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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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5. Sling Psychrometer						

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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).

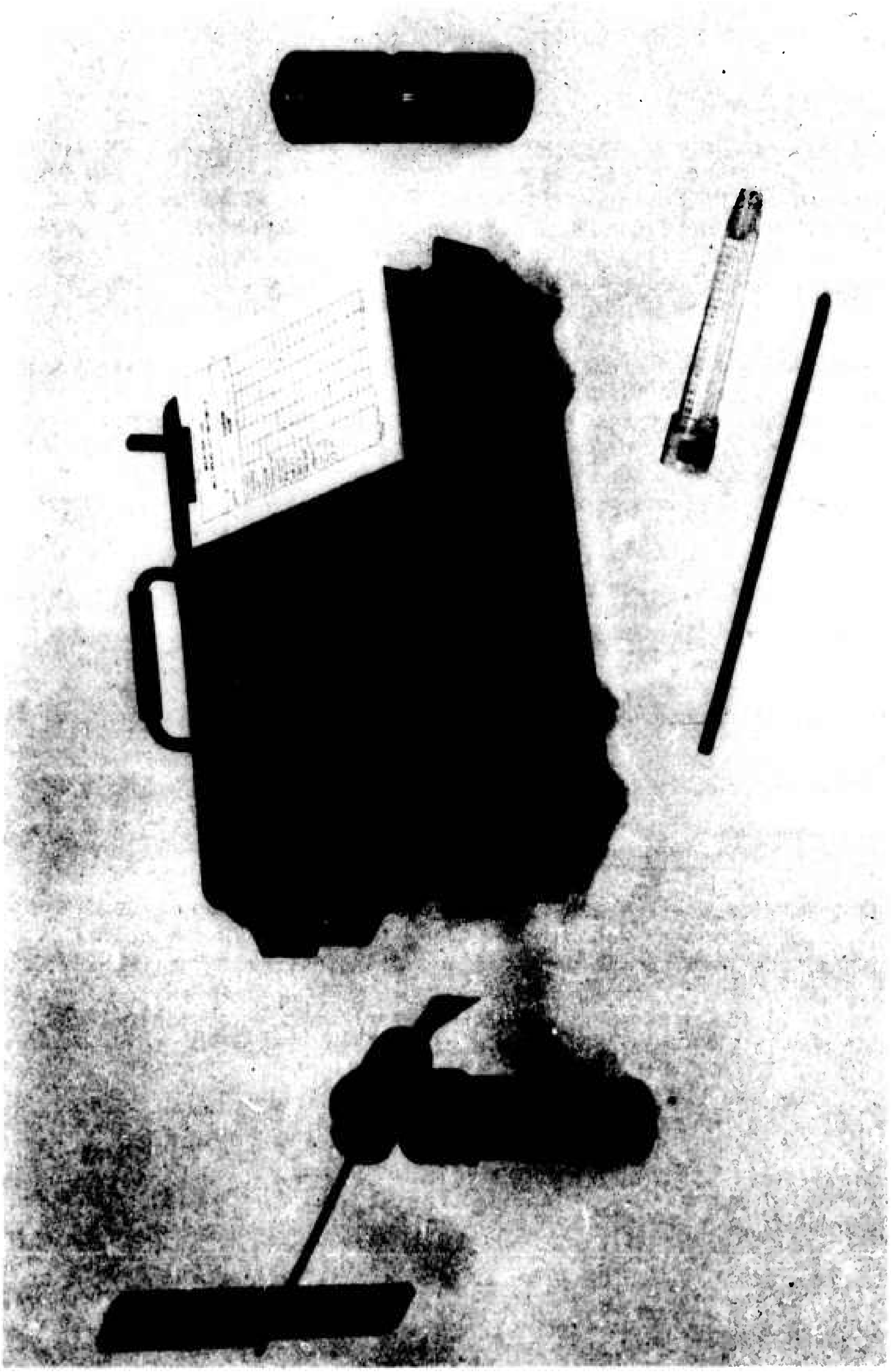


Figure 1. Meteorological Measuring Set AN/TMQ-22.

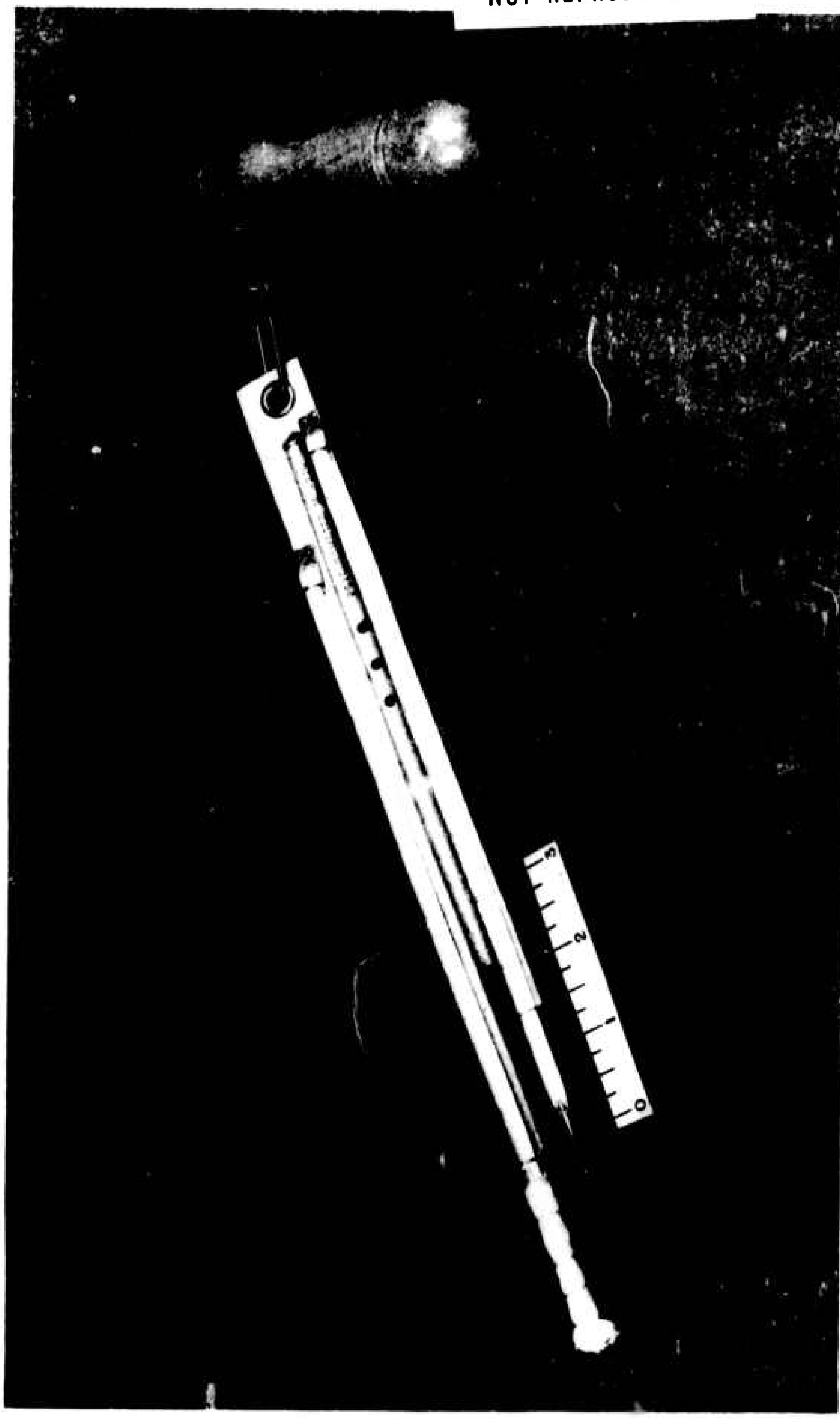


Figure 2. Sling Psychrometer ML-224.

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

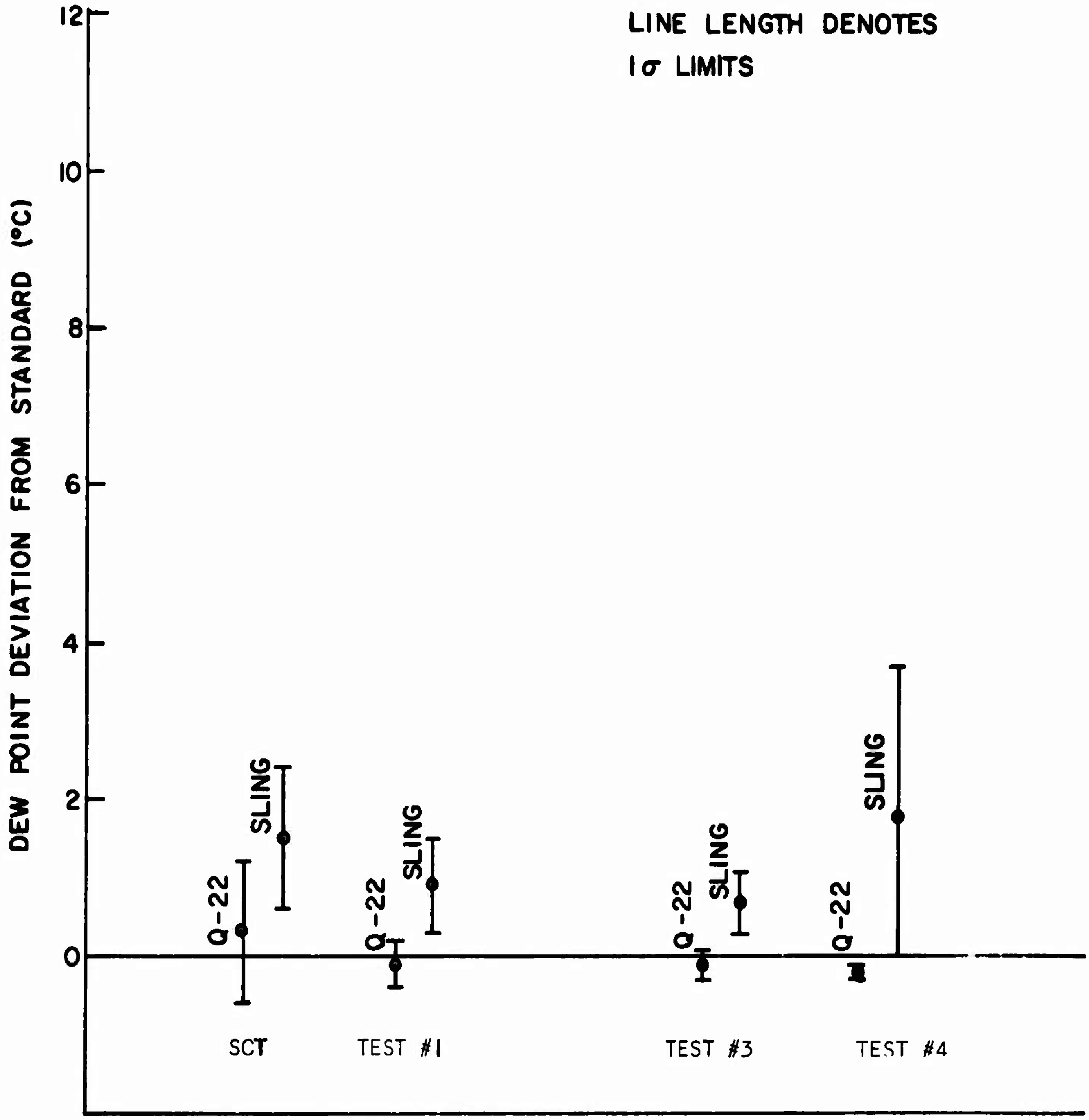


FIG. 3
DEW POINT ERROR COMPARISON
100-65% RELATIVE HUMIDITY RANGE

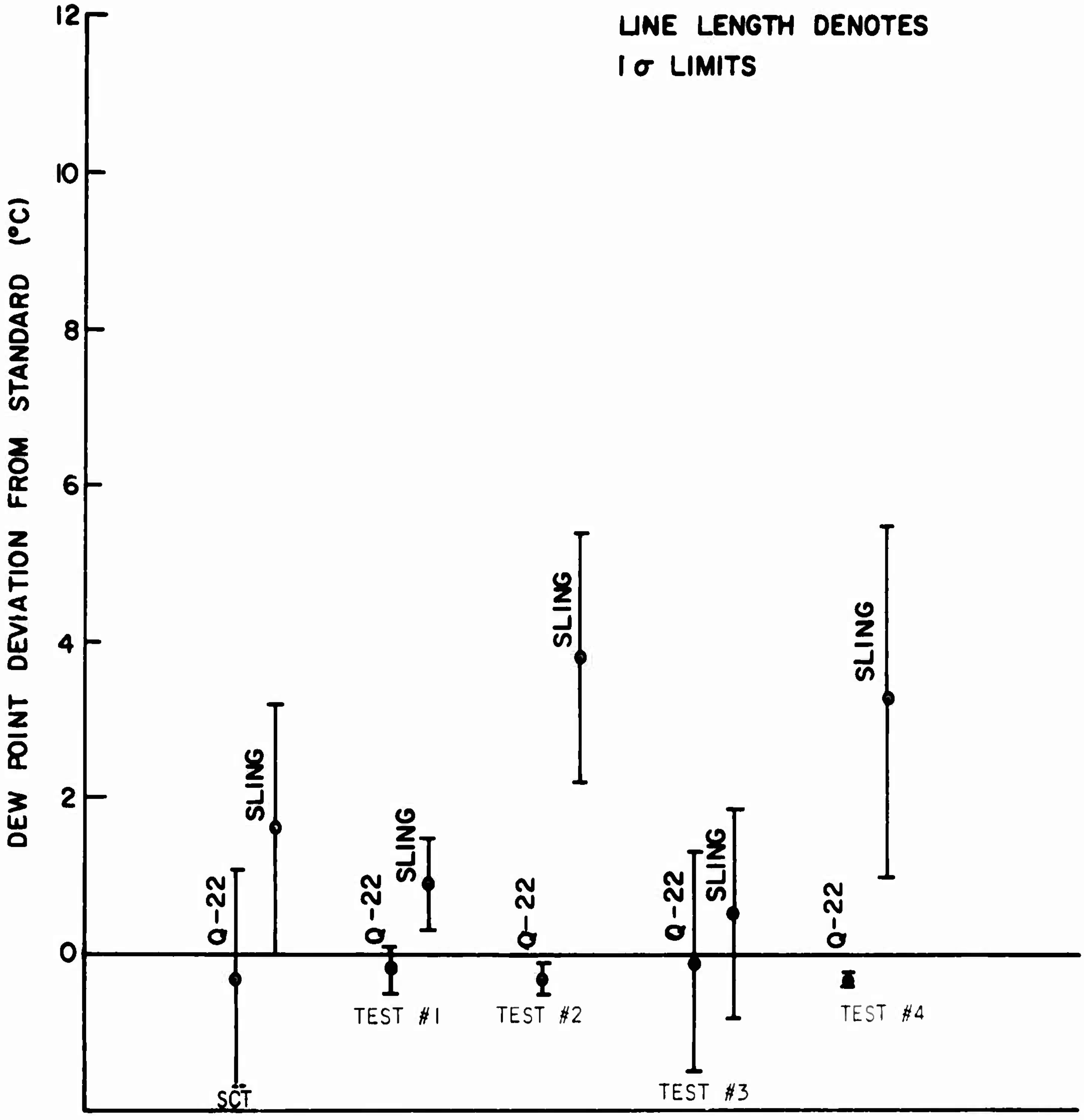


FIG. 4
DEW POINT ERROR COMPARISON
65-50% RELATIVE HUMIDITY RANGE

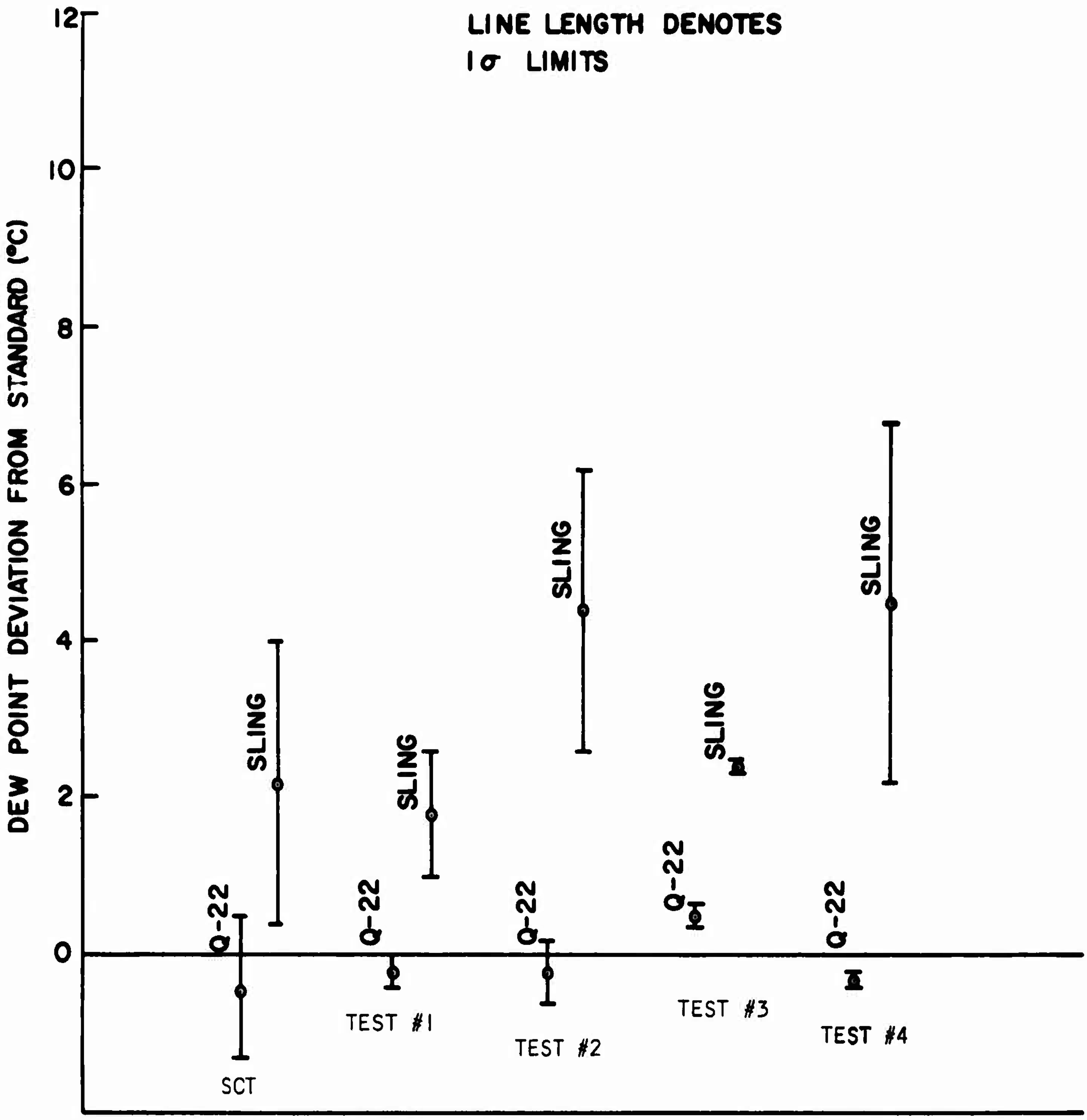


FIG. 5
DEW POINT ERROR COMPARISON
50-35% RELATIVE HUMIDITY RANGE

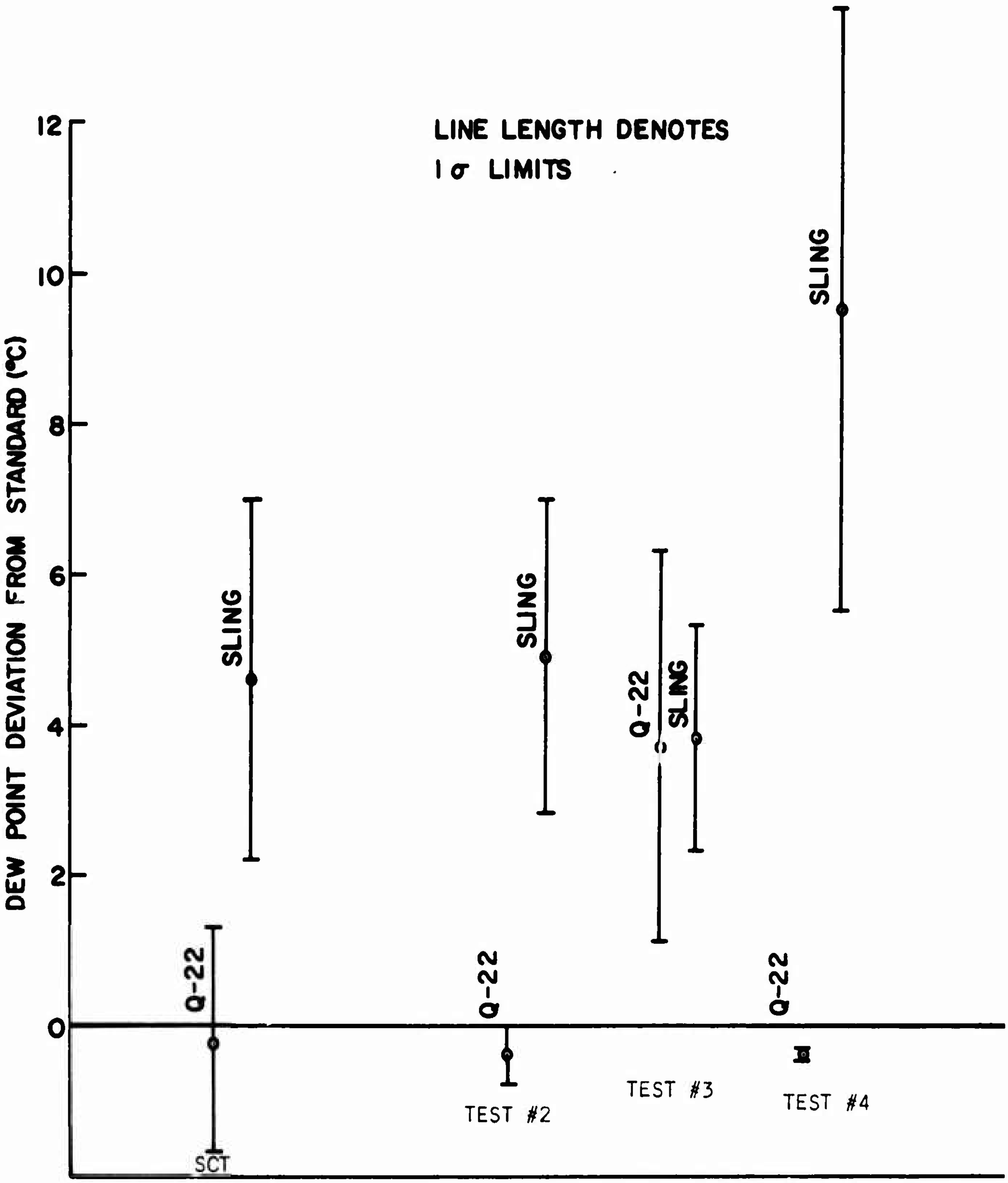
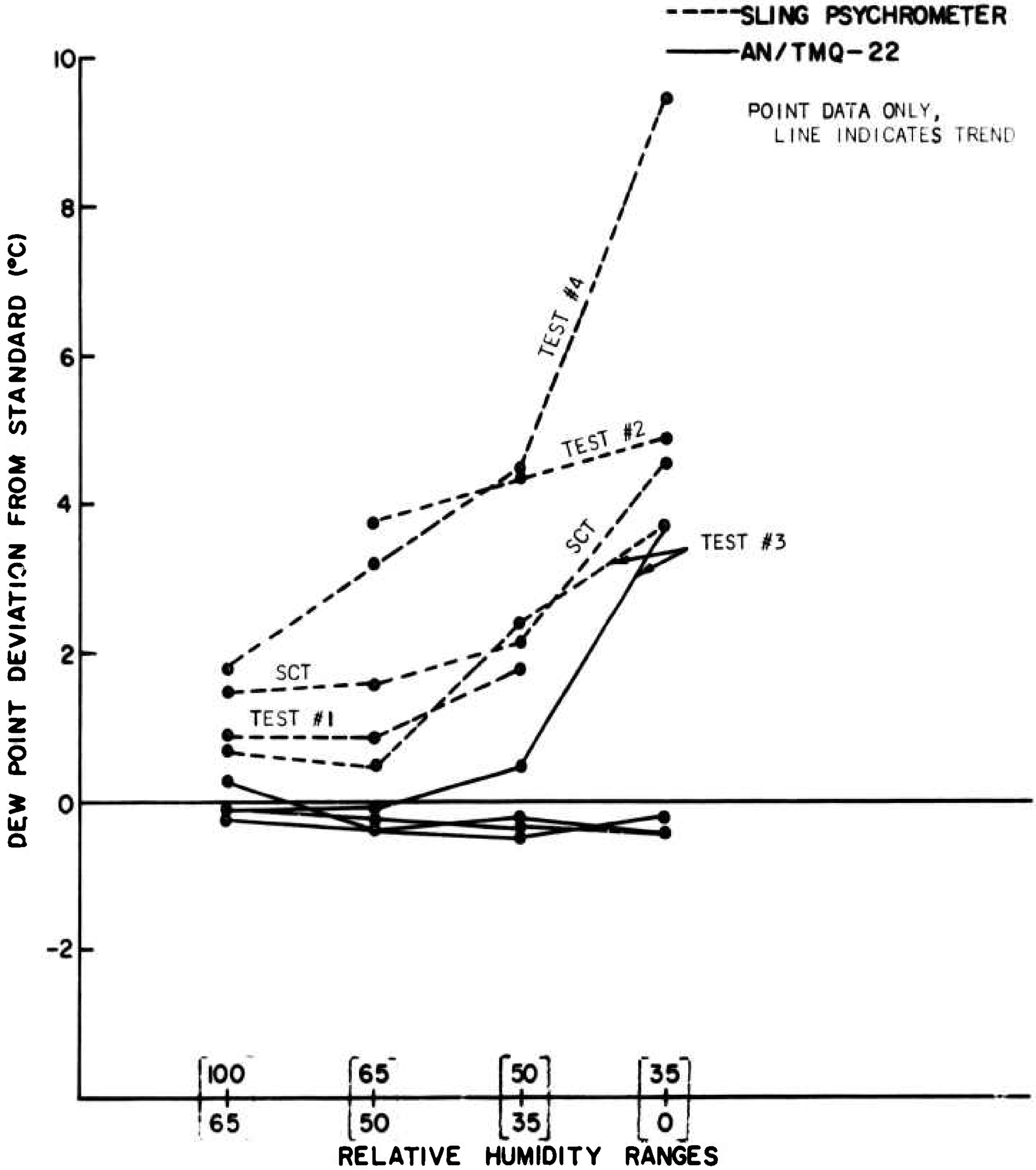
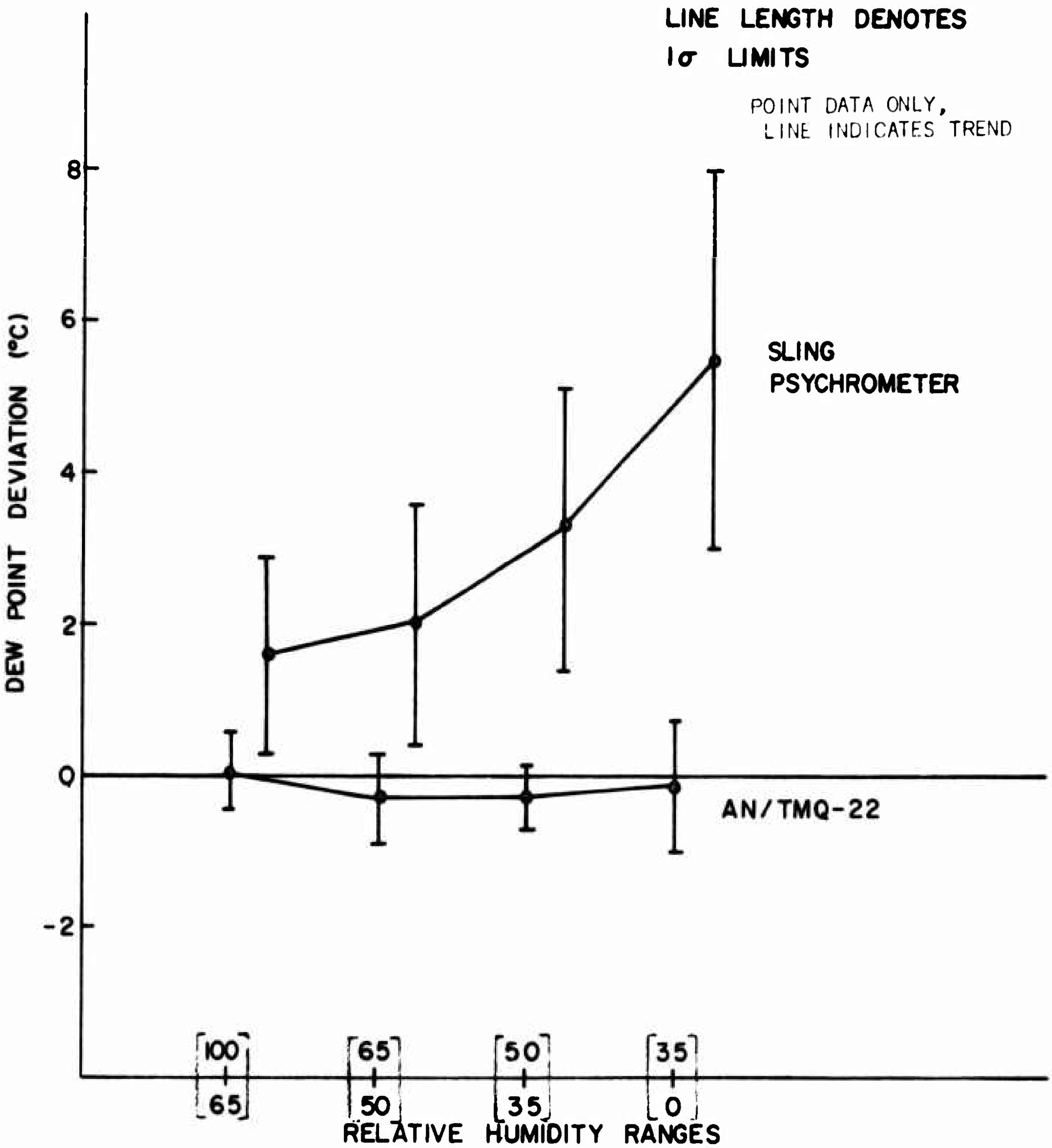


FIG. 6
DEW POINT ERROR COMPARISON
35-0% RELATIVE HUMIDITY RANGE



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.

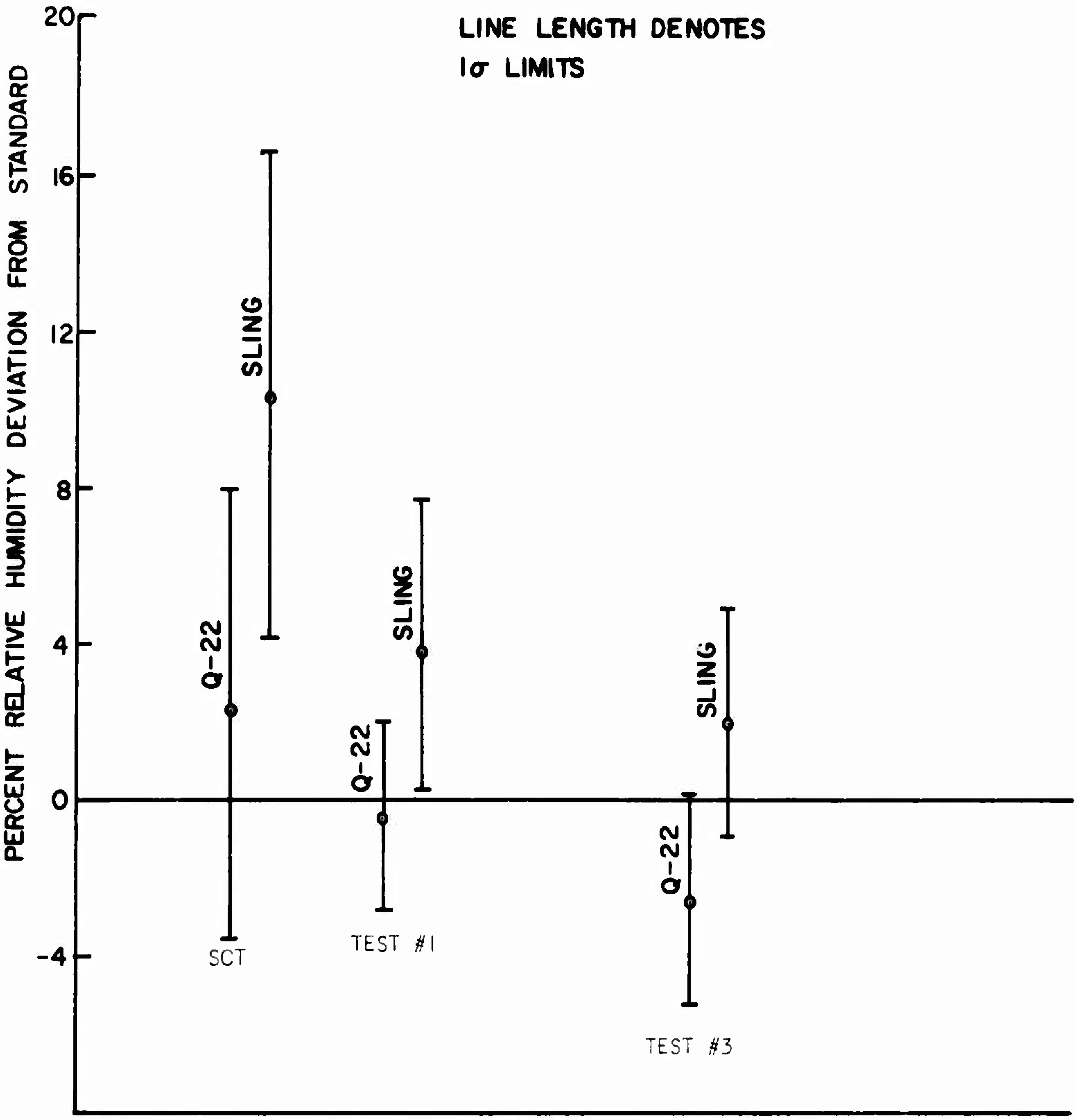


FIG. 9
RELATIVE HUMIDITY ERROR COMPARISON
100-65% RANGE

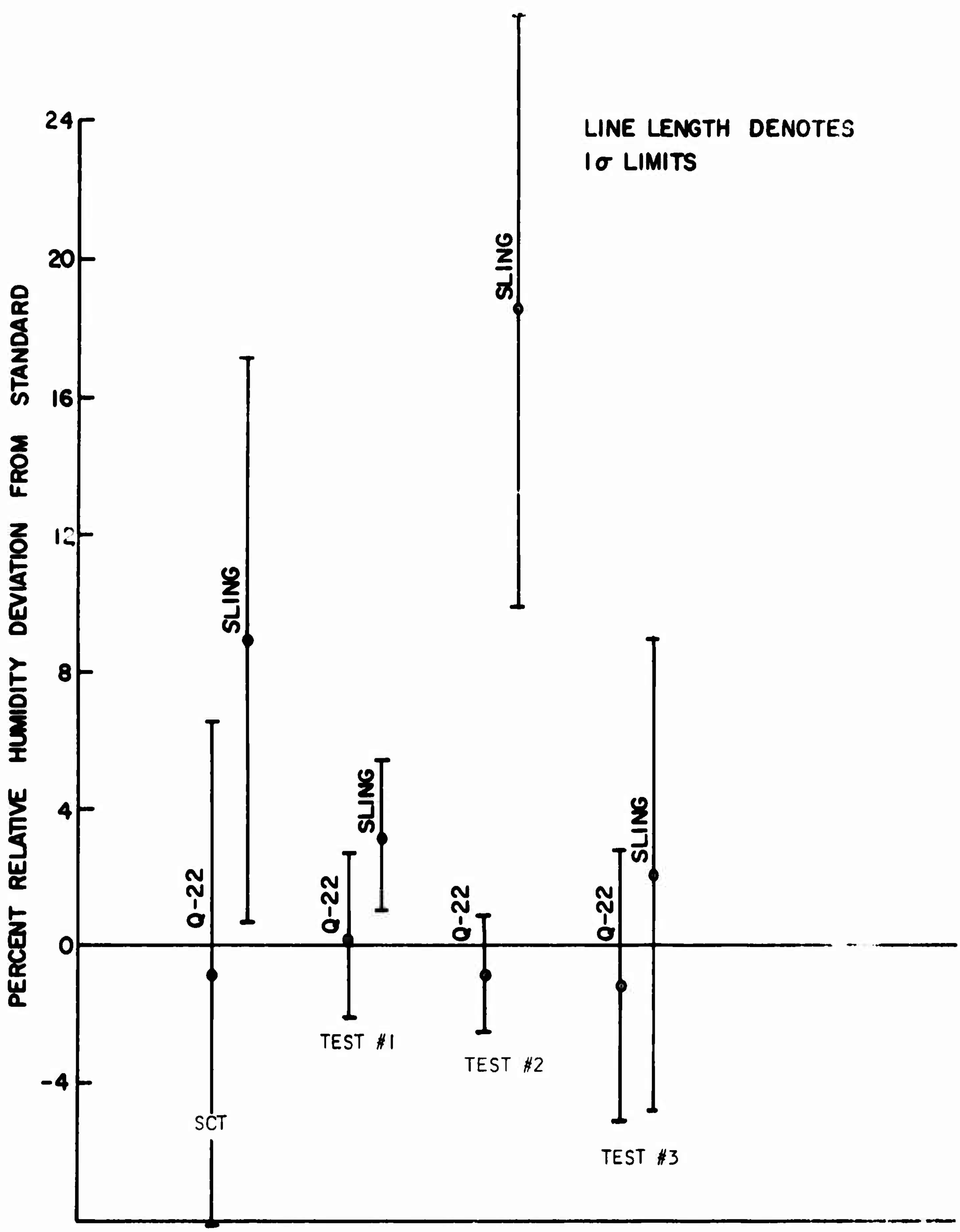


FIG. 10
RELATIVE HUMIDITY ERROR COMPARISON
65-50% RANGE

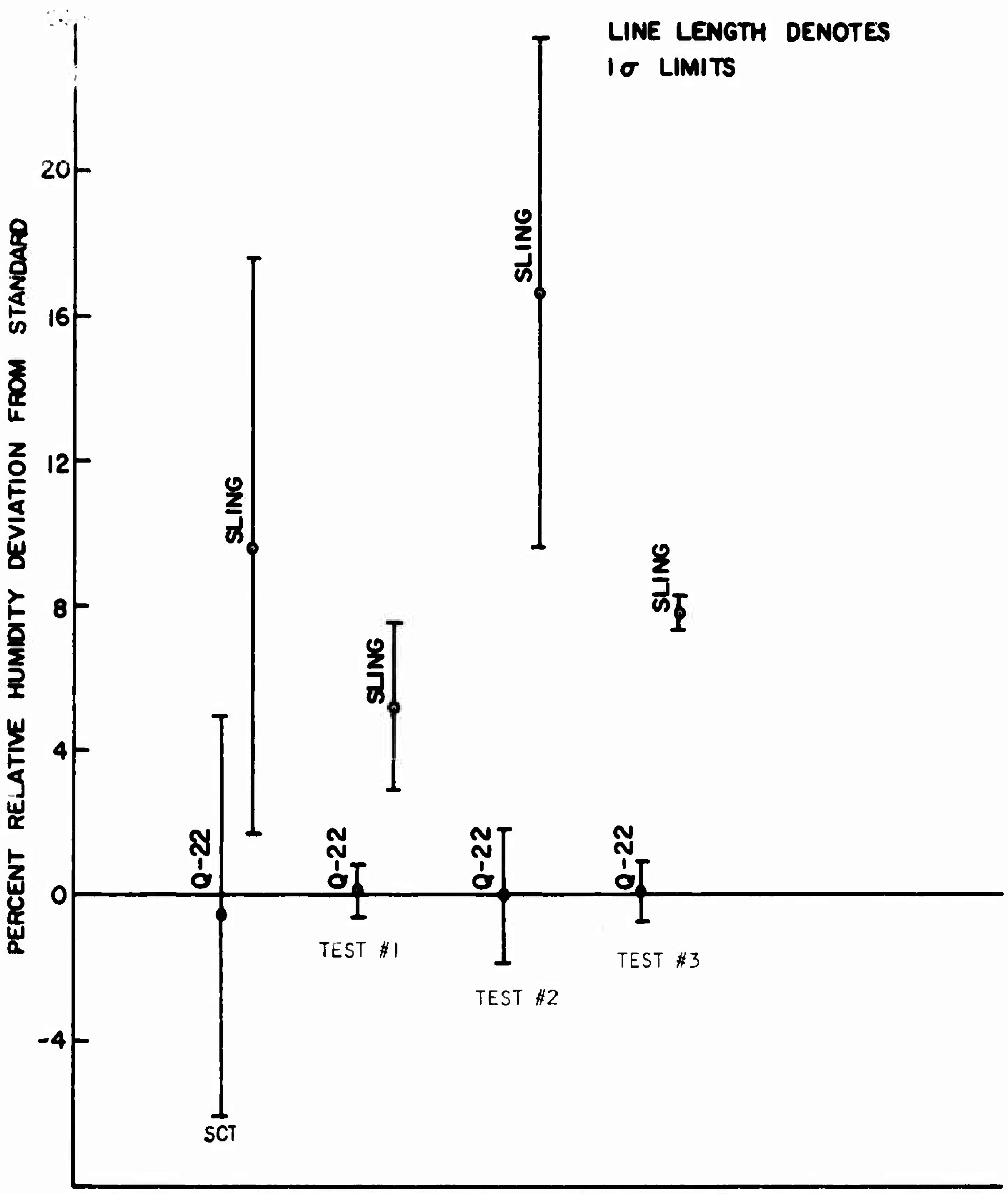


FIG. 11
RELATIVE HUMIDITY ERROR COMPARISON
50 - 35% RANGE

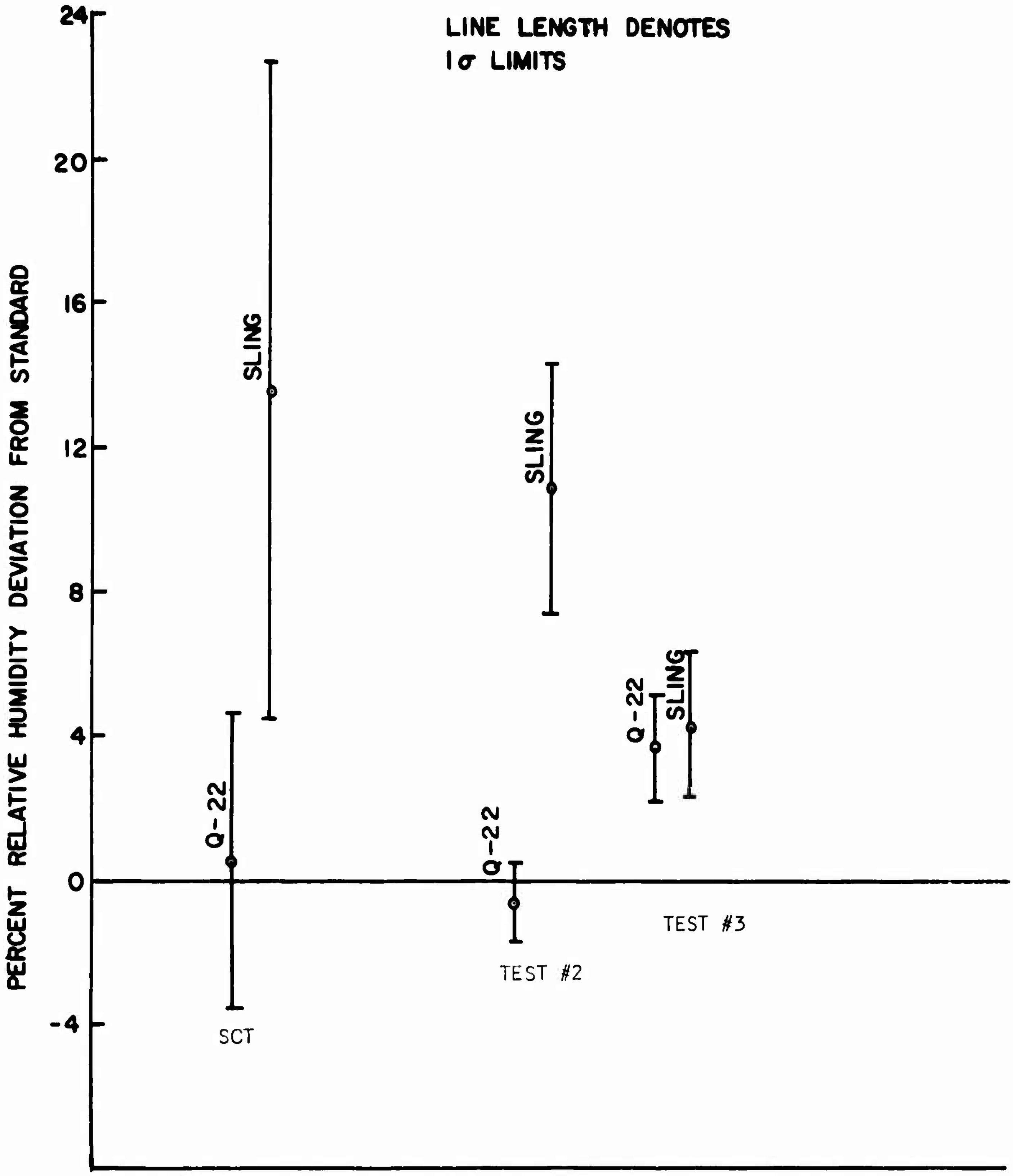
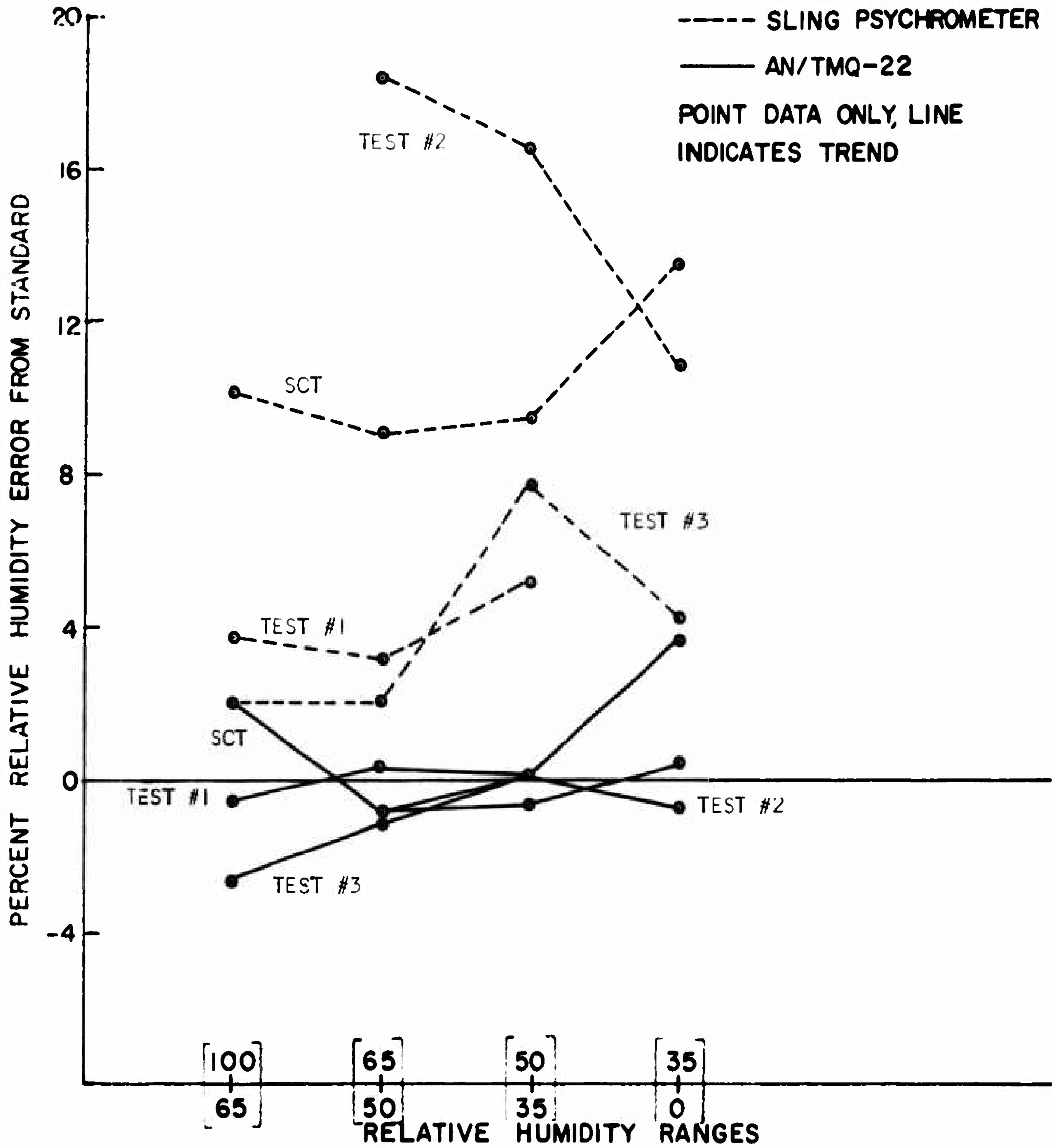
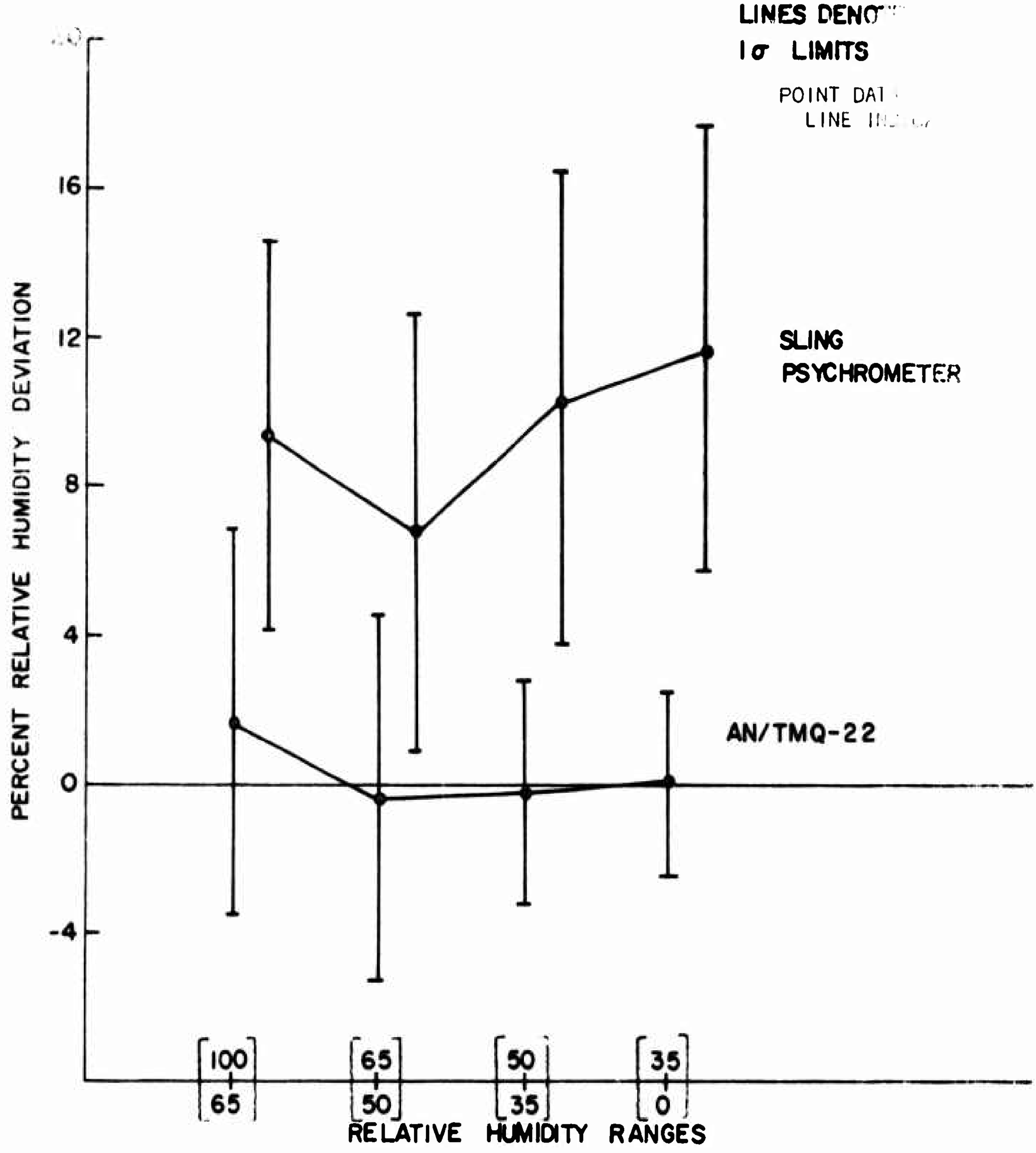


FIG. 12
RELATIVE HUMIDITY ERROR COMPARISON
35-0% RANGE



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

Measurement Error

Effect on Calculated Dew Point

	Relative Humidity 30%	Relative Humidity 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.

The [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 may 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 6-15, 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.

LITERATURE CITED

1. Spencer-Gregory and Rourke, 1957, "Hygrometry," Crosby Lockwood and Son.

2. Dodd, Arthur, 1969, "Areal and Temporal Occurrence of High Dew Points and Associated Temperatures," Technical Report 70-4-ES, US Army Natick Laboratory. AD 707 918.

3. Symons, G. J., 1882, "A Contribution to the History of Hygrometers," Q. J. Roy. Meteor. Soc., Vol. VII.

4. World Meteorological Organization, 1961, "Guide to Meteorological Instrument and Observing Practices," WMO No. 8-TP-3.

5. Bindon, H. H., 1965, "A Critical Review of Tables and Charts Used in Psychrometry," from Humidity and Moisture, edited by Arnold Wexler, Vol. I, Reinhold Publishing Company.

6. Best, A. C., 1930, "Instruments for Obtaining Dry and Wet-Bulb Temperatures," Q. J. Roy. Meteor. Soc., Vol. 56.

7. Lenhard, Maj. R. W., and B. D. Weiss, 1963, "Error Analysis of the Modified Humidity-Temperature Measuring Set AN/TMQ-11," Report AFCRL-63-845, Aerospace Instrumentation Laboratory, Office of Aerospace Research, L. G. Hanscom Field, Bedford, Mass.

ATMOSPHERIC SCIENCES RESEARCH PAPERS

1. Webb, W.L., "Development of Droplet Size Distributions in the Atmosphere," June 1954.
2. Hansen, F. V., and H. Rachele, "Wind Structure Analysis and Forecasting Methods for Rockets," June 1954.
3. Webb, W. L., "Net Electrification of Water Droplets at the Earth's Surface," *J. Meteorol.*, December 1954.
4. Mitchell, R., "The Determination of Non-Ballistic Projectile Trajectories," March 1955.
5. Webb, W. L., and A. McPike, "Sound Ranging Technique for Determining the Trajectory of Supersonic Missiles," #1, March 1955.
6. Mitchell, R., and W. L. Webb, "Electromagnetic Radiation through the Atmosphere," #1, April 1955.
7. Webb, W. L., A. McPike, and H. Thompson, "Sound Ranging Technique for Determining the Trajectory of Supersonic Missiles," #2, July 1955.
8. Barichivich, A., "Meteorological Effects on the Refractive Index and Curvature of Microwaves in the Atmosphere," August 1955.
9. Webb, W. L., A. McPike and H. Thompson, "Sound Ranging Technique for Determining the Trajectory of Supersonic Missiles," #3, September 1955.
10. Mitchell, R., "Notes on the Theory of Longitudinal Wave Motion in the Atmosphere," February 1956.
11. Webb, W. L., "Particulate Counts in Natural Clouds," *J. Meteorol.*, April 1956.
12. Webb, W. L., "Wind Effect on the Aerobee," #1, May 1956.
13. Rachele, H., and L. Anderson, "Wind Effect on the Aerobee," #2, August 1956.
14. Beyers, N., "Electromagnetic Radiation through the Atmosphere," #2, January 1957.
15. Hansen, F. V., "Wind Effect on the Aerobee," #3, January 1957.
16. Kershner, J., and H. Bear, "Wind Effect on the Aerobee," #4, January 1957.
17. Hoidale, G., "Electromagnetic Radiation through the Atmosphere," #3, February 1957.
18. Querfeld, C. W., "The Index of Refraction of the Atmosphere for 2.2 Micron Radiation," March 1957.
19. White, Lloyd, "Wind Effect on the Aerobee," #5, March 1957.
20. Kershner, J. G., "Development of a Method for Forecasting Component Ballistic Wind," August 1957.
21. Layton, Ivan, "Atmospheric Particle Size Distribution," December 1957.
22. Rachele, Henry and W. H. Hatch, "Wind Effect on the Aerobee," #6, February 1958.
23. Beyers, N. J., "Electromagnetic Radiation through the Atmosphere," #4, March 1958.
24. Prosser, Shirley J., "Electromagnetic Radiation through the Atmosphere," #5, April 1958.
25. Armendariz, M., and P. H. Taft, "Double Theodolite Ballistic Wind Computations," June 1958.
26. Jenkins, K. R. and W. L. Webb, "Rocket Wind Measurements," June 1958.
27. Jenkins, K. R., "Measurement of High Altitude Winds with Loki," July 1958.
28. Hoidale, G., "Electromagnetic Propagation through the Atmosphere," #6, February 1959.
29. McLardie, M., R. Helvey, and L. Traylor, "Low-Level Wind Profile Prediction Techniques," #1, June 1959.
30. Lamberth, Roy, "Gustiness at White Sands Missile Range," #1, May 1959.
31. Beyers, N. J., B. Hinds, and G. Hoidale, "Electromagnetic Propagation through the Atmosphere," #7, June 1959.
32. Beyers, N. J., "Radar Refraction at Low Elevation Angles (U)," Proceedings of the Army Science Conference, June 1959.
33. White, L., O. W. Thiele and P. H. Taft, "Summary of Ballistic and Meteorological Support During IGY Operations at Fort Churchill, Canada," August 1959.
34. Hainline, D. A., "Drag Cord-Aerovane Equation Analysis for Computer Application," August 1959.
35. Hoidale, G. B., "Slope-Valley Wind at WSMR," October 1959.
36. Webb, W. L., and K. R. Jenkins, "High Altitude Wind Measurements," *J. Meteorol.*, 16, 5, October 1959.

37. White, Lloyd, "Wind Effect on the Aerobee," #9, October 1959.
38. Webb, W. L., J. W. Coffman, and G. Q. Clark, "A High Altitude Acoustic Sensing System," December 1959.
39. Webb, W. L., and K. R. Jenkins, "Application of Meteorological Rocket Systems," J. Geophys. Res., 64, 11, November 1959.
40. Duncan, Louis, "Wind Effect on the Aerobee," #10, February 1960.
41. Helvey, R. A., "Low-Level Wind Profile Prediction Techniques," #2, February 1960.
42. Webb, W. L., and K. R. Jenkins, "Rocket Sounding of High-Altitude Parameters," *Proc. GM Rel. Symp.*, Dept. of Defense, February 1960.
43. Armendariz, M., and H. H. Monahan, "A Comparison Between the Double Theodolite and Single-Theodolite Wind Measuring Systems," April 1960.
44. Jenkins, K. R., and P. H. Taft, "Weather Elements in the Tularosa Basin," July 1960.
45. Beyers, N. J., "Preliminary Radar Performance Data on Passive Rocket-Borne Wind Sensors," IRE TRANS, MIL ELECT, MIL-4, 2-3, April-July 1960.
46. Webb, W. L., and K. R. Jenkins, "Speed of Sound in the Stratosphere," June 1960.
47. Webb, W. L., K. R. Jenkins, and G. Q. Clark, "Rocket Sounding of High Atmosphere Meteorological Parameters," *IRE Trans. Mil. Elect.*, MIL-4, 2-3, April-July 1960.
48. Helvey, R. A., "Low-Level Wind Profile Prediction Techniques," #3, September 1960.
49. Beyers, N. J., and O. W. Thiele, "Meteorological Wind Sensors," August 1960.
50. Armijo, Larry, "Determination of Trajectories Using Range Data from Three Non-colinear Radar Stations," September 1960.
51. Carnes, Patsy Sue, "Temperature Variations in the First 200 Feet of the Atmosphere in an Arid Region," July 1961.
52. Springer, H. S., and R. O. Olsen, "Launch Noise Distribution of Nike-Zeus Missiles," July 1961.
53. Thiele, O. W., "Density and Pressure Profiles Derived from Meteorological Rocket Measurements," September 1961.
54. Diamond, M. and A. B. Gray, "Accuracy of Missile Sound Ranging," November 1961.
55. Lamberth, R. L. and D. R. Veith, "Variability of Surface Wind in Short Distances," #1, October 1961.
56. Swanson, R. N., "Low-Level Wind Measurements for Ballistic Missile Application," January 1962.
57. Lamberth, R. L. and J. H. Grace, "Gustiness at White Sands Missile Range," #2, January 1962.
58. Swanson, R. N. and M. M. Hoidale, "Low-Level Wind Profile Prediction Techniques," #4, January 1962.
59. Rachele, Henry, "Surface Wind Model for Unguided Rockets Using Spectrum and Cross Spectrum Techniques," January 1962.
60. Rachele, Henry, "Sound Propagation through a Windy Atmosphere," #2, February 1962.
61. Webb, W. L., and K. R. Jenkins, "Sonic Structure of the Mesosphere," *J. Acous. Soc. Amer.*, 34, 2, February 1962.
62. Tourin, M. H. and M. M. Hoidale, "Low-Level Turbulence Characteristics at White Sands Missile Range," April 1962.
63. Miers, Bruce T., "Mesospheric Wind Reversal over White Sands Missile Range," March 1962.
64. Fisher, E., R. Lee and H. Rachele, "Meteorological Effects on an Acoustic Wave within a Sound Ranging Array," May 1962.
65. Walter, E. L., "Six Variable Ballistic Model for a Rocket," June 1962.
66. Webb, W. L., "Detailed Acoustic Structure Above the Tropopause," *J. Applied Meteorol.*, 1, 2, June 1962.
67. Jenkins, K. R., "Empirical Comparisons of Meteorological Rocket Wind Sensors," *J. Appl. Meteor.*, June 1962.
68. Lamberth, Roy, "Wind Variability Estimates as a Function of Sampling Interval," July 1962.
69. Rachele, Henry, "Surface Wind Sampling Periods for Unguided Rocket Impact Prediction," July 1962.
70. Traylor, Larry, "Coriolis Effects on the Aerobee-Hi Sounding Rocket," August 1962.
71. McCoy, J., and G. Q. Clark, "Meteorological Rocket Thermometry," August 1962.
72. Rachele, Henry, "Real-Time Prelaunch Impact Prediction System," August 1962.

73. Beyers, N. J., O. W. Thiele, and N. K. Wagner, "Performance Characteristics of Meteorlogical Rocket Wind and Temperature Sensors," October 1962.
74. Coffman, J., and R. Price, "Some Errors Associated with Acoustical Wind Measurements through a Layer," October 1962.
75. Armendariz, M., E. Fisher, and J. Serna, "Wind Shear in the Jet Stream at WSMR," November 1962.
76. Armendariz, M., F. Hansen, and S. Carnes, "Wind Variability and its Effect on Rocket Impact Prediction," January 1963.
77. Querfeld, C., and Wayne Yunker, "Pure Rotational Spectrum of Water Vapor, I: Table of Line Parameters," February 1963.
78. Webb, W. L., "Acoustic Component of Turbulence," *J. Applied Meteorol.*, 2, 2, April 1963.
79. Beyers, N. and L. Engberg, "Seasonal Variability in the Upper Atmosphere," May 1963.
80. Williamson, L. E., "Atmospheric Acoustic Structure of the Sub-polar Fall," May 1963.
81. Lamberth, Roy and D. Veith, "Upper Wind Correlations in Southwestern United States," June 1963.
82. Sandlin, E., "An analysis of Wind Shear Differences as Measured by AN/FPS-16 Radar and AN/GMD-1B Rawinsonde," August 1963.
83. Diamond, M. and R. P. Lee, "Statistical Data on Atmospheric Design Properties Above 30 km," August 1963.
84. Thiele, O. W., "Mesospheric Density Variability Based on Recent Meteorological Rocket Measurements," *J. Applied Meteorol.*, 2, 5, October 1963.
85. Diamond, M., and O. Essenwanger, "Statistical Data on Atmospheric Design Properties to 30 km," *Astro. Aero. Engr.*, December 1963.
86. Hansen, F. V., "Turbulence Characteristics of the First 62 Meters of the Atmosphere," December 1963.
87. Morris, J. E., and B. T. Miers, "Circulation Disturbances Between 25 and 70 kilometers Associated with the Sudden Warming of 1963," *J. of Geophys. Res.*, January 1964.
88. Thiele, O. W., "Some Observed Short Term and Diurnal Variations of Stratospheric Density Above 30 km," January 1964.
89. Sandlin, R. E., Jr. and E. Armijo, "An Analysis of AN/FPS-16 Radar and AN/GMD-1B Rawinsonde Data Differences," January 1964.
90. Miers, B. T., and N. J. Beyers, "Rocketsonde Wind and Temperature Measurements Between 30 and 70 km for Selected Stations," *J. Applied Meteorol.*, February 1964.
91. Webb, W. L., "The Dynamic Stratosphere," *Astronautics and Aerospace Engineering*, March 1964.
92. Low, R. D. H., "Acoustic Measurements of Wind through a Layer," March 1964.
93. Diamond. M., "Cross Wind Effect on Sound Propagation," *J. Applied Meteorol.*, April 1964.
94. Lee, R. P., "Acoustic Ray Tracing," April 1964.
95. Reynolds, R. D., "Investigation of the Effect of Lapse Rate on Balloon Ascent Rate," May 1964.
96. Webb, W. L., "Scale of Stratospheric Detail Structure," *Space Research V*, May 1964.
97. Barber, T. L., "Proposed X-Ray-Infrared Method for Identification of Atmospheric Mineral Dust," June 1964.
98. Thiele, O. W., "Ballistic Procedures for Unguided Rocket Studies of Nuclear Environments (U)," Proceedings of the Army Science Conference, June 1964.
99. Horn, J. D., and E. J. Trawle, "Orographic Effects on Wind Variability," July 1964.
100. Hoidale, G., C. Querfeld, T. Hall, and R. Mireles, "Spectral Transmissivity of the Earth's Atmosphere in the 250 to 500 Wave Number Interval," #1, September 1964.
101. Duncan, L. D., R. Ensey, and B. Engebos, "Athena Launch Angle Determination," September 1964.
102. Thiele, O. W., "Feasibility Experiment for Measuring Atmospheric Density Through the Altitude Range of 60 to 100 KM Over White Sands Missile Range," October 1964.
103. Duncan, L. D., and R. Ensey, "Six-Degree-of-Freedom Digital Simulation Model for Unguided, Fin-Stabilized Rockets," November 1964.

104. Hoidale, G., C. Querfeld, T. Hall, and R. Mireles, "Spectral Transmissivity of the Earth's Atmosphere in the 250 to 500 Wave Number Interval," #2, November 1964.

105. Webb, W. L., "Stratospheric Solar Response," *J. Atmos. Sci.*, November 1964.

106. McCoy, J. and G. Clark, "Rocketsonde Measurement of Stratospheric Temperature," December 1964.

107. Farone, W. A., "Electromagnetic Scattering from Radially Inhomogeneous Spheres as Applied to the Problem of Clear Atmosphere Radar Echoes," December 1964.

108. Farone, W. A., "The Effect of the Solid Angle of Illumination or Observation on the Color Spectra of 'White Light' Scattered by Cylinders," January 1965.

109. Williamson, L. E., "Seasonal and Regional Characteristics of Acoustic Atmospheres," *J. Geophys. Res.*, January 1965.

110. Armendariz, M., "Ballistic Wind Variability at Green River, Utah," January 1965.

111. Low, R. D. H., "Sound Speed Variability Due to Atmospheric Composition," January 1965.

112. Querfeld, C. W., 'Mie Atmospheric Optics," *J. Opt. Soc. Amer.*, January 1965.

113. Coffman, J., "A Measurement of the Effect of Atmospheric Turbulence on the Coherent Properties of a Sound Wave," January 1965.

114. Rachele, H., and D. Veith, "Surface Wind Sampling for Unguided Rocket Impact Prediction," January 1965.

115. Ballard, H., and M. Izquierdo, "Reduction of Microphone Wind Noise by the Generation of a Proper Turbulent Flow," February 1965.

116. Mireles, R., "An Algorithm for Computing Half Widths of Overlapping Lines on Experimental Spectra," February 1965.

117. Richart, H., "Inaccuracies of the Single-Theodolite Wind Measuring System in Ballistic Application," February 1965.

118. D'Arcy, M., "Theoretical and Practical Study of Aerobee-150 Ballistics," March 1965.

119. McCoy, J., "Improved Method for the Reduction of Rocketsonde Temperature Data," March 1965.

120. Mireles, R., "Uniqueness Theorem in Inverse Electromagnetic Cylindrical Scattering," April 1965.

121. Coffman, J., "The Focusing of Sound Propagating Vertically in a Horizontally Stratified Medium," April 1965.

122. Farone, W. A., and C. Querfeld, "Electromagnetic Scattering from an Infinite Circular Cylinder at Oblique Incidence," April 1965.

123. Rachele, H., "Sound Propagation through a Windy Atmosphere," April 1965.

124. Miers, B., "Upper Stratospheric Circulation over Ascension Island," April 1965.

125. Rider, L., and M. Armendariz, " A Comparison of Pibal and Tower Wind Measurements," April 1965.

126. Hoidale, G. B., "Meteorological Conditions Allowing a Rare Observation of 24 Micron Solar Radiation Near Sea Level," *Meteorol. Magazine*, May 1965.

127. Beyers, N. J., and B. T. Miers, "Diurnal Temperature Change in the Atmosphere Between 30 and 60 km over White Sands Missile Range," *J. Atmos. Sci.*, May 1965.

128. Querfeld, C., and W. A. Farone, "Tables of the Mie Forward Lobe," May 1965.

129. Farone, W. A., Generalization of Rayleigh-Gans Scattering from Radially Inhomogeneous Spheres," *J. Opt. Soc. Amer.*, June 1965.

130. Diamond, M., "Note on Mesospheric Winds Above White Sands Missile Range," *J. Applied Meteorol.*, June 1965.

131. Clark, G. Q., and J. G. McCoy, "Measurement of Stratospheric Temperature," *J. Applied Meteorol.*, June 1965.

132. Hall, T., G. Hoidale, R. Mireles, and C. Querfeld, "Spectral Transmissivity of the Earth's Atmosphere in the 250 to 500 Wave Number Interval," #3, July 1965.

133. McCoy, J., and C. Tate, "The Delta-T Meteorological Rocket Payload," June 1964.

134. Horn, J. D., "Obstacle Influence in a Wind Tunnel," July 1965.

135. McCoy, J., "An AC Probe for the Measurement of Electron Density and Collision Frequency in the Lower Ionosphere," July 1965.

136. Miers, B. T., M. D. Kays, O. W. Thiele and E. M. Newby, "Investigation of Short Term Variations of Several Atmospheric Parameters Above 30 KM," July 1965.

137. Serna, J., "An Acoustic Ray Tracing Method for Digital Computation," September 1965.
138. Webb, W. L., "Morphology of Noctilucent Clouds," *J. Geophys. Res.*, 70, 18, 4463-4475, September 1965.
139. Kays, M., and R. A. Craig, "On the Order of Magnitude of Large-Scale Vertical Motions in the Upper Stratosphere," *J. Geophys. Res.*, 70, 18, 4453-4462, September 1965.
140. Rider, L., "Low-Level Jet at White Sands Missile Range," September 1965.
141. Lamberth, R. L., R. Reynolds, and Morton Wurtele, "The Mountain Lee Wave at White Sands Missile Range," *Bull. Amer. Meteorol. Soc.*, 46, 10, October 1965.
142. Reynolds, R. and R. L. Lamberth, "Ambient Temperature Measurements from Radiosondes Flown on Constant-Level Balloons," October 1965.
143. McCluney, E., "Theoretical Trajectory Performance of the Five-Inch Gun Probe System," October 1965.
144. Pena, R. and M. Diamond, "Atmospheric Sound Propagation near the Earth's Surface," October 1965.
145. Mason, J. B., "A Study of the Feasibility of Using Radar Chaff For Stratospheric Temperature Measurements," November 1965.
146. Diamond, M., and R. P. Lee, "Long-Range Atmospheric Sound Propagation," *J. Geophys. Res.*, 70, 22, November 1965.
147. Lamberth, R. L., "On the Measurement of Dust Devil Parameters," November 1965.
148. Hansen, F. V., and P. S. Hansen, "Formation of an Internal Boundary over Heterogeneous Terrain," November 1965.
149. Webb, W. L., "Mechanics of Stratospheric Seasonal Reversals," November 1965.
150. U. S. Army Electronics R & D Activity, "U. S. Army Participation in the Meteorological Rocket Network," January 1966.
151. Rider, L. J., and M. Armendariz, "Low-Level Jet Winds at Green River, Utah," February 1966.
152. Webb, W. L., "Diurnal Variations in the Stratospheric Circulation," February 1966.
153. Beyers, N. J., B. T. Miers, and R. J. Reed, "Diurnal Tidal Motions near the Stratopause During 48 Hours at WSMR," February 1966.
154. Webb, W. L., "The Stratospheric Tidal Jet," February 1966.
155. Hall, J. T., "Focal Properties of a Plane Grating in a Convergent Beam," February 1966.
156. Duncan, L. D., and Henry Rachele, "Real-Time Meteorological System for Firing of Unguided Rockets," February 1966.
157. Kays, M. D., "A Note on the Comparison of Rocket and Estimated Geostrophic Winds at the 10-mb Level," *J. Appl. Meteor.*, February 1966.
158. Rider, L., and M. Armendariz, " A Comparison of Pibal and Tower Wind Measurements," *J. Appl. Meteor.*, 5, February 1966.
159. Duncan, L. D., "Coordinate Transformations in Trajectory Simulations," February 1966.
160. Williamson, L. E., "Gun-Launched Vertical Probes at White Sands Missile Range," February 1966.
161. Randhawa, J. S., Ozone Measurements with Rocket-Borne Ozonesondes," March 1966.
162. Armendariz, Manuel, and Laurence J. Rider, "Wind Shear for Small Thickness Layers," March 1966.
163. Low, R. D. H., "Continuous Determination of the Average Sound Velocity over an Arbitrary Path," March 1966.
164. Hansen, Frank V., "Richardson Number Tables for the Surface Boundary Layer," March 1966.
165. Cochran, V. C., E. M. D'Arcy, and Florencio Ramirez, "Digital Computer Program for Five-Degree-of-Freedom Trajectory," March 1966.
166. Thiele, O. W., and N. J. Beyers, "Comparison of Rocketsonde and Radiosonde Temperatures and a Verification of Computed Rocketsonde Pressure and Density," April 1966.
167. Thiele, O. W., "Observed Diurnal Oscillations of Pressure and Density in the Upper Stratosphere and Lower Mesosphere," April 1966.
168. Kays, M. D., and R. A. Craig, "On the Order of Magnitude of Large-Scale Vertical Motions in the Upper Stratosphere," *J. Geophy. Res.*, April 1966.
169. Hansen, F. V., "The Richardson Number in the Planetary Boundary Layer," May 1966.

170. Ballard, H. N., "The Measurement of Temperature in the Stratosphere and Mesosphere," June 1966.
171. Hansen, Frank V., "The Ratio of the Exchange Coefficients for Heat and Momentum in a Homogeneous, Thermally Stratified Atmosphere," June 1966.
172. Hansen, Frank V., "Comparison of Nine Profile Models for the Diabatic Boundary Layer," June 1966.
173. Rachele, Henry, "A Sound-Ranging Technique for Locating Supersonic Missiles," May 1966.
174. Farone, W. A., and C. W. Querfeld, "Electromagnetic Scattering from Inhomogeneous Infinite Cylinders at Oblique Incidence," *J. Opt. Soc. Amer.* 56, 4, 476-480, April 1966.
175. Mireles, Ramon, "Determination of Parameters in Absorption Spectra by Numerical Minimization Techniques," *J. Opt. Soc. Amer.* 56, 5, 644-647, May 1966.
176. Reynolds, R., and R. L. Lamberth, "Ambient Temperature Measurements from Radiosondes Flown on Constant-Level Balloons," *J. Appl. Meteorol.*, 5, 3, 304-307, June 1966.
177. Hall, James T., "Focal Properties of a Plane Grating in a Convergent Beam," *Appl. Opt.*, 5, 1051, June 1966
178. Rider, Laurence J., "Low-Level Jet at White Sands Missile Range," *J. Appl. Meteorol.*, 5, 3, 283-287, June 1966.
179. McCluney, Eugene, "Projectile Dispersion as Caused by Barrel Displacement in the 5-Inch Gun Probe System," July 1966.
180. Armendariz, Manuel, and Laurence J. Rider, "Wind Shear Calculations for Small Shear Layers," June 1966.
181. Lamberth, Roy L., and Manuel Armendariz, "Upper Wind Correlations in the Central Rocky Mountains," June 1966.
182. Hansen, Frank V., and Virgil D. Lang, "The Wind Regime in the First 62 Meters of the Atmosphere," June 1966.
183. Randhawa, Jagir S., "Rocket-Borne Ozonesonde," July 1966.
184. Rachele, Henry, and L. D. Duncan, "The Desirability of Using a Fast Sampling Rate for Computing Wind Velocity from Pilot-Balloon Data," July 1966.
185. Hinds, B. D., and R. G. Pappas, "A Comparison of Three Methods for the Correction of Radar Elevation Angle Refraction Errors," August 1966.
186. Riedmuller, G. F., and T. L. Barber, "A Mineral Transition in Atmospheric Dust Transport," August 1966.
187. Hall, J. T., C. W. Querfeld, and G. B. Hoidale, "Spectral Transmissivity of the Earth's Atmosphere in the 250 to 500 Wave Number Interval," Part IV (Final), July 1966.
188. Duncan, L. D. and B. F. Engebos, "Techniques for Computing Launcher Settings for Unguided Rockets," September 1966.
189. Duncan, L. D., "Basic Considerations in the Development of an Unguided Rocket Trajectory Simulation Model," September 1966.
190. Miller, Walter B., "Consideration of Some Problems in Curve Fitting," September 1966.
191. Cermak, J. E., and J. D. Horn, "The Tower Shadow Effect," August 1966.
192. Webb, W. L., "Stratospheric Circulation Response to a Solar Eclipse," October 1966.
193. Kennedy, Bruce, "Muzzle Velocity Measurement," October 1966.
194. Traylor, Larry E., "A Refinement Technique for Unguided Rocket Drag Coefficients," October 1966
195. Nusbaum, Henry, "A Reagent for the Simultaneous Microscope Determination of Quartz and Halides," October 1966.
196. Kays, Marvin and R. O. Olsen, "Improved Rocketsonde Parachute-derived Wind Profiles," October 1966.
197. Engebos, Bernard F. and Duncan, Louis D., "A Nomogram for Field Determination of Launcher Angles for Unguided Rockets," October 1966.
198. Webb, W. L., "Midlatitude Clouds in the Upper Atmosphere," November 1966.
199. Hansen, Frank V., "The Lateral Intensity of Turbulence as a Function of Stability," November 1966.
200. Rider, L. J. and M. Armendariz, "Differences of Tower and Pibal Wind Profiles," November 1966.
201. Lee, Robert P., "A Comparison of Eight Mathematical Models for Atmospheric Acoustical Ray Tracing," November 1966.
202. Low, R. D. H., et al., "Acoustical and Meteorological Data Report SOTRAN I and II," November 1966.

203. Hunt, J. A. and J. D. Horn, "Drag Plate Balance," December 1966.
204. Armendariz, M., and H. Rachele, "Determination of a Representative Wind Profile from Balloon Data," December 1966.
205. Hansen, Frank V., "The Aerodynamic Roughness of the Complex Terrain of White Sands Missile Range," January 1967.
206. Morris, James E., "Wind Measurements in the Subpolar Mesopause Region," January 1967.
207. Hall, James T., "Attenuation of Millimeter Wavelength Radiation by Gaseous Water," January 1967.
208. Thiele, O. W., and N. J. Beyers, "Upper Atmosphere Pressure Measurements With Thermal Conductivity Gauges," January 1967.
209. Armendariz, M., and H. Rachele, "Determination of a Representative Wind Profile from Balloon Data," January 1967.
210. Hansen, F. V., "The Aerodynamic Roughness of the Complex Terrain of White Sands Missile Range, New Mexico," January 1967.
211. D'Arcy, Edward M., "Some Applications of Wind to Unguided Rocket Impact Prediction," March 1967.
212. Kennedy, Bruce, "Operation Manual for Stratosphere Temperature Sonde," March 1967.
213. Hoidale, G. B., S. M. Smith, A. J. Blanco, and T. L. Barber, "A Study of Atmospheric Dust," March 1967.
214. Longyear, J. Q., "An Algorithm for Obtaining Solutions to Laplace's Titad Equations," March 1967.
215. Rider, L. J., "A Comparison of Pibal with Raob and Rawin Wind Measurements," April 1967.
216. Breeland, A. H., and R. S. Bonner, "Results of Tests Involving Hemispherical Wind Screens in the Reduction of Wind Noise," April 1967.
217. Webb, Willis L., and Max C. Bolen, "The D-region Fair-Weather Electric Field," April 1967.
218. Kubinski, Stanley F., "A Comparative Evaluation of the Automatic Tracking Pilot-Balloon Wind Measuring System," April 1967.
219. Miller, Walter B., and Henry Rachele, "On Nonparametric Testing of the Nature of Certain Time Series," April 1967.
220. Hansen, Frank V., "Spacial and Temporal Distribution of the Gradient Richardson Number in the Surface and Planetary Layers," May 1967.
221. Randhawa, Jagir S., "Diurnal Variation of Ozone at High Altitudes," May 1967.
222. Ballard, Harold N., "A Review of Seven Papers Concerning the Measurement of Temperature in the Stratosphere and Mesosphere," May 1967.
223. Williams, Ben H., "Synoptic Analyses of the Upper Stratospheric Circulation During the Late Winter Storm Period of 1966," May 1967.
224. Horn, J. D., and J. A. Hunt, "System Design for the Atmospheric Sciences Office Wind Research Facility," May 1967.
225. Miller, Walter B., and Henry Rachele, "Dynamic Evaluation of Radar and Photo Tracking Systems, " May 1967.
226. Bonner, Robert S., and Ralph H. Rohwer, "Acoustical and Meteorological Data Report - SOTRAN III and IV," May 1967.
227. Rider, L. J., "On Time Variability of Wind at White Sands Missile Range, New Mexico," June 1967.
228. Randhawa, Jagir S., "Mesospheric Ozone Measurements During a Solar Eclipse," June 1967.
229. Beyers, N. J., and B. T. Miers, "A Tidal Experiment in the Equatorial Stratosphere over Ascension Island (8S)", June 1967.
230. Miller, W. B., and H. Rachele, "On the Behavior of Derivative Processes," June 1967
231. Walters, Randall K., "Numerical Integration Methods for Ballistic Rocket Trajectory Simulation Programs," June 1967.
232. Hansen, Frank V., "A Diabatic Surface Boundary Layer Model," July 1967.
233. Butler, Ralph L., and James K. Hall, "Comparison of Two Wind Measuring Systems with the Contraves Photo-Theodolite," July 1967.
234. Webb, Willis L., "The Source of Atmospheric Electrification," June 1967.

235. Hinds, B. D., "Radar Tracking Anomalies over an Arid Interior Basin," August 1967.
236. Christian, Larry O., "Radar Cross Sections for Totally Reflecting Spheres," August 1967.
237. D'Arcy, Edward M., "Theoretical Dispersion Analysis of the Aerobee 350," August 1967.
238. Anon., "Technical Data Package for Rocket-Borne Temperature Sensor," August 1967.
239. Glass, Roy I., Roy L. Lamberth, and Ralph D. Reynolds, "A High Resolution Continuous Pressure Sensor Modification for Radiosondes," August 1967.
240. Low, Richard D. H., "Acoustic Measurement of Supersaturation in a Warm Cloud," August 1967.
241. Rubio, Roberto, and Harold N. Ballard, "Time Response and Aerodynamic Heating of Atmospheric Temperature Sensing Elements," August 1967.
242. Seagraves, Mary Ann B., "Theoretical Performance Characteristics and Wind Effects for the Aerobee 150," August 1967.
243. Duncan, Louis Dean, "Channel Capacity and Coding," August 1967.
244. Dunaway, G. L., and Mary Ann B. Seagraves, "Launcher Settings Versus Jack Settings for Aerobee 150 Launchers - Launch Complex 35, White Sands Missile Range, New Mexico," August 1967.
245. Duncan, Louis D., and Bernard F. Engebos, "A Six-Degree-of-Freedom Digital Computer Program for Trajectory Simulation," October 1967.
246. Rider, Laurence J., and Manuel Armendariz, "A Comparison of Simultaneous Wind Profiles Derived from Smooth and Roughened Spheres," September 1967.
247. Reynolds, Ralph D., Roy L. Lamberth, and Morton G. Wurtele, "Mountain Wave Theory vs Field Test Measurements," September 1967.
248. Lee, Robert P., "Probabilistic Model for Acoustic Sound Ranging," October 1967.
249. Williamson, L. Edwin, and Bruce Kennedy, "Meteorological Shell for Standard Artillery Pieces - A Feasibility Study," October 1967.
250. Rohwer, Ralph H., "Acoustical, Meteorological and Seismic Data Report - SOTRAN V and VI," October 1967.
251. Nordquist, Walter S., Jr., "A Study in Acoustic Direction Finding," November 1967.
252. Nordquist, Walter S., Jr., "A Study of Acoustic Monitoring of the Gun Probe System," November 1967.
253. Avara, E. P., and B. T. Miers, "A Data Reduction Technique for Meteorological Wind Data above 30 Kilometers," December 1967.
254. Hansen, Frank V., "Predicting Diffusion of Atmospheric Contaminants by Consideration of Turbulent Characteristics of WSMR," January 1968.
255. Randhawa, Jagir S., "Rocket Measurements of Atmospheric Ozone," January 1968.
256. D'Arcy, Edward M., "Meteorological Requirements for the Aerobee-350," January 1968.
257. D'Arcy, Edward M., "A Computer Study of the Wind Frequency Response of Unguided Rockets," February 1968.
258. Williamson, L. Edwin, "Gun Launched Probes - Parachute Expulsion Tests Under Simulated Environment," February 1968.
259. Beyers, Norman J., Bruce T. Miers, and Elton P. Avara, "The Diurnal Tide Near the Stratopause over White Sands Missile Range, New Mexico," February 1968.
260. Traylor, Larry E., "Preliminary Study of the Wind Frequency Response of the Honest John M50 Tactical Rocket," March 1968.
261. Engebos, B. F., and L. D. Duncan, "Real-Time Computations of Pilot Balloon Winds," March 1968.
262. Butler, Ralph and L. D. Duncan, "Empirical Estimates of Errors in Double-Theodolite Wind Measurements," February 1968.
263. Kennedy, Bruce, et al., "Thin Film Temperature Sensor," March 1968.
264. Bruce, Dr. Rufus, James Mason, Dr. Kenneth White and Richard B. Gomez, "An Estimate of the Atmospheric Propagation Characteristics of 1.54 Micron Laser Energy," March 1968.

265. Ballard, Harold N., Jagir S. Randhawa, and Willis L. Webb, "Stratospheric Circulation Response to a Solar Eclipse," March 1968.
266. Johnson, James L., and Orville C. Kuberski, "Timing Controlled Pulse Generator," April 1968.
267. Blanco, Abel J., and Glenn B. Hoidale, "Infrared Absorption Spectra of Atmospheric Dust," May 1968.
268. Jacobs, Willie N., "Automatic Pibal Tracking System," May 1968.
269. Morris, James E., and Marvin D. Kays, "Circulation in the Arctic Mesosphere in Summer," June 1968.
270. Mason, James B., "Detection of Atmospheric Oxygen Using a Tuned Ruby Laser," June 1968.
271. Armendariz, Manuel, and Virgil D. Lang, "Wind Correlation and Variability in Time and Space," July 1968.
272. Webb, Willis L., "Tropospheric Electrical Structure," July 1968.
273. Miers, Bruce T., and Elton P. Avara, "Analysis of High-Frequency Components of AN/FPS-16 Radar Data," August 1968.
274. Dunaway, Gordon L., "A Practical Field Wind Compensation Technique for Unguided Rockets," August 1968.
275. Seagraves, Mary Ann B., and Barry Butler, "Performance Characteristics and Wind Effects for the Aerobee 150 with VAM Booster," September 1968.
276. Low, Richard D. H., "A Generalized Equation for Droplet Growth Due to the Solution Effect," September 1968.
277. Jenkins, Kenneth R., "Meteorological Research, Development, Test, and Evaluation Rocket," September 1968.
278. Williams, Ben H., and Bruce T. Miers, "The Synoptic Events of the Stratospheric Warming of December 1967 - January 1968," September 1968.
279. Tate, C. L., and Bruce W. Kennedy, "Technical Data Package for Atmospheric Temperature Sensor Mini-Loki," September 1968.
280. Rider, Laurence J., Manuel Armendariz, and Frank V. Hansen, "A Study of Wind and Temperature Variability at White Sands Missile Range, New Mexico," September 1968.
281. Duncan, Louis D., and Walter B. Miller, "The Hull of a Channel," September 1968.
282. Hansen, Frank V., and Gary A. Ethridge, "Diffusion Nomograms and Tables for Rocket Propellants and Combustion By-Products," January 1968.
283. Walters, Randall K., and Bernard F. Engebos, "An Improved Method of Error Control for Runge-Kutta Numerical Integration," October 1968.
284. Miller, Walter B., "A Non-Entropy Approach to Some Topics in Channel Theory," November 1968.
285. Armendariz, Manuel, Laurence J. Rider, and Frank V. Hansen, "Turbulent Characteristics in the Surface Boundary Layer," November 1968.
286. Randhawa, Jagir S., "Rocket Measurements of the Diurnal Variation of Atmospheric Ozone," December 1968.
287. Randhawa, Jagir S., "A Guide to Rocketsonde Measurements of Atmospheric Ozone," January 1969.
288. Webb, Willis L., "Solar Control of the Stratospheric Circulation," February 1969.
289. Lee, Robert P., "A Dimensional Analysis of the Errors of Atmospheric Sound Ranging," March 1969.
290. Barber, T. L., "Degradation of Laser Optical Surfaces," March 1969.
291. D'Arcy, E. M., "Diffusion of Resonance Excitation Through a One-Dimensional Gas," March 1969.
292. Randhawa, J. S., "Ozone Measurements from a Stable Platform near the Stratopause Level," March 1969.
293. Rubio, Roberto, "Faraday Rotation System for Measuring Electron Densities," March 1969.
294. Olsen, Robert, "A Design Plan for Investigating the Atmospheric Environment Associated with High Altitude Nuclear Testing," March 1969.
295. Monahan, H. H., M. Armendariz, and V. D. Lang, "Estimates of Wind Variability Between 100 and 900 Meters," April 1969.
296. Rinehart, G. S., "Fog Drop Size Distributions - Measurement Methods and Evaluation," April 1969.

297. D'Arcy, Edward M., and Henry Rachele, "Proposed Prelaunch Real-Time Impact Prediction System for the Aerobee-350 Rocket," May 1969.
298. Low, Richard D. H., "A Comprehensive Report on Nineteen Condensation Nuclei (Part I - Equilibrium Growth and Physical Properties)," May 1969.
299. Randhawa, J. S., "Vertical Distribution of Ozone in the Winter Subpolar Region," June 1969.
300. Rider, Laurence J., and Manuel Armendariz, "Vertical Wind Component Estimates up to 1.2km Above Ground, July 1969.
301. Duncan, L. D., and Bernard F. Engebos, "A Rapidly Converging Iterative Technique for Computing Wind Compensation Launcher Settings for Unguided Rockets," July 1969.
302. Gomez, R. B. and K. O. White, "Erbium Laser Propagation in Simulated Atmospheres I. Description of Experimental Apparatus and Preliminary Results,"July 1969.
303. Hansen, Frank V., and Juana Serna, "A Dimensionless Solution for the Wind and Temperature Profiles in the Surface Boundary Layer," September 1969.
304. Webb, Willis L., "Global Electrical Currents," October 1969.
305. Webb, Willis L., "The Cold Earth," October, 1969.
306. Johnson, Neil L., "Program Description for the Automatic Graphical Presentation of Atmospheric Temperature-Pressure Data on a Skew T, Log P diagram 'SKEWT'," September 1969.
307. Hoidale, G. B., A. J. Blanco, N. L. Johnson, and R. V. Doorey, "Variations in the Absorbtion Spectra of Atmospheric Dust," October 1969.
308. Campbell, G. S., "Measurement of Air Temperature Fluctuations with Thermocouples," October 1969.
309. Miers, B. T., and R. O. Olsen, "Short-Term Density Variations Over White Sands Missile Range," October 1969.
310. White, K. O., and S. A. Schleusener, "Real Time Laser Propagation Data Analysis Technique," October 1969.
311. Randhawa, J. S., "Technical Data Package for Rocket-Borne Ozonesonde," October 1969.
312. Ballard, Harold N., "The Thermistor Measurement of Temperature in the 30-65 km Atmospheric Region," November 1969.
313. Miers, B. T., and J. E. Morris, "Circulation in the Equatorial Mesosphere in Winter," November 1969.
314. Nordquist, Walter S., Jr. "Determination of the Temperature and Pressure of the Lifting Condensation Level," November 1969.
315. Beyers, N. J., and B. T. Miers, "Measurements from a Zero-Pressure Balloon in the Stratopause (48 km)." December 1969.
316. Ballard, H. N., N. J. Beyers, and M. Izquierdo, "A Constant-Altitude Experiment at 48 Kilometers," December 1969.
317. Dunaway, Gordon L., "A Wind-Weighting Technique to Predict Velocity Vector Azimuth Angles for Unguided Rockets," December 1969.
318. Olsen, Robert O., "An Evaluation of Inflatable Falling Sphere Density Data," December 1969.
319. Sharpe, J. M., Jr., "Nacreous Clouds at White Sands Missile Range," January 1970.
320. Seagraves, M. A. B., and M. E. Hoidale, "Unguided Rockets: Fundamentals of Prelaunch Impact Prediction," January 1970.
321. Beyers, N. J., and B. T. Miers, "Measurements from a Zero-Pressure Balloon in the Stratopause (48 km)," December 1969.
322. Ballard, H. N., N. J. Beyers, and M. Izquierdo, "A Constant-Altitude Experiment at 48 Kilometers," December 1969.
323. Seagraves, M. A. B., "Theoretical Performance Characteristics and Wind Effects for the Aerobee 170," February 1970.
324. Sharpe, J. M., Jr., "Nacreous Clouds at White Sands Missile Range," January 1970.
325. Seagraves, M. A. B., and M. E. Hoidale, "Unguided Rockets: Fundamentals of Prelaunch Impact Prediction," January 1970.
326. Seagraves, M. A. B., "Theoretical Performance Characteristics and Wind Effects for the Aerobee 170," February 1970.

327. Webb, W. L., "Atmospheric Neutral-Electrical Interactions," March 1970.
328. White, K. O., E. H. Holt, and R. F. Woodcock, "The Erbium Doped Glass Laser - Performance and Atmospheric Propagation Characteristics," March 1970
329. Randhawa, J. S., "A Balloon Measurement of Ozone Near Sunrise," April 1970.
330. Kays, Marvin, and E. P. Avara, "Errors Associated with Meteorological Data above 30 km," April 1970.
331. Eddy, Amos, E. P. Avara, Marvin Kays, and Marty Yerg, "A Technique to Identify Certain Relative Errors in Radar X-Y Plots," May 1970.
332. Rinehart, Gayle S., "A New Method for Detecting Micron-Sized Sulfate and Water-Soluble Particles and Its Usage," May 1970.
333. Miller, W. B., L. E. Traylor, and A. J. Blanco, "Some Statistical Aspects of Power Law Profiles," May 1970.
334. Hansen, F. V., and J. Serna, "Numerical Interpretation of the Wind, Temperature and Specific Humidity Profiles for the Surface Boundary Layer of the Atmosphere," June 1970.
335. Miers, B. T., and J. E. Morris, "Mesospheric Winds over Ascension Island in January," July 1970.
336. Pries, T. H., "Strong Surface Wind Gusts at Holloman AFB (March-May)," July 1970.
337. Campbell, G. S., F. V. Hansen, and R. A. Dise, "Turbulence Data Derived from Measurements on the 32-Meter Tower Facility: White Sands Missile Range, New Mexico," July 1970.
338. D'Arcy, E. M., and B. F. Engebos, "Wind Effects On Unguided Rockets Fired Near Maximum Range," July 1970.
339. Monahan, H. H., and M. Armendariz, "Gust Factor Variations with Height and Atmospheric Stability," August 1970.
340. Rider, L. J., and M. Armendariz, "Nocturnal Maximum Winds in the Planetary Boundary Layer at WSMR," August 1970.
341. Hansen, F. V., "A Technique for Determining Vertical Gradients of Wind and Temperature in the Surface Boundary Layer," August 1970.
342. Webb, W. L., "Electrical Structure of the D- and E-Region," July 1970.
343. Hansen, F.V., "An Examination of the Exponential Power Law in the Surface Boundary Layer," September 1970.
344. Duncan, L. D., and R. K. Walters, "Editing of Radiosonde Angular Data," September 1970.
345. Duncan, L. D., and W. J. Vechione, "Vacuum-Tube Launchers and Boosters," September 1970.
346. Rinehart, Gayle S., "Humidity Generating Apparatus and Microscope Chamber for Use with Flowing Gas Atmospheres," October 1970.
347. Lindberg, James D., "The UncertaintyPrinciple: A Limitation on Meteor Trail Radar Wind Measurements," October 1970.
348. Randhawa, J. S., "Technical Data Package for Rocket-Borne Ozone-Temperature Sensor," October 1970.
349. Miller, W. B., A. J. Blanco, and L. E. Traylor, "Impact Deflection Estimators from Single Wind Measurements," September 1970.
350. Miers, B. T., R. O. Olsen, and E. P. Avara, "Short Time Period Atmospheric Density Variations and A Determination of Density Errors from Selected Rocketsonde Sensors," October 1970.
351. Rinehart, Gayle S., "Sulfates and Other Water Solubles Larger than 0.15 Radius in a Continental Nonurban Atmosphere," October 1970.
352. Shinn, J. H., "An Introduction to the Hyperbolic Diffusion Equation," November 1970.
353. Avara, E. P., and M. Kays, "Some Aspects of the Harmonic Analysis of Irregularly Spaced Data," November 1970.
354. Randhawa, J. S., B. H. Williams, and M. D. Kays, "Meteorological Influence of a Solar Eclipse on the Stratosphere," December 1970.
355. Randhawa, J. S., "Stratopause Diurnal Ozone Varition," January 1971.
356. Nordquist, W. S., Jr., and N. L. Johnson, "One-Dimensional Quasi-Time-Dependent Numerical Model of Cumulus Cloud Activity," December 1970.

357. Low, R. D. H., "A Comprehensive Report on Nineteen Condensation Nuclei, Part II," January 1971.
358. Avara, E. P., and M. D. Kays, "The Effect of Interpolation of Data Upon the Harmonic Coefficients," January 1971.
359. Avara, E. P., "The Analysis of Variance of Time Series Data, Part I: One-Way Layout," January 1971.
360. Avara, E. P., "The Analysis of Variance of Time Series Data, Part II: Two-Way Layout," January 1971.
361. Armendariz, M., L. J. Rider, G. S. Campbell, D. Favier, and J. Serna, "Turbulence Measurements from a T-Array of Meteorological Sensors," February 1971.
362. Engebos, B. F., and L. J. Rider, "Vertical Wind Effects on the 2.75-inch Rocket," March 1971.
363. Rinehart, G. S., "Evidence for Sulfate as a Major Condensation Nucleus Constituent in Nonurban Fog," March 1971.
364. Kennedy, B. W., E. P. Avara, and B. T. Miers, "Data Reduction Program for Rocketsonde Temperatures," March 1971.
365. Maynard, Harry, "A Radix-2 Fast Fourier Transform Program," March 1971.
366. Henley, D. C., and G. B. Hoidale, "Attenuation and Dispersion of Acoustic Energy by Atmospheric Dust," March 1971.
367. Randhawa, J. S., "The Vertical Distribution of Ozone near the Equator," April 1971.
368. Ethridge, G. A., "A Method for Evaluating Model Parameters by Numerical Inversion," April 1971.
369. Cionco, R. M., "Application of the Ideal Canopy Flow Concept to Natural and Artificial Roughness Elements," April 1971.
370. Businger, J. A., K. Sahashi, N. Monji, and B. Prasad, "The Study of the Dynamic Structure of the Lower Atmosphere," July 1970.
371. Duncan, L. D., "A Statistical Model for Estimation of Variability Variances from Noisy Data," May 1971.
372. Miller, W. B., "On Approximation of Mean and Variance-Covariance Matrices of Transformations of Joint Random Variables," May 1971.
373. Pries, T. H., and G. S. Campbell, "Spectral Analyses of High-Frequency Atmospheric Temperature Fluctuations," May 1971.
374. Shinn, J. H., "Steady-State Two-Dimensional Air Flow in Forests and the Disturbance of Surface Layer Flow by a Forest Wall," May 1971.
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