A BAROMETRIC SURVEY OF NHRE MESONET STATION HEIGHTS[1]

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Abstract

The mesoscale meteorological surface network established for the support of the National Hail Research Experiment (NHRE) 1973 field experiment has been barometrically surveyed. Pressure (height) increments for each station referenced to several datum stations were derived from this survey. Also derived were absolute geometric heights for each station. Two methods of obtaining this data were employed; first, determination of mean station pressures for the three-month length of the field experiment from daily observations of station pressure, and secondly, measurement of all station pressures on one given day using the digital aneroid barometer. Excellent agreement between these two independent methods was noted. A discussion of instrumental accuracy based on tests conducted is also presented.

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A BAROMETRIC SURVEY OF NHRE MESONET STATION HEIGHTS

Introduction

The mesoscale meteorological network of thirty three stations established by NHRE for support of the 1973 hail suppression and research experiment in northeast Colorado is shown in Figure 1. The geometric heights above sea level of Stations 1, 2, 3, 027 (Kimball, Nebraska, Municipal Airport), and 884 (Sterling, Colorado, Municipal Airport) were known through accurate survey or published airport runway heights. In addition, the height of station 807 (New Raymer airport) was approximately known. The remaining stations have not been surveyed and their height thus not accurately known. Because of the tilted nature of the network terrain (it falls off some 1,300 feet from Grover to Sterling, a distance of about 65 miles), it is necessary, for instance, to reduce station pressure measurements to some common elevation so that pressure gradients may be satisfactorily represented. Thus it is the purpose of this technical note to provide not only reasonably accurate absolute geometric heights, but appropriate pressure (height) increments for each station referenced to several datum stations, for the use of those who may work with NHRE mesonetwork data.

In consideration of the expense of a complete conventional survey of the network, barometric methods for obtaining this data were employed. Excellent agreement between two independent methods was found, thereby lending confidence to the accuracy of the results obtained.

Methods

Season-Mean Station Pressures

The first method employed was to determine season-mean station pressures for each station based on observed daily pressures at given times (which,

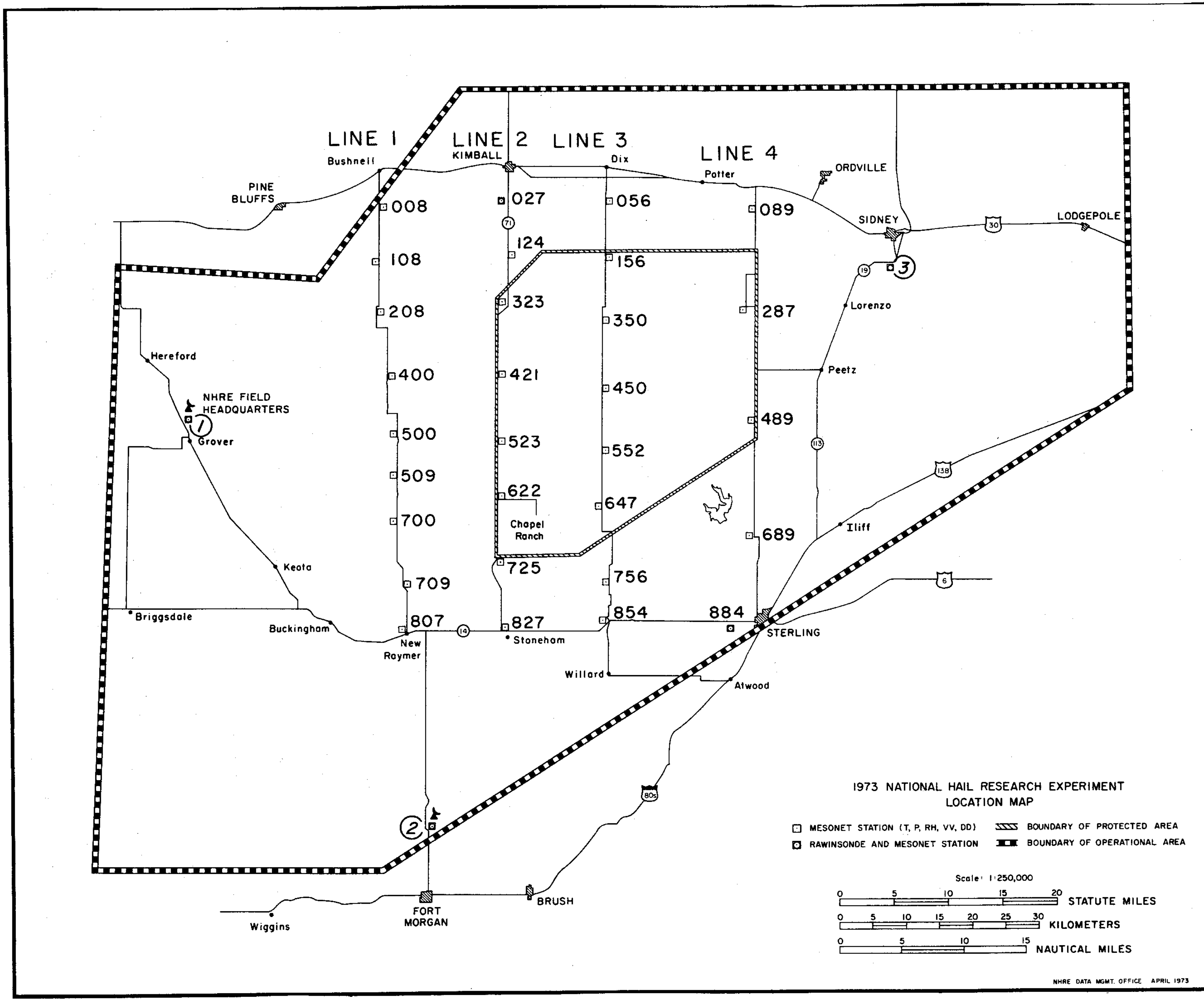

Figure 1 Location map showing stations of the 1973 NHRE Mesonet

unfortunately, varied from station to station) during the NHRE 1973 field experiment. The hail study season treated lasted from 15 May through 31 July. The effects of daily synoptic conditions were expected to cancel over this averaging period, leaving pressure differences between stations due essentially only to variations in elevation.

Because of time differences in the servicing of these stations as the observers progressed southward each morning along each of the four lines of stations (Figure 1), it was necessary to determine a measure of the mean diurnal pressure variation experienced in this region and make appropriate adjustments to the seasonal averages so that all mean pressures would be on a common time basis. The approximate mid-way point (1000 hours) in the servicing run for each line (about 3 hours) was chosen for the time base.

Diurnal Variation of Station Pressure

Inasmuch as the diurnal pressure variation for Colorado appears to reach a maximum in the morning (summertime) at about 0730-0830 local time, and a minimum at about 1630-1730 (Berry, 1945; Godske, 1957), the difference between the season mean pressures at 0830 and 1730 was determined from the strip chart records for three widely spaced stations, numbers 008, 089 and 854. The average hourly pressure change during this period was 0.24 mb and this factor was used, apportionately, to add small increments of pressure to mean station pressures from observation times later than 1000 hours, and subtract increments from those observed earlier than that. A comparative hourly diurnal pressure change factor is found in Godske (1957): a long term mean diurnal pressure variation for Colorado Springs in the summer showed an average hourly change of 0.28 mb.

It might be of interest to note that in the wintertime in Colorado, the diurnal maximum in pressure occurs at about 1000, and the minimum at about 1600 hours local time.

The season-mean pressure for each station, adjusted thusly to a common time base, was then available for consideration of relative pressure differences between adjacent stations.

Station Pressure Measurement

The second method employed was to measure mesonet station pressures with the digital aneroid barometer. Two measurement schemes were considered: one, to make thirty two sets of simultaneous measurements at pairs of stations, one station of each pair being a common datum station; two, on a day with a flat pressure field, make successive measurements of station pressure at all sites in as short a time as possible. Because of the communications problems inherent with the first method, the second method was chosen.

On 22 October 1973, a large high pressure area dominated Colorado and the Great Plains, providing the outlook for only small pressure changes in the mesonetwork (Figure 2). Four digital aneroid barometers were taken to the Sterling, Colorado, Municipal Airport (station number 884) where they were intercompared before proceeding into the network to an assigned north-south line of stations. A microbarograph was installed in the instrument shelter at Sterling Airport to provide confirmation of the anticipated flatness of the pressure field.

Measurements were made at ground level adjacent to the instrument shelter at each site. Approximately one hour to one hour and fifteen

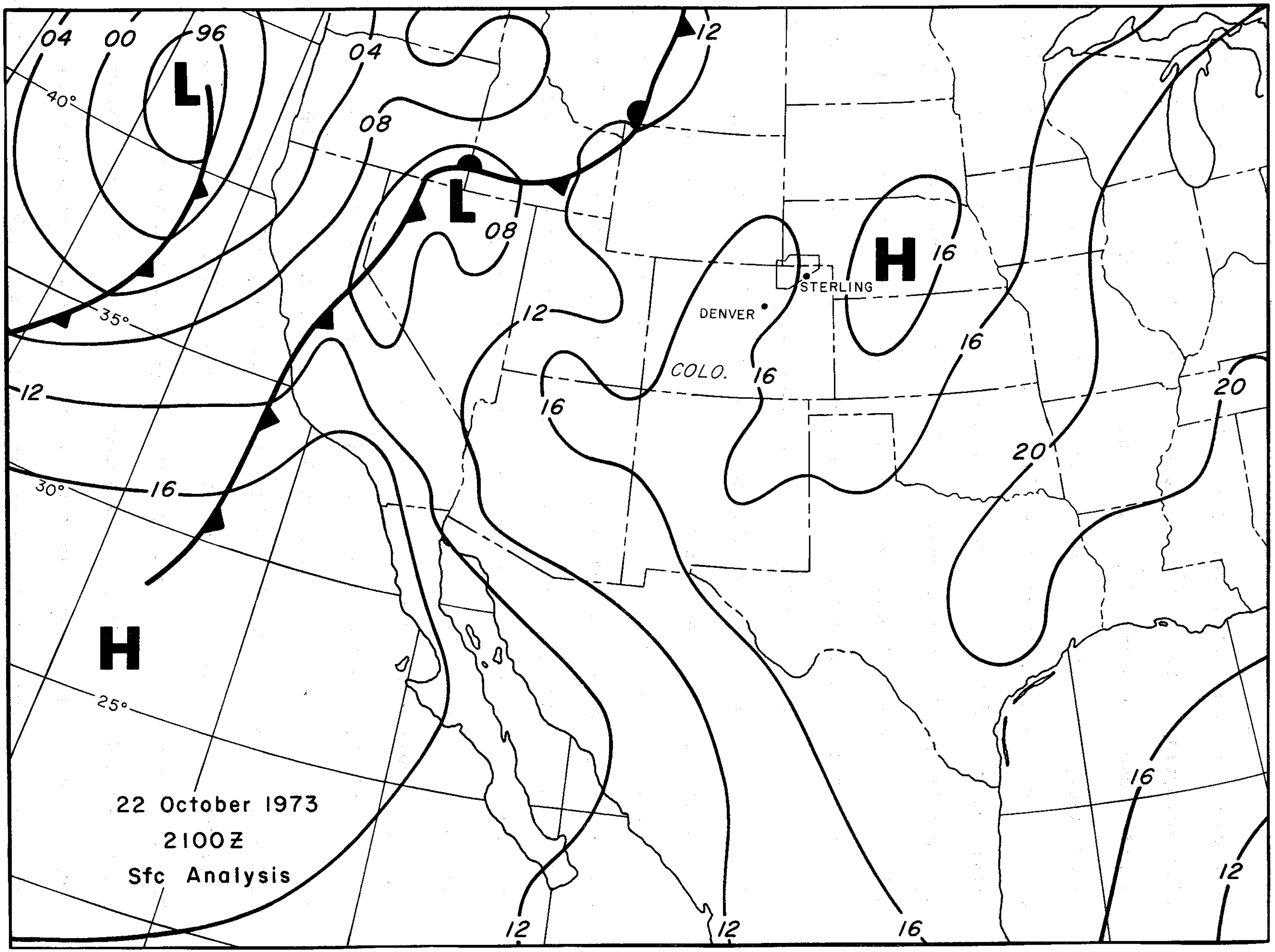

Figure 2 Surface chart, 22 October 1973, 2100 Z

minutes was required to measure pressures of all of the stations in a given line, excepting station numbers 1, 2, and 3, for which the heights were already known. This procedure was repeated for a total of three times. In addition, the barometer used on the line of stations between numbers 884 and 089 was taken to stations 056 and 027 where station pressure measurements were made for an effective intercomparison with the instruments used on those lines. Darkness prevented a visit with this instrument to station 008, so initial intercomparison data from Sterling was used to substitute one instrument's reading for that of another. Thus, the four north-south lines were effectively related to one another by pressure measurements made with one instrument on the northernmost row of stations. (See Figure 1)

As the last two measurement runs were made during a period when the pressure trace was essentially constant, (see Figures 3 and 4, which show microbarograph traces for the period 1500-1800 local time on 22 October 1973, at Sterling, Colorado, and Kimball, Nebraska, respectively) only these two of the three runs were averaged and used for determining the relative pressure difference between adjacent stations.

Instrumental Accuracy

The digital aneroid barometers used for these measurements, the Mechanism Ltd, Type M1991A, and the Negretti and Zambra, Type M2236A, are, as a class, considered excellent for determining relative differences in pressure for a closely spaced range of heights, while the mercurical barometers are to be preferred for absolute pressure measurements (Middleton & Spilhaus, 1953). The accuracy in absolute pressure measurement for this class of instrument is 0.3 mb. It is perhaps more useful to examine the threshold of sensitivity for the instrument, which is claimed

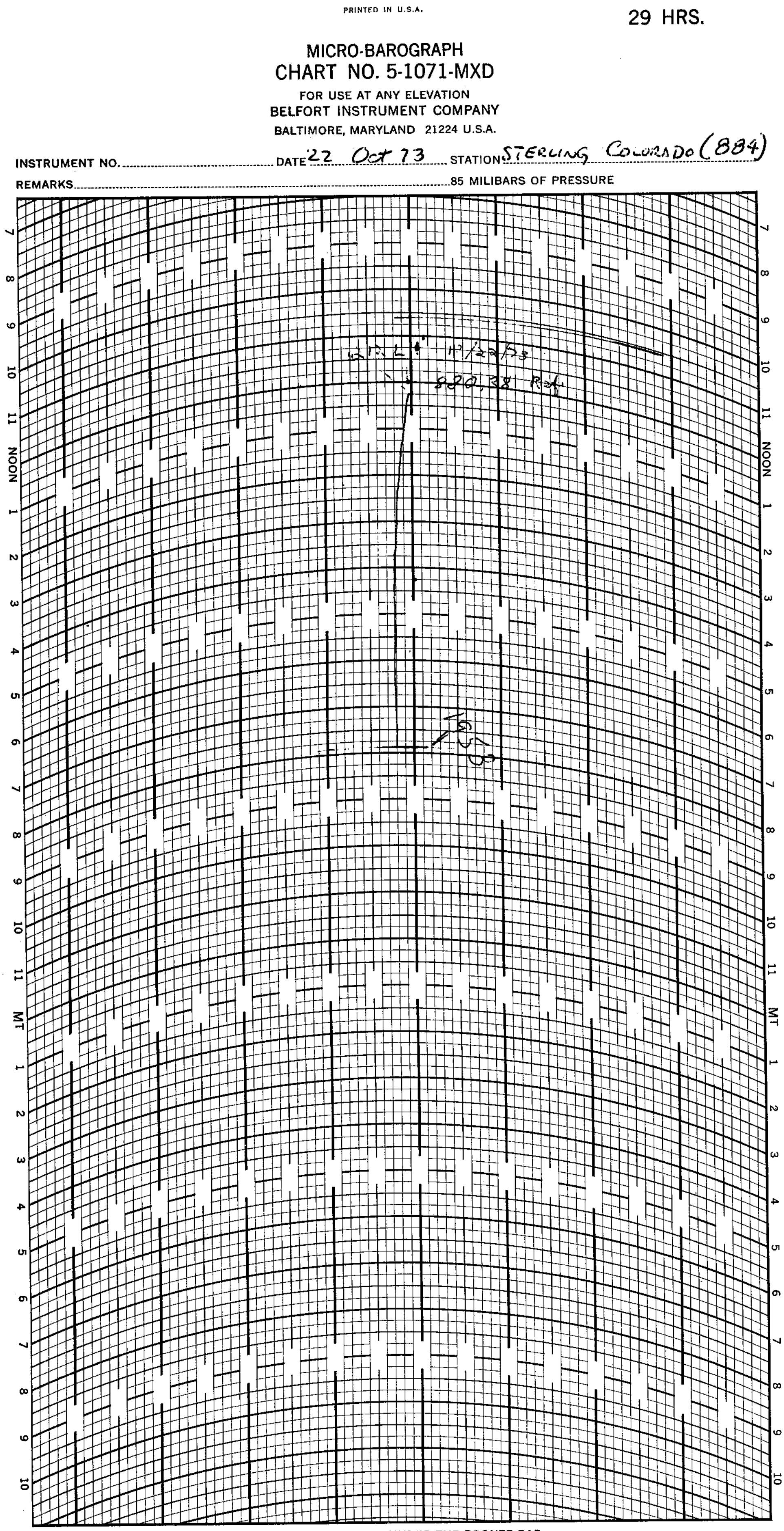

Figure 3 Microbarograph trace, Sterling, Colorado, 22 October 1973

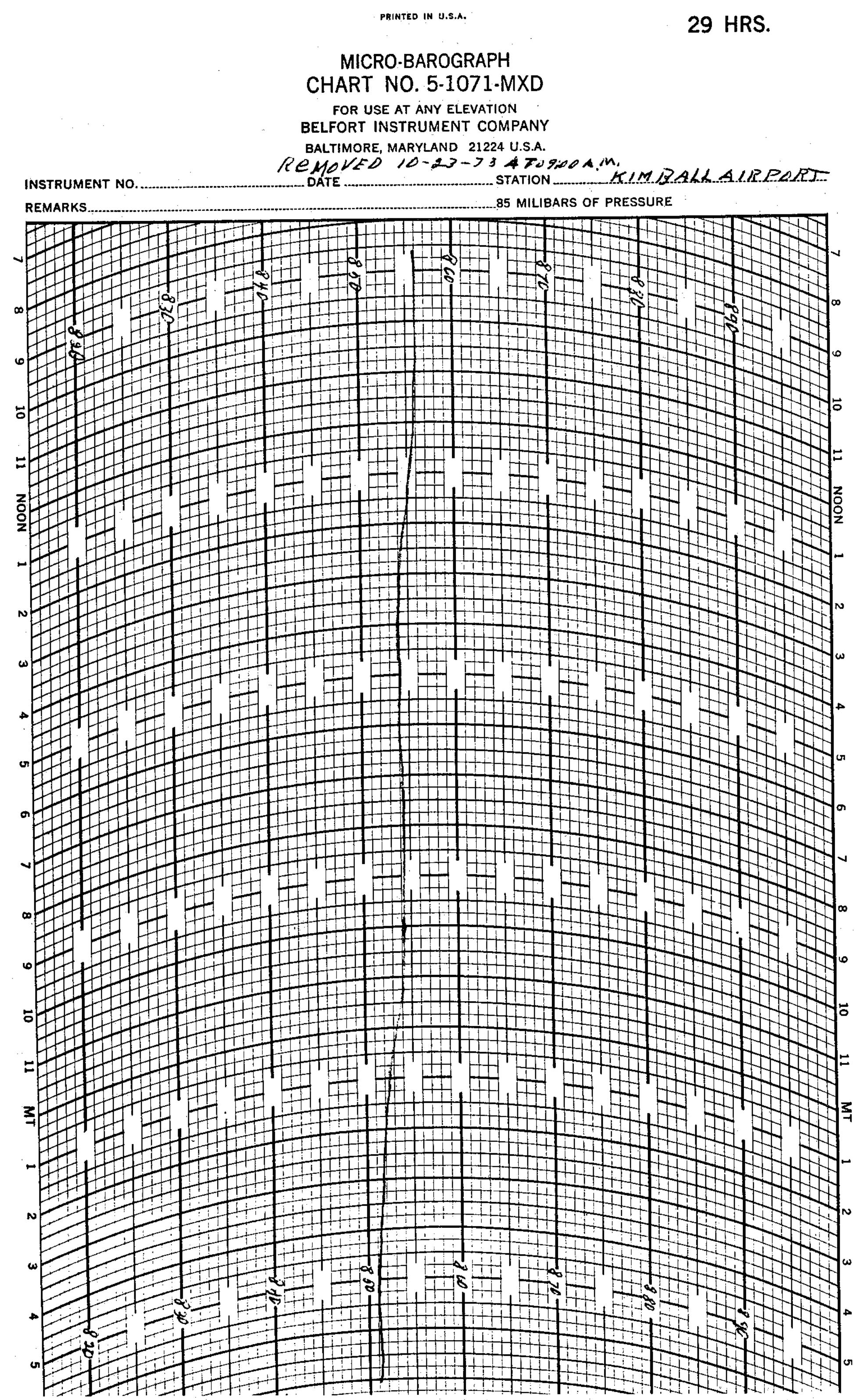

Figure 4 Microbarograph trace, Kimball, Nebraska, 22 October 1973

to be 0.02 mb, or an equivalent change in height of about 8.4 inches at the altitude of the NCAR Mesa Laboratory.

In an effort to determine realistic limits of accuracy for the measurements made with the instruments, a careful intercomparison and calibration was performed for the four instruments using known height intervals at NCAR. An office chair, a four-drawer filing cabinet, a staircase, and the vertical distance from the floor of the second basement to the floor of the penthouse in the South Tower were used. These known height intervals will be referred to as "Test Height Intervals 1, 2, 3, and 4", respectively. Pressure measurements were made at the base and top of each known height interval. Four or five measurements were made at each level for each instrument. The digital mechanism was very slowly turned in order to avoid either overshooting the reading upon seeing the electron tube indication ("cat's eye" tube), or introducing backlash of the mechanism. With this instrument, the pressure is to be read while moving the digital mechanism in one direction only; that from lower pressure to higher pressure.

It appears that with practice and painstaking care, an operator can obtain a reading repeatability with this type of instrument to about one or two hundredths of a mb, which is also the limitation of scale resolution. More realistic operation yields readings which may vary three to five hundredths of a mb, or perhaps more, in field work with its attendent stress.

The average of repeated individual pressure differentials measured between base and top of each known height interval for each instrument is shown in Table 1. These were subsequently averaged for the four instruments and converted through the hypsometric equation to equivalent heights which are then compared with the known heights. It is seen that

TABLE 1

A calibration test & comparison of four aneroid digital barometers

Instrument No.	Test Height Intervals			
	1	2	3	4
NSF 14428	-----	0.08 mb	0.20 mb	2.17 mb
NSF 13001	-----	0.09	0.15	2.14
NSF 15570	-----	0.10	0.19	2.34
NSF 14427	-----	0.12	0.24	2.36
Average		0.10	0.19	2.25

ΔP's converted to heights using table 58 of the Smithsonian Tables (20 C and 800 mb).

Test Height Intervals	Measured Height	Actual Height	Error Feet	Error mb
1 (apparently indeterminate)	---	1.5 feet	----	----
2	3.5 feet	2.8	+0.7	+0.02
3	6.7	6.4	-0.3	-0.01
4	79	79.5	-0.5	-0.015

the errors are equal to or smaller than the error representing an accuracy based on the threshold of sensitivity claimed for this instrument.

Thus it is concluded that the accuracy of this class instrument for height interval determinations is markedly superior to the $\sim \pm$ 10 feet, or $\sim$ 0.3 mb ($\sim$ 3 m) accuracy cited for absolute pressure measurements. The accuracy obtainable in field usage, on larger, less closely spaced height intervals, for instance, will not be as good as the lab measurement accuracy obtained, but probably will approach the pressure differential equivalent of ± 1-2 feet (about ± 0.3 - 0.7 m).

Comparison of Methods

Comparison of the pressure differentials between adjacent stations (south to north along each of the four lines of stations) for the two sets of pressure differentials derived from independent methods showed excellent agreement. The largest disparity was 0.43 mb. The typical difference was much smaller; the mean being 0.03 mb with a standard deviation of 0.17 mb. Not knowing which set of data was nearer "truth", it was deemed appropriate to simply average the two sets of corresponding pressure differentials and use them, in relation to a datum station, to portray the pressure and height topographies.

Discussion of Results

Table 2 presents pressure increments representing essentially only the height difference between each station and Sterling, Colorado, station 884. The equivalent pressure increments of the stations with known heights, stations 1, 2, and 3, have been included in this and the following Tables. Note that Sterling (datum station) has the highest pressure in the network and Grover, station 1, the greatest negative pressure increment; i.e., the highest elevation in the network. Because of the magnitude of some of these

TABLE 2

Pressure increments which represent height increments above Sterling, Colorado, for each NHRE mesonet station

Station No.	ΔP (mb)	Station No.	ΔP	Station No.	ΔP	Station No.	ΔP
008	-33.17	027	-26.52	056	-22.67	089	-13.95
108	-35.73	124	-27.51	156	-22.36		
208	-37.26	323	-30.44	350	-24.56	287	-11.38
400	-35.82	421	-32.48	450	- 9.22		
500	-38.08	523	-20.10	552	- 8.26	489	-17.16
509	-23.22	622	-18.03	647	-11.33		
700	-24.83	725	-14.72	756	- 9.35	689	- 0.28
709	-20.29	827	-18.39	854	-11.97		
807	-22.92					884	0
1	-39.29						
2	-15.82						
3	- 8.54						

Note: pressure increments for stations 1, 2, and 3 were not measured, but were derived from known station heights.

increments (about 40 mb), two stations near the average mean station pressure in the network were chosen as datum stations so that the maximum increments would be closer to 20 mb. These stations, 662 and 489, are presented as datum stations in Tables 3 and 4. It might be noted that the mean seasonal station pressure varied from about 840 mb at Grover to about 880 mb at Sterling.

Table 5 presents the absolute geometric heights of the NHRE mesonetwork stations. The conversion of pressure increment to height increment was made using the hypsometric equation. The appropriate average pressure differentials between Sterling and the subject stations were used and 20C was chosen for the fictitious mean virtual temperature in the layer. The actual surface temperature peaked in the range of 20-23C over the network with very light wind and scattered cirrus present. A one degree change in temperature is equivalent to about a tenth of a foot change in height per mb. Therefore, for a 20 mb deep layer, for example, the maximum height change for a one degree change would be about two feet. The agreement obtained with actual heights indicates the appropriateness of the use of 20C.

Finally, the corresponding height increment for each mesonet station was added to the known height of the Sterling station to produce the heights presented in Table 5.

How accurate are these pressure/height determinations made under field conditions? It was mentioned at the outset of this note that the height of two airports in the previously unsurveyed portion of the network were known. Compared to the derived height of Kimball Airport, 4,901 feet, is the surveyed height of 4,900 feet. At New Raymer Airport the derived

TABLE 3

Pressure increments which represent height increments above or below Station 622 for each NHRE mesonet station

Station No.	ΔP(mb)	Station No.	ΔP	Station No.	ΔP	Station No.	ΔP
008	-15.14	027	- 8.49	056	- 4.64	089	+ 4.08
108	-17.70	124	- 9.48	156	- 4.33		
208	-19.23	323	-12.41	350	- 6.53	287	+6.65
400	-17.79	421	-14.45	450	+ 8.81		
500	-20.05	523	- 2.07	552	+ 9.77	489	+ 0.87
509	- 5.19	622	0	647	+ 6.70		
700	- 6.80	725	+ 3.31	756	+ 8.68	689	+17.75
709	- 2.26	827	- 0.36	854	+ 6.06		
807	- 4.89					884	+18.03
1	-21.26						
2	+ 2.21						
3	+ 9.49						

Note: pressure increments for stations 1, 2, and 3 were not measured, but were derived from known heights.

TABLE 4

Pressure increments which represent height increments above or below Station 489 for each NHRE mesonet station

Station No.	ΔP (mb)	Station No.	ΔP	Station No.	ΔP	Station No.	ΔP
008	-16.01	027	- 9.36	056	- 5.51	089	+ 3.21
108	-18.57	124	-10.35	156	- 5.20		
208	-20.1	323	-13.28	350	- 7.40	287	+ 5.78
400	-18.66	421	-15.32	450	+ 7.94		
500	-20.92	523	- 2.94	552	+ 8.90	489	0
509	- 6.06	622	- 0.87	647	+ 5.83		
700	- 7.67	725	+ 2.44	756	+ 7.81	689	+16.88
709	- 3.13	827	- 1.23	854	+ 5.19		
807	- 5.76					884	+17.16
1	-22.13						
2	+ 1.34						
3	+ 8.62						

Note: pressure increments for stations 1, 2, and 3 were not measured, but were derived from known heights.

TABLE 5

Absolute geometric heights above sea level for each NHRE mesonet station

Station No.	Height ft	Height m	Station No.	Height ft	Height m	Station No.	Height ft	Height m	Station No.	Height ft	Height m
008	5122	1561	027	4901	1494	056	4774	1455	089	4488	1368
108	5208	1587	124	4934	1504	156	4764	1452			
208	5259	1603	323	5031	1533	350	4836	1474	287	4405	1343
400	5211	1588	421	5099	1554	450	4334	1321			
500	5286	1611	523	4689	1429	552	4303	1312	489	4593	1400
509	4792	1461	622	4622	1409	647	4403	1342			
700	4845	1477	725	4513	1376	756	4339	1323	689	4046	1233
709	4696	1431	827	4633	1412	854	4424	1348			
807	4782	1458							884	4037	1230
1	5332	1625									
2	4550	1373									
3	4312	1314									

Notes: (1) Actual surveyed height of Station 027 (Kimball Airport) is 4900 feet. Actual height of Station 807 (New Raymer Airport) is believed to be 4782 feet.

(2) Heights of stations 1, 2, and 3 were not determined from the barometric survey but were previously known from accurate survey or published airport runway heights.

height is 4,782 versus what is believed to be the actual height, 4,782 feet. (This height was used by Colorado State University in their hail study operations at New Raymer ten years ago.) It is believed to be the runway height adjacent to the instrument shelter (personal communication - R. H. Bushnell, NCAR).

It would be comforting to believe that the zero to one foot of error obtained in these instances were not just simple coincidence. The evidence presented herein suggests that the instrument has the capability of such accuracy. The analysis technique employed herein, however, with its attendant assumptions, provides, it would seem, some further degree of uncertainty making the attainment of such accuracy surprising. In the final analysis, it may be much more realistic to consider these results (heights above sea level) subject to a ± 5 foot uncertainty. The pressure increments presented are believed to have an uncertainty equivalent to the ± 1-2 foot error cited earlier.

Acknowledgments

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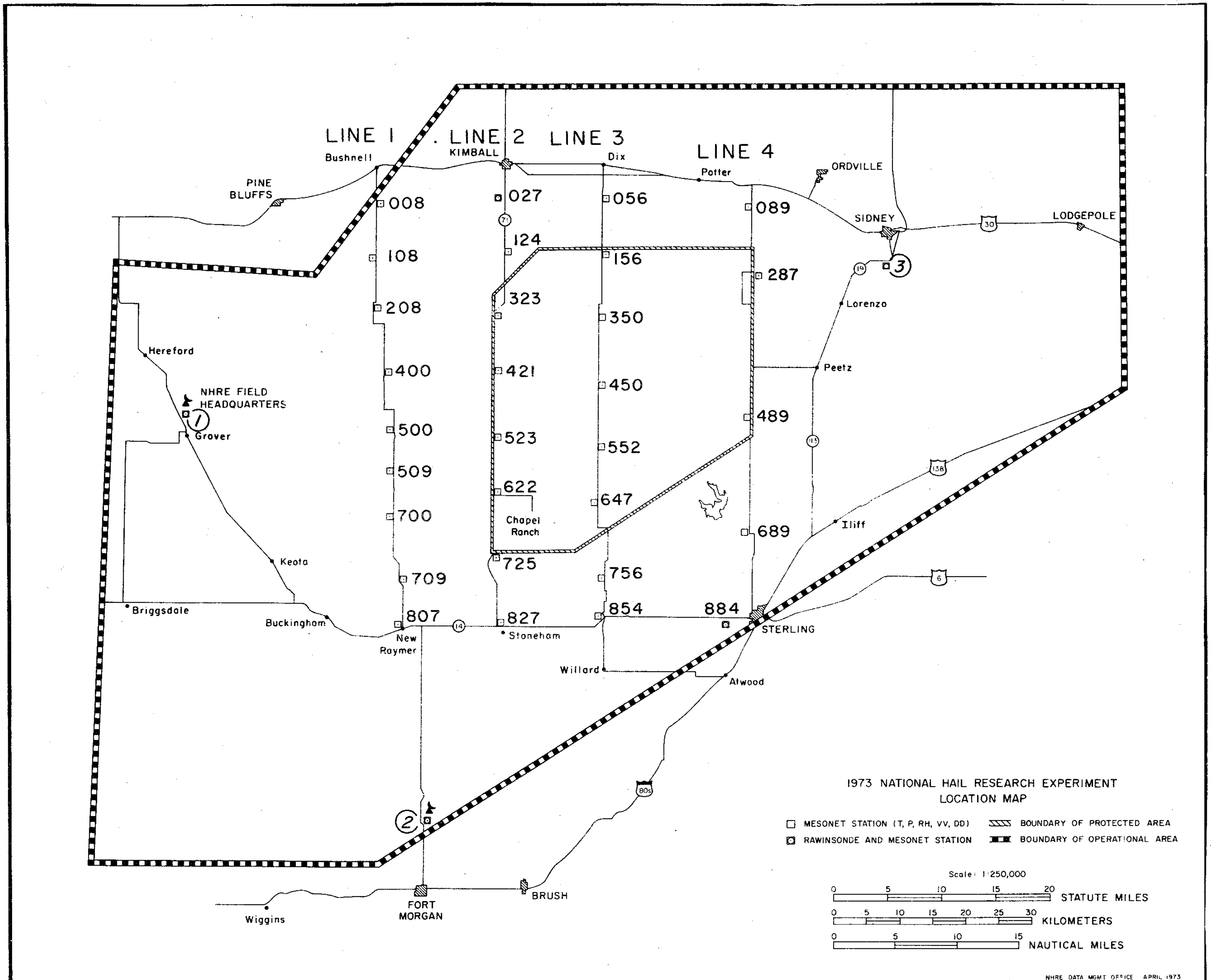

Figure 1 Location map showing stations of the 1973 NHRE Mesonet

-Errata-

Revised Locations of Mesonet Stations 323 and 287