actual under extreme conditions.

Temperature-Humidity Index (THI)

The temperature-humidity index is presently being used as a means of measuring personal discomfort due to weather conditions. Although other indices have been devised which are probably more representative, the THI has gained the greatest acceptance.

The THI is calculated by the use of the formula $THI = (T_d + T_w)0.4 + 15$ where T_d is the dry-bulb temperature in °F, T_w the wet-bulb temperature. By definition, a THI of 70 means that no one is uncomfortable, whereas a reading of 80 indicates that everybody is uncomfortable, and higher readings indicate that work efficiency or amount will decrease proportionately.

For purposes of comparison, a basic THI of 84 was chosen since this indicates the highest value for non-degenerative human operation. A THI of 84 and an air temperature reading of 90°F will mean a relative humidity of 75%. If one now works backward and assumes this is the reading obtained which was in error by +9% RH, the actual conditon will be 62% RH with a THI of 83. It appears, then, that in this range, an error of 10% RH will cause an error in THI of 1°.

Artillery Projectile Firing

The primary meteorological factors affecting the trajectory of a ballistic device are wind, air temperature, and air density. The relative humidity, in turn, affects the value of the air density.

The same assumptions concerning the error will be made as were made for the calculation of density altitude in the previous section, namely, a 9% RH error attributable only to the wet-bulb reading.

A complete radiosonde flight data reduction was not attempted since this approach will affect the final solution very slightly. The problem steps are listed below.

1. Use Artillery Altitude Pressure Density Chart ML-574A. Assume a surface air temperature of 50°C and a pressure of 1000 mb. The effect of 100% relative humidity on virtual temperature is 8°C. Since the assumed RH error is ~ +10%, the effect will be an error in virtual temperature of +0.8°C.

2. Use FM 6-16, Tables for Artillery Meteorology. The effect on the percent of standard surface air density caused by a +0.8°C change in virtual temperature (around 40°C) at 1000 mb is -0.2%.

3. Use, for this example, the firing tables FT-8-J-3 for the 8-inch cannon. Page xxiii of the October 1960 edition gives a sample problem.

The pertinent conditions are entry range to target - 11,759 meters with a charge 7. Page 239 yields the individual correction factors in range due to, among other factors, air density. At a range of 11,800 meters, an increase of 1% in air density will decrease the range by 42.5 meters. Since the error in step 2 above is 0.2%, the range increase is then ~9 meters. In this particular problem, the total range correction was -374 m for a corrected entry range of 11,385 m. With the new error (9 m) introduced, the corrected range will be 11,394 m. Following through the problem, the fire commands will remain essentially the same. However, the range probable error for 11,000 meters (page 244) is 19 m. Since the new error introduced was an increase of 9 meters, the shell will travel 9 meters further than anticipated. This, while not affecting range probable error, is equivalent to 0.47 range probable errors.

APPENDIX B

NOTES ON PSYCHROMETER ERRORS

There are numerous methods of detecting water vapor in the air, ranging the gamut from pure psychrometric devices to dew point hygrometers to spectroscopic hygrometers and beyond.

The two basic psychrometers in use today are the sling psychrometer and the motor-ventilated psychrometer such as the Assman type. Unaspirated types are also used, but their accuracy is in doubt. According to Symons [3], the first use of a wet-bulb thermometer to determine humidity was by Hutton in 1792. In 1802, Boeckmann was making observations with a wick-covered thermometer, and finally in 1817, Gordon used a silk-covered thermometer. From these beginnings the sling psychrometer was developed that is still in current field use. A motor-ventilated psychrometer was developed by Assman just prior to 1900 and also is in field use.

The dew point hygrometer principle was first discovered by Regnault in 1845, and that instrument is considered a primary standard today.

Although tests must have been made regarding the accuracy of the sling psychrometer, none was found in the author's limited literature search; however, various articles and publications discuss probable error causes and possible errors.

The World Meteorological Organization Guide [4], in a section on the measurement of atmospheric humidity, lists several error sources, all of which were noted in this report. A statement on general accuracy concluded that if a 0.5°C error existed in the wet-bulb reading, it would mean a 2% RH error at +15°C and a 7% error at +5°C. In addition, the American psychrometer tables are based upon a ventilation rate of 1-1.5 m/sec, and variations from this would alter the psychrometric constant and thus the calculated humidity.

In Humidity and Moisture [5], a collection of papers based on a symposium held in 1963, Bindon of the Canadian Department of Transport stated that an error of 0.2°C in wet-bulb depression would cause a 3% RH error at +10°C. He also warned that pressure influences could be considerable if not used in the calculations of relative humidity.

Best [6] conducted tests to determine the most suitable instrument to measure wet- and dry-bulb temperatures aboard ship by a relatively unskilled observer. The equipment tested included two types of sling psychrometers and two types of Assman psychrometers. He concluded that a modified Assman unit was the best choice. (The dimensions of the modified unit are the ones in use today.) He also stated that the slings

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compared very well with his standard; however, he quoted only a single mean of the ratio of depression between the sling and his standard, and so no really definitive values were obtainable.

In a report from US Air Force Cambridge Research Laboratories, Lenhard and Weiss [7] examined and made an error analysis of an AN/TMQ-11 humidity-temperature measuring set. The test data were from field observations made with the AN/TMQ-11 and sling psychrometer ML-24. They concluded that the random observing error of the ML-24 was greater than the AN/TMQ-11. The readings between the sets were compared, and a statement was made to the estimated difference between the readings. Unfortunately, there was no predetermined measurement standard used and so the question of actual accuracy still remains; however, since a correlation could be made between the two devices, the offset error is, in effect, discernible but not assessable.

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