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NOAA Technical Memorandum ERL NSSL-68

THE NSSL/WKY-TV TOWER DATA COLLECTION PROGRAM: APRIL - JULY 1972

R. Craig Goff
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National Severe Storms Laboratory
Norman, Oklahoma
May 1974

E R R A T A

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Pg 23	line 8: Fig 22 not Fig 21
Pg 24	Fig 23: ordinate should have units (°)
Pg 24	Footnote, line 1: Delete $\lvert\Delta T\rvert$ before the period
Pg 32	4th to last line: Delete "Since the squall . . . to west," and capitalize "P" in "pre-storm."
Pg 30	Table 4: Index #17 T, <u>26m</u>, delta mode
Pg 38	References: Carter, J. K. (1970): Should read ERL NSSL-50 not ERL NSSL-62.

National Severe Storms Laboratory
Norman, Oklahoma
May, 1974

NOTICE

The NOAA Environmental Research Laboratories does not endorse any proprietary product or proprietary material mentioned in this publication.

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K	Coefficient of expansion of thermometer glass.
n	Number of degree graduations emergent from bath.
P	Pressure.
R	Rainfall.
S	Emergent stem correction.
T	Temperature.
T_b	Bath temperature.
T_w	Wet-bulb temperature.
t	Emergent stem temperature.
U	Wind speed.
w	Vertical velocity.
α	Wind direction.
σ_α	Standard deviation of wind direction.
σ_T	Standard deviation of temperature.
σ_U	Standard deviation of wind speed.
$\lvert\Delta\alpha\rvert$	Absolute value of the wind direction difference (time series data).
$\lvert\Delta U\rvert$	Absolute value of the wind speed difference (time series data).

THE NSSL/WKY-TV TOWER DATA COLLECTION PROGRAM: APRIL - JULY 1972

R. Craig Goff and W. David Zittel

Since 1966, the National Severe Storms Laboratory has operated meteorological instruments on a 481 m TV tower north of Oklahoma City. Initially, only horizontal wind and temperature data from seven levels were sensed and recorded, but thereafter the tower program gradually expanded. Later, relative humidity and vertical velocity sensors were added, and in 1968 data were recorded digitally for the first time.

In this report the calibration, operation, and maintenance of tower sensors and signal conditioning equipment, as implemented in 1972, are described in detail. Also discussed at length are procedures used for quality control. The report includes a survey of research objectives. Strip chart and digital data available are summarized in two appendices.

1. INTRODUCTION

The National Severe Storms Laboratory (NSSL) has gathered meteorological data from a tall tower (the WKY-TV transmitter) since 1966. In the last 5 yr (1968-1972), data have been collected primarily in spring when the likelihood of severe thunderstorms is high. During the 1972 spring and early summer, 3 mo of nearly continuous meteorological data were collected in digital form.

The 1972 data were routinely recorded at 1-min intervals and during stormy periods, at 10-sec intervals. Horizontal wind speed and direction, vertical wind speed, dry- and wet-bulb temperatures, surface pressure, and rainfall were recorded. This report presents a brief history of the tower and a description of the site follows; calibration and maintenance procedures, problems in data collection, and quality control procedures are discussed in detail. A summary of the data collected and a short discussion of proposed research is presented.

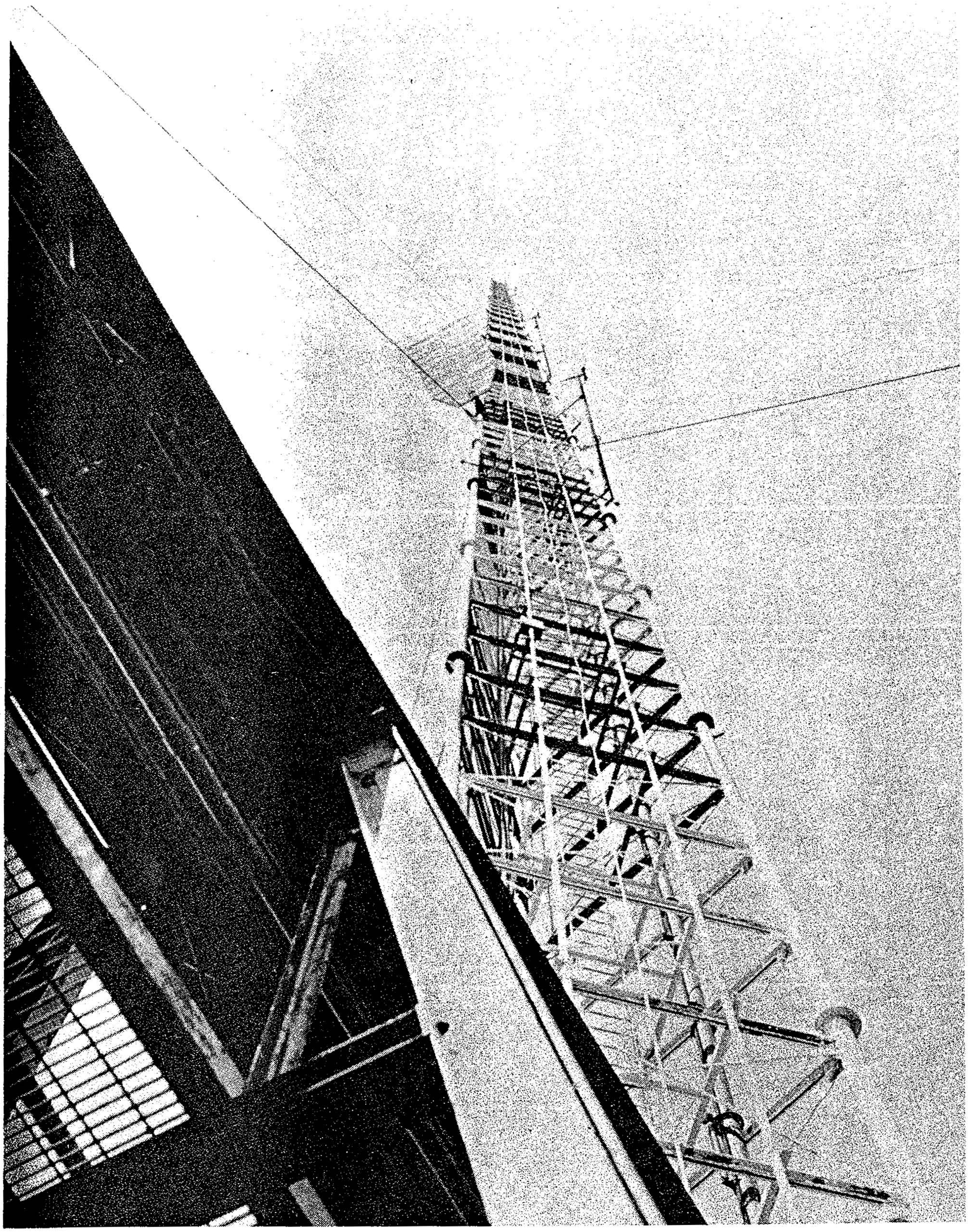

Figure 1. Southwest face of NSSL meteorological tower.

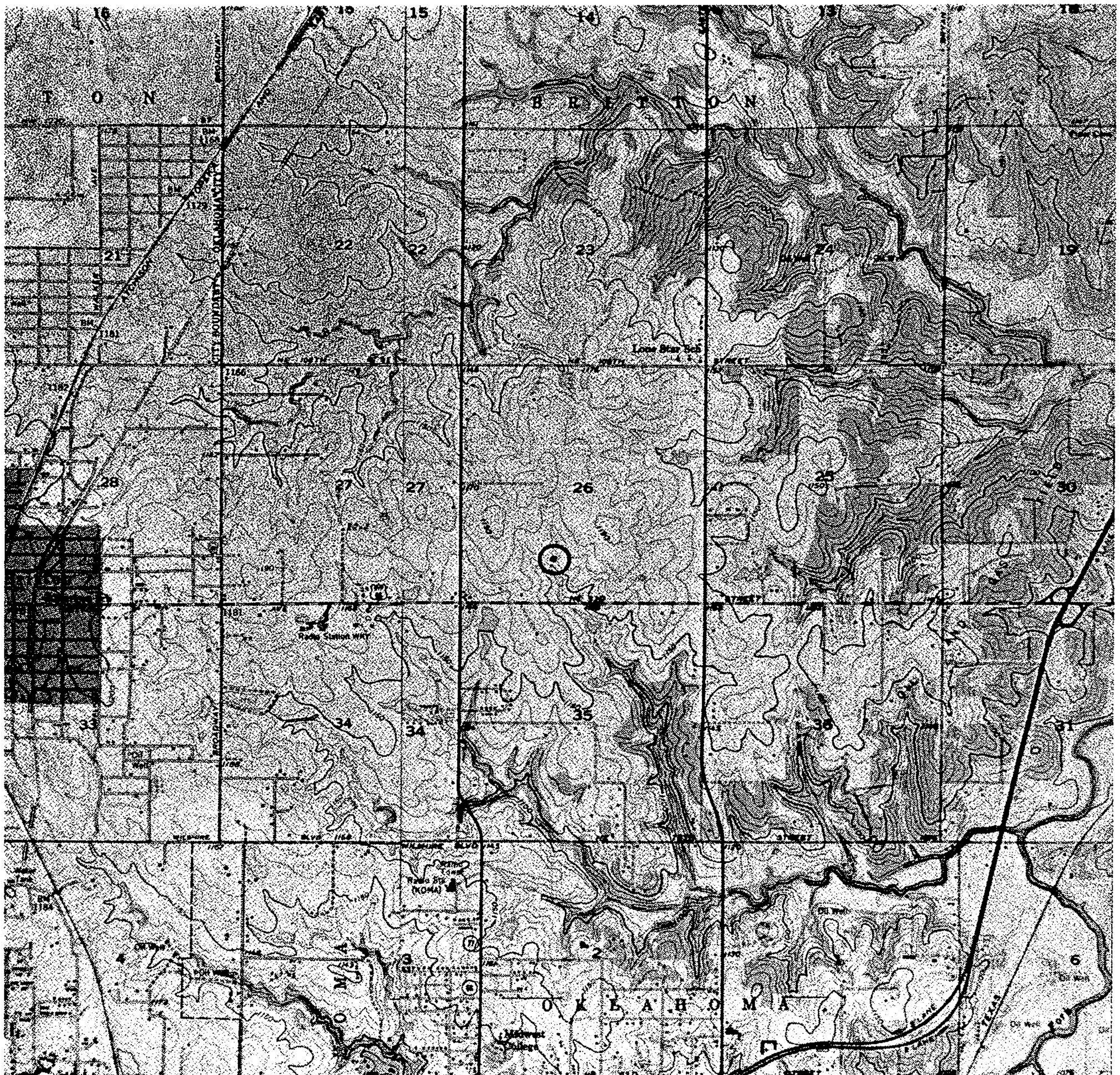

Figure 2. USGS quadrangle map of tower locale.

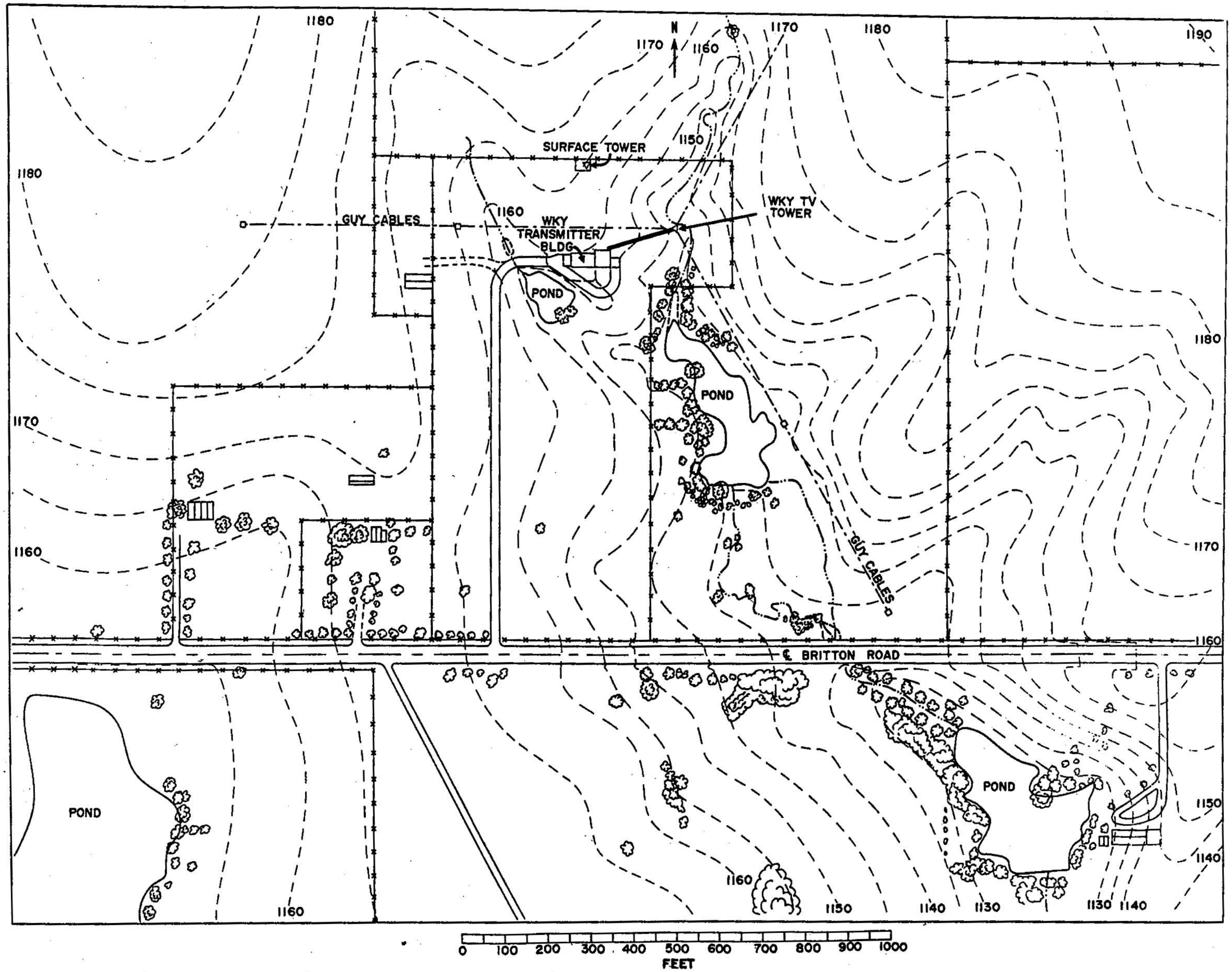

Figure 3. Large-scale map of roughness elements near tower.

2. HISTORY

In 1966, with WKY Television Systems cooperation and National Aeronautics and Space Administration (NASA) financial support, the National Severe Storms Laboratory (NSSL) installed meteorological instruments on the 481 m WKY-TV transmitting tower (Fig. 1). The objective was to provide a vertical probe that would yield thunderstorm information in the boundary layer while complementing other existing NSSL programs (e.g., radar, surface networks, and upper air networks).

During 1966 and 1967, 1 yr of wind observations and 6 mo of temperature data were collected on analog strip charts. Climatological studies made from these data define average characteristics in the lower portion of the planetary boundary layer. After the first year of operation, data were collected routinely in the spring during the annual severe storm period primarily for NSSL use but occasionally for outside interests.

Digital data acquisition with magnetic tape started in 1968. In 1970 relative humidity and vertical velocity sensors were added. A new tower level at 26 m was installed in 1971, replacing surface wind and temperature observations collected from a site about 75 m northwest of the tower. Rainfall and pressure were recorded at the surface for the first time in 1971. In 1972, a faster response wet-bulb system replaced the Phys-Chemical Research Corporation Model PCRC-11 relative humidity sensors.

3. TOWER SITE AND TERRAIN

The tower, located at 35°42.2'N, 97°29.4'W, is approximately 10 km north-northeast of downtown Oklahoma City and 357° at 36.8 km from NSSL. The Oklahoma City suburbs extend to within 4 km south and west of the tower site. The area surrounding the tower consists of gently rolling terrain with no more than 40 m change in elevation within a 4 km radius of the tower (Fig. 2). The land is used for agriculture; wooded areas are confined generally to gullies and around ponds. The tower stands at the north end of a small draw oriented southeast-northwest (Fig. 3). A pond, surrounded by trees 5 to 8 m tall, extends from about 65 m south to 200 m south-southeast of the tower. The WKY-TV transmitter building is 65 m west-southwest of the tower and is about 12 m high relative to the tower base; therefore, the lowest tower level is 14 m above the top of the building. The area west through north to southeast of the tower is free of large obstructions for about 1 km. Additional information about the physical character of the site is provided by Sanders and Weber (1970); they also give details on the aerodynamic roughness (z_o) properties.

4. INSTRUMENTATION AND CALIBRATION

4.1 Introduction

Instruments for horizontal wind and temperature are mounted at 26, 44, 89, 177, 266, 355, and 444 m on the 481 m WKY-TV tower. At 26, 177 and 444 m, vertical velocity and wet-bulb temperature sensors are also mounted. Pressure and rainfall are measured at the surface. Figure 4 illustrates the instrumen-

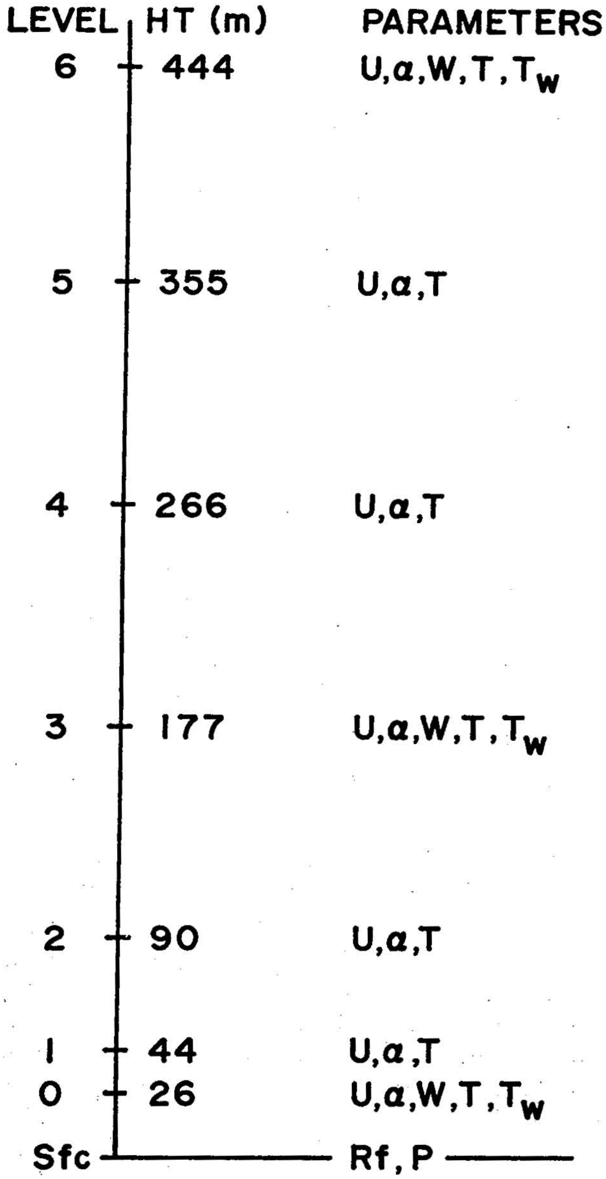

Figure 4. Tower instrumentation at each level.

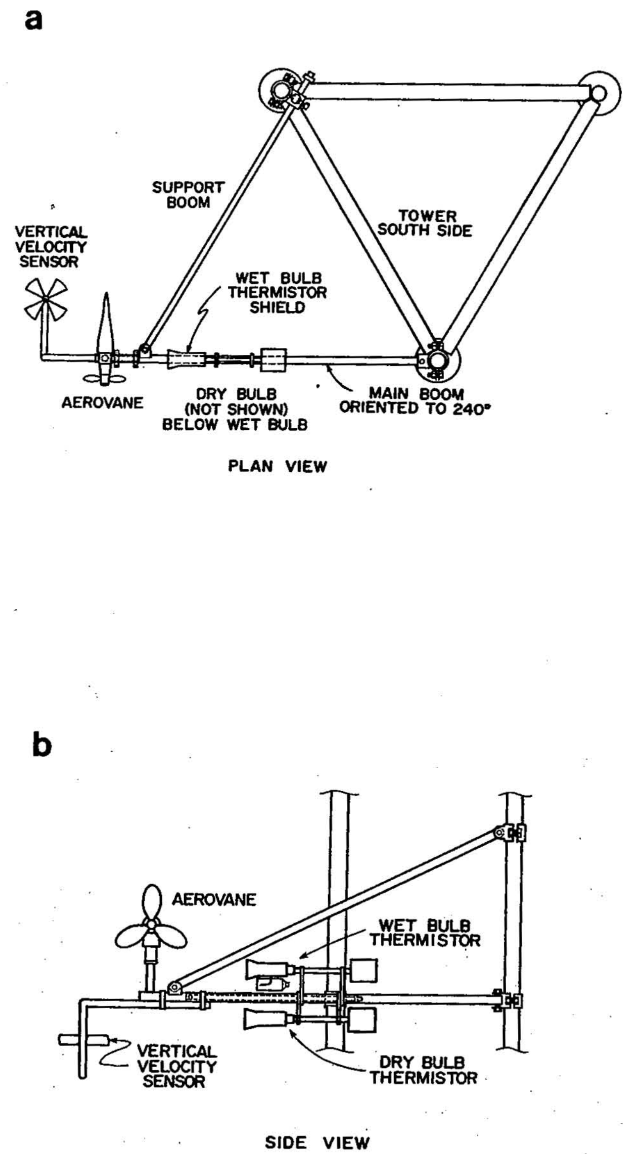

Figure 5. Tower instrument boom configuration.

tation at each level while Fig. 5 shows the boom configuration plan. The main boom is aligned to an azimuth angle of 240°. The orientation represents a compromise between instrument accessibility and favorable exposure for measuring the horizontal winds. Figure 6, from the Gill et al. (1966) study and adapted to the tower by Carter (1970), indicates the tower's effect on wind speed as a function of direction. Between 350° and 70° (through north) the tower may reduce the wind speed up to 40% but the winds are within this section less than 25% of the time (Crawford and Hudson, 1970). The prevailing wind is from the south and southwest.

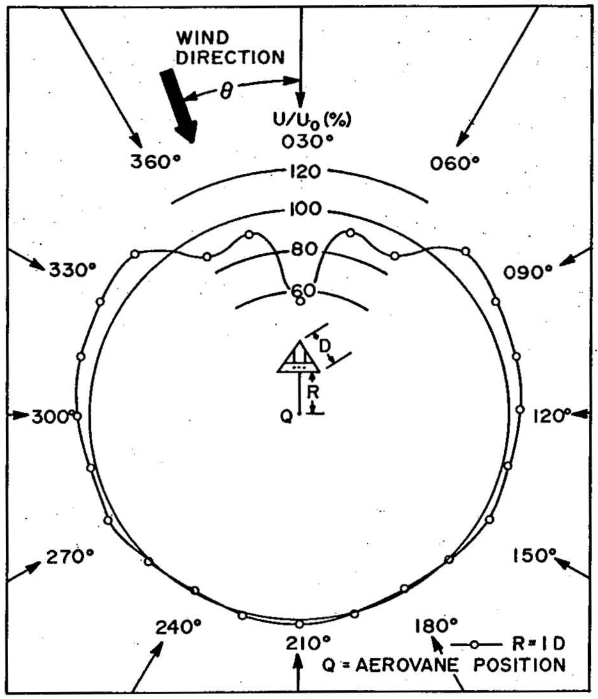

Figure 6. Tower effects of wind speed (modified for NSSL Tower; original from Gill et al., 1966).

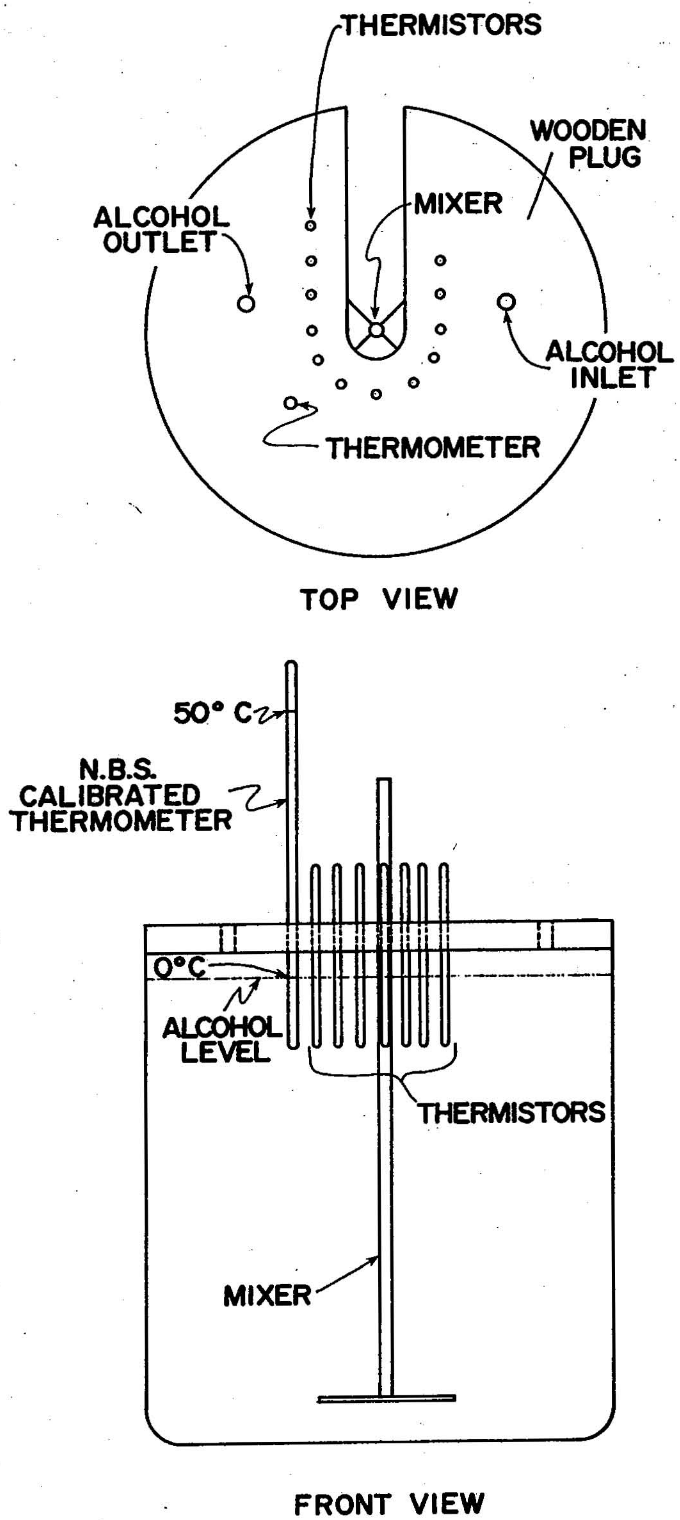

Figure 7. Thermistor calibration apparatus.

4.2 Dry-Bulb Temperature System

The temperature is measured on the tower with Yellow Spring's linearized thermistor composites housed in aspirated radiation shields and mounted on the tower booms (Fig. 5). Two independent electrical systems are used: one gives directly the ambient temperature at 26 and 444 m; the other measures the difference in air temperature between a reference thermistor at 444 m and those at each level (Carter, 1970). Two temperature observations at 26 m provide the redundancy desirable for quality control (see sec. 8).

The thermistors are calibrated each winter. The testing apparatus (Fig. 7) consists of an alcohol bath continuously stirred with a mechanical mixer into which the sensors and a National Bureau of Standards (NBS) certified liquid-in-glass thermometer

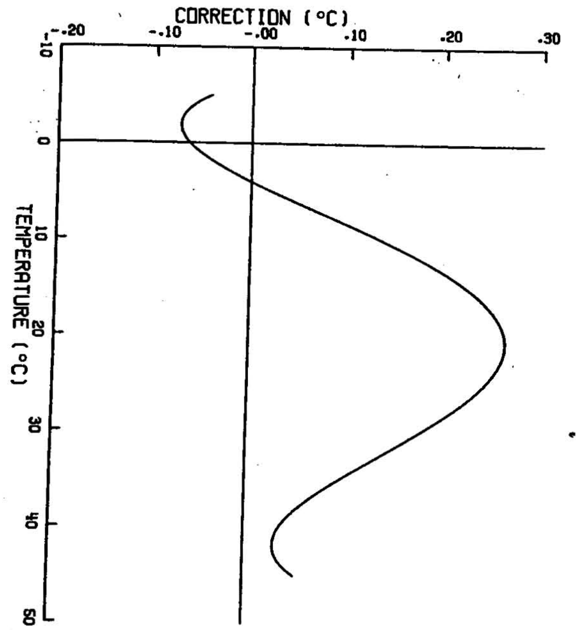

Figure 8. Chebyshev polynomial fitted to thermistor corrections.

(U.S. Dept. of Commerce, 1966) are placed. The thermistors are wired in a circuit similar to that at the tower and connected to a digital voltmeter for direct temperature read-out. The bath temperature is raised from -10C to 50C in approximately 1C increments by adding heated alcohol. Since the NBS thermometer is calibrated for total immersion, we correct for the emergent stem with

$$S = Kn(T_b - t) \quad (1)$$

where S is emergent stem correction; K is coefficient of expansion of thermometer glass (=0.00016); n is number of degree graduations emergent from bath; T_b is bath temperature and t is emergent stem temperature.

Correction to absolute temperature for the thermometer (National Bureau of Standards) is also applied. The sum of the immersion correction, S, correction to absolute temperature, and correction for each thermistor comprise the total correction. Fifth order polynomials are fitted to the correction data of each thermistor (Fig. 8). Subsequently, these polynomials are used to determine the actual temperature during tape archiving.

4.3 Wet-Bulb Temperature System

The wet-bulb temperature system used on the tower is a modified dry-bulb system. The system consists of a thermistor covered with a wick mounted in an aspirated shield. The wick runs to a water supply through a small hole in the bottom of the shield (Fig. 9). After the wick is primed, capillary action maintains saturation. The electrical circuitry is similar to that used for the ambient dry-bulb thermistors. The shielded wet-bulb thermistors are mounted on the boom above the shielded dry-bulb sensors (Fig. 5b).

The system was tested in the early autumn of 1971 both in a closed chamber and in a field test. In the closed chamber test, two NBS certified liquid-in-glass reference thermometers (one used as a wet-bulb thermometer) were mounted side by side (Fig. 10). Dry- and wet-bulb thermistor probes were mounted in an aspirated shield with the wet bulb behind the dry bulb (in the field, two separate shields were used). The shield was placed downstream from the reference thermometers. A fan evaporated water from a pan and circulated the air within the chamber. Water evaporating from the wet-bulb thermometer wick was assumed to have a negligible effect on the readings.

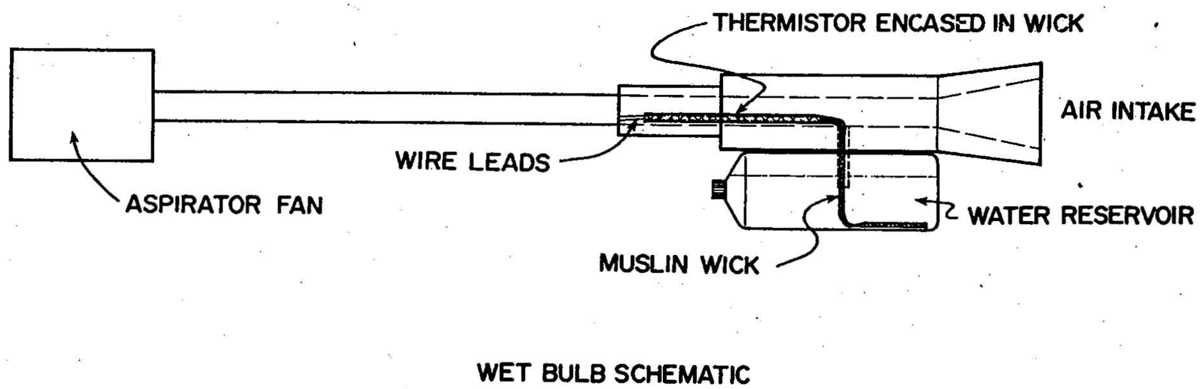

Figure 9. Schematic of wet-bulb thermistor, radiation shield, and water reservoir apparatus.

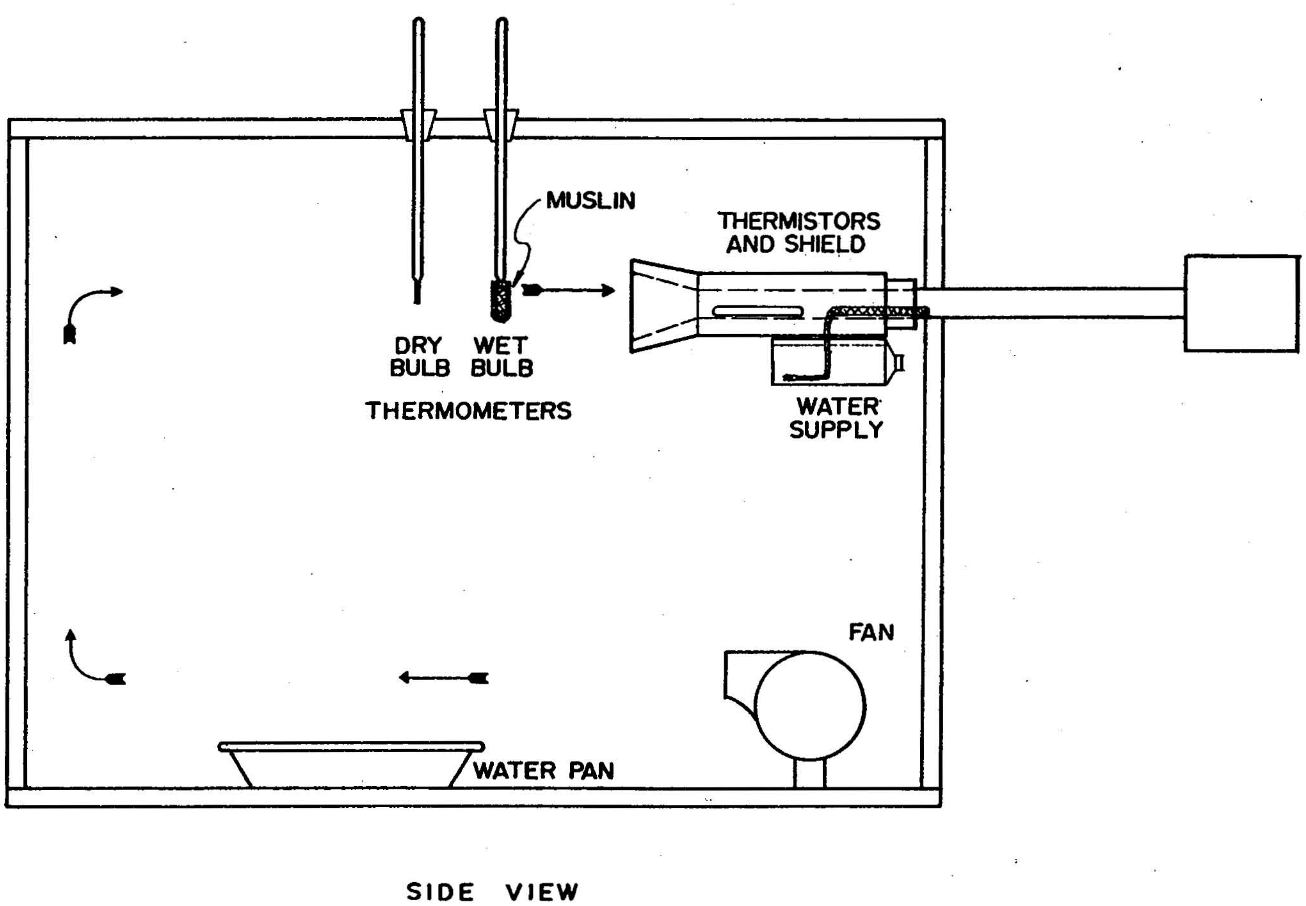

Figure 10. Humidity test chamber for wet-bulb thermistors and thermometers.

The test results indicated that the time constant (see Gill and Hexter, 1972) of the wet-bulb thermistor was roughly 1 min with an accuracy of ± 2% of true relative humidity. The thermistors used in the wet-bulb system were calibrated as described in Section 4.2.

4.4 Horizontal Wind System

Wind speed and direction are sensed with Bendix Model 120 aerovanes and recorded on analog strip charts. The aerovanes are mounted at seven levels on the tower as shown in Figs. 4a and 4b. The manufacturer's specification for the aerovanes is given by Carter (1970). In August 1971, the aerovanes were tested in the National Center for Atmospheric Research (NCAR) wind tunnel in Boulder, Colorado. Wind speed settings at 5, 10, 15, 20, 25, 30, 40 and 50 kt were determined by a pitot tube arrangement and a R. M. Young model 1200 wind sensor. The aerovane output was displayed on a digital voltmeter and analog strip chart. Figure 11 shows the deviations of the aerovane digital voltmeter readings from the Hook gage readings. The average deviation from the Hook gage values is -0.85 kt. Since the manufacture's specifications for aerovanes list an accuracy of ± 0.5 kt, a maximum difference of 1 kt between two instruments is reasonable. The data in Fig. 11 have a maximum scatter of 0.4 kt between 5 and 40 kt. Below 50 kt wind speed, all the aerovanes agree well. At 50 kt, wind tunnel effects apparently become serious (not shown).[1]

Later in 1972, the aerovane wind speed output was checked against a sonic anemometer. Assuming high accuracy for the sonic, the results are indeed favorable, as Fig. 12 taken from Hanafusa and Mitsuta attests (private communication).

Before mounting the aerovanes, we bench tested the output by connecting the transducers to a fixed rpm motor. Generators are adjusted to a constant voltage output (9.2 V at 1800 rpm) corresponding to 75.6 kt. The test is repeated on the tower except that the output is read at the tower base. The wind generator is adjusted if necessary to compensate for line voltage loss.

To calibrate the wind direction sensor, we place a specially built jig over the boom (oriented to 240°) with the vane locked in position parallel to the boom. We then read the direction on a synchro-to-digital converter and correct to 240°, if necessary, by adjusting the vane base connector. Accuracy is roughly ± 3°.

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[1]The wind tunnel facility was located in a small room and exhaust air was buffeted by the wall directly behind the tunnel outlet. In addition, the motor driving the fan had an unexplainable 10-sec oscillation that became significant about 40 kt. At the time of the test, it was not possible to determine the dynamic character of the aerovane; i.e., determine the distance constant for wind speed or natural wavelength and damping ratio for the wind direction. Definitions of dynamic and static characteristics follow Gill and Hexter (1972).

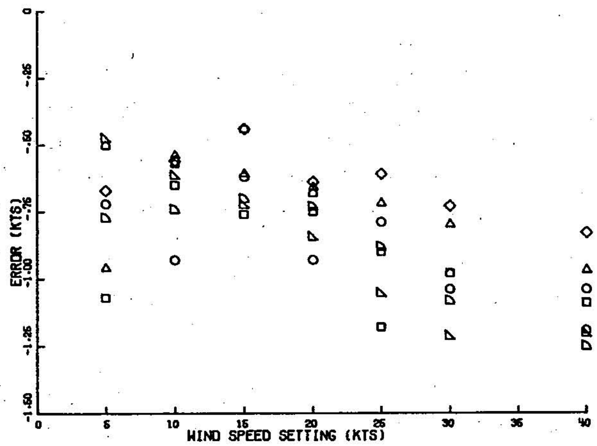

Figure 11. Deviations in aerovane wind speed output from indicated true tunnel speed. (Symbols represent different aerovanes.)

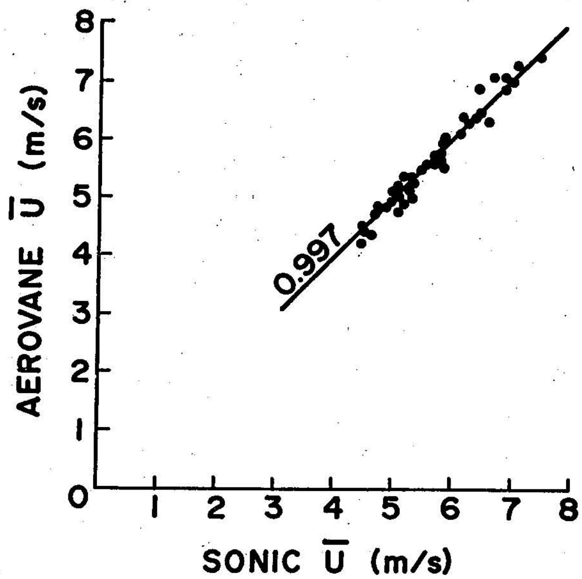

Figure 12. Comparison of sonic anemometer and aerovane (wind speed). Scatter coefficient indicated.

4.5 Vertical Velocity

R. M. Young Model 1200 propeller anemometers are used to measure the vertical wind speed at 26, 177 and 444 m. The data are recorded both digitally on magnetic tape and on strip charts. Output from the instrument is tested on the ground and on the tower with a fixed rpm motor for clockwise and counterclockwise rotation. Since the transducer is not adjustable, velocities are linearly scaled for each instrument by determining a sensitivity constant. Full-scale values are $\pm$ 0.500 V $\pm$ 0.003 V at 1800 rpm (11 m sec^{-1}). The anemometer is vertically oriented by a carpenter's level.[2] Deviations of up to 3° from the vertical can be expected.

4.6 Pressure

Surface pressure is measured using the Belfort Model 6069 aneroid barometer mounted in a ventilated instrument rack in the transmitter building. The sensor is calibrated against a conventional mercury barometer. As with other aneroid barometers, tapping the instrument helps overcome effects of dead band and hysteresis. To do this during routine data collection, an automatic tapping

[2]This alignment procedure is not completely satisfactory. The alignment can only be made by eye and with the boom pulled in from its normal position. Remote electronic leveling will be used soon.

tapping device was designed and installed. The tapper strikes the top of the instrument box once each minute. During rapid pressure changes, sudden jumps in the data are detectable at sampling rates less than 1 min.

4.7 Rainfall

Rainfall is measured with Belfort Model 5-780 single traverse instrument located 75 m northwest of the tower. The chart recording mechanism has been removed and replaced by a gear train driven transducer. The transducer output is linearly proportional to the amount of rainfall. The raingage is calibrated before the start of the season using weights equivalent to 1 inch of rain per weight. Accuracy is roughly $\pm$ 0.05 inch.

4.8 Signal Conditioning Apparatus

Figure 13 is a block diagram of Digi-Data, Inc. signal conditioning equipment used at the tower. Forty channels of data, written in an IBM-compatible format at 200 bpi, are recorded sequentially in two 20-channel blocks (e.g., in a 10-sec sampling mode; alternate sets of 20 parameters are sampled every 5 sec). Each data channel is digitized in a three-bit BCD word and each record is 76 characters (bits) including "housekeeping" information (Carter, 1970). An electrically operated digital clock is an integral part of the data formater (not shown in Fig. 13). Because AC power interruptions recycle the clock, a battery powered digital clock will be installed in 1973.

5. DATA COLLECTION PROGRAM DURING 1972

During 1971, data were collected on magnetic tape on storm days and suspected storm days. Since no serious problems were encountered in 1971, it seemed feasible to collect at least 2 mo of "continuous" data in the spring of 1972. Significant differences between sporadic and continuous data operation programs were soon obvious. They involved problems of data handling, manpower, and routine preventive maintenance (Sec. 7). Despite a small computer and a limited staff, data handling improvements were made over previous years. For example, turnaround time for archiving ranged from 54 hr to 14 days in 1972, with about a 10-day average. This compares favorably with the 7 to 9 mo turnaround time in 1970 and the 4 to 6 mo turnaround time in 1971. Preventive maintenance was important but often could not be performed because of continuous data requirements. Toward the end of the spring season, this factor caused some mechanical failures serious enough to force a lengthy shutdown of the tower equipment facility, which of course, left large gaps in the data set (Sec. 9).

Ice, snow and cold weather restricted tower work between 15 November and 15 March. However, to catch significant storms the tower facility had to be operational before 15 April. This means that between 15 March and 15 April time and the weather are critical elements. In 1972, the tower was operational 2 days before the proposed seasonal deadline. Data collection proceeded smoothly for about 5 weeks. Only relatively minor problems with the reference thermistor and the vertical velocity sensors were encountered (see Sec. 6). On 27 May, during a severe thunderstorm, lightning caused a failure of the signal conditioning equipment and thereafter, problems with the recorder and other components persisted for about 1 mo.

In mid-June, we believed that convective activity might continue a few more weeks and decided to continue collecting data one more month. The forecast proved accurate; from 27 June to 3 July three significant storms occurred. The "spring" program was terminated on 12 July, but the tower operation continued for some time at the request of the University of Oklahoma Meteorology and Electrical Engineering Departments as part of their acoustic radar program.

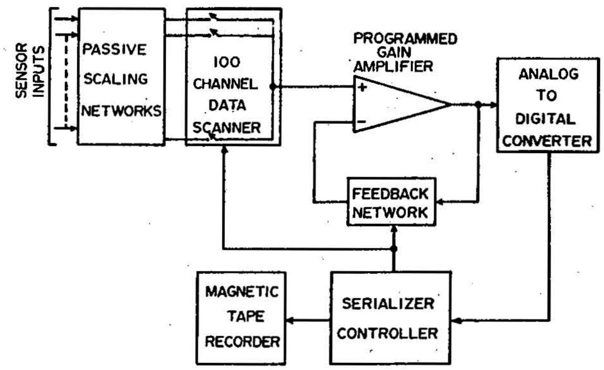

Figure 13. Signal conditioning system block diagram.

6. MAINTENANCE PROCEDURES

For the first 2 mo, the following equipment was checked daily: the digital and analog recording systems, power supply and amplifier calibration voltages, and sensor output. After the equipment proved stable, checking was reduced to two or three times weekly. The routine included checking the digital recorder for power failures, and setting the digital clock to WWV time. The channel recording sequence was checked. If any malfunction had occurred, it was logged and the system corrected before a new tape was loaded. Usually the time required to change a tape was 10 to 15 min. However, when the system required a complete check-out, delays of over an hour resulted. In normal operation, a tape lasted 6 days at a 1-min sampling rate and about 27 hr at a 10-sec rate.

The analog strip chart recorders were checked for possible internal failures and for possible sensor malfunction. Time registration marks were entered on each chart. The horizontal wind charts advanced 3 inches per hour and required changing every 2 wk. The vertical velocity sensors were recorded at 8 inches per hour and charts were changed every 3 1/2 to 5 1/2 days depending upon the type of recorder used. Temperature data were not recorded on analog strip charts because the recorders overloaded the circuitry.

Power supplies for the raingage, microbarometer, ambient, delta, and wet-bulb temperature circuits, and two amplifiers in the digital system were checked daily. Table 1 shows the calibration voltages and typical corrections for the power supplies and amplifiers. Mechanical linkage in the raingage was characterized by a large dead band near zero output. This required adjustment each time the rain bucket was emptied.

Wet- and dry-bulb temperatures were read daily. For the dry-bulb output, the delta system was checked against the ambient system by comparing the 26 m delta temperature to the computed difference between the 444 m and the 26 m ambient temperatures. Possible bad data produced by the wick drying on the wet-bulb probe was checked by noting the behavior of vertical profiles and by checking the 1200 GMT Tinker Air Force Base rawinsonde observation. The wet-bulb water reservoirs ($\sim$ 1 liter capacity) required refilling every 1 to 2 wks.

Table 1. Sensor Circuit Calibration Voltages and Corrections.

SENSOR CIRCUIT	CALIBRATION (V)	TYPICAL CORRECTION (V)
Temperature		
Ambient Dry	1.4715	± 0.001
Ambient Wet	1.4715	± 0.001
Delta Dry	1.4715	± 0.001
Pressure	10.80	None
Raingage		
Dry Bucket Before Rainfall	1.00	None
Dry Bucket After Rainfall	1.00	± 0.05
Amplifier		
Gain of One	3.60	± 0.01
Gain of Ten	5.00	± 0.02

7. PROBLEMS IN DATA COLLECTION

Problems associated with the tower data collection program divide into two groups: those due to location or environment of the data acquisition equipment and those due to electronic malfunction or breakdown. Three difficulties in location were identifiable. First, the remoteness of the site made it difficult to monitor the system. Since no direct linkup of data transmittal between NSSL and the tower existed, and manpower limitations prohibited stationing personnel at the site, monitoring had been done only during maintenance checks and when storms threatened. Over 80% of the time the tower was unmonitored. Second, the tower being situated in rolling terrain produced evidence of nearby natural (and unnatural) obstacles in the data. Third, cold and/or windy weather frequently prevented staff members from working on the tower. With a temperature of 0C and a 10 m sec^{-1} wind, it is impossible to work bare-handed for more than a few minutes. Thus, a problem needing repairs had to wait for favorable meteorological conditions.

Unlike other tower facilities where data are generally collected under "ideal" conditions, NSSL collects data primarily during adverse weather with increased risk of instrument failure. The vertical velocity sensor is most susceptible to direct damage from high winds and hail; the light polystyrene propeller blades break rather easily. Furthermore, high winds occasionally tilt the axis of the sensor away from the vertical (see Sec. 8). Elderkin et al. (1972) found that an error in orientation of as little as 1° produced significant errors in their data. High winds also prevent necessary repairs on occasion. Replacing a broken anemometer propeller and replenishing the water supply of the wet-bulb sensor are typical repairs.

The digital data acquisition system was susceptible to disruption by lightning and power failures that caused the digital clock to malfunction. During most storms an attendant was present to reset the clock and mount a new tape if required. If power failures occurred during an unattended period, the accuracy of the recorded time was considered questionable. A more severe problem was traced to voltage transients that caused component failures. An amplifier failure on 27 May resulted in a 6 hr gap in the data. Moreover, voltage transients weakened other digital recorder components. Certain mechanical relays in the scanner, weakened in such a manner, produced intermittent errors. Another problem was aerovane direction synchros that were interfaced to the recorder through a 360° potentiometer. Because the potentiometer had a "dead" spot when the vane pointed due north, erroneous values were frequently recorded on tape. One interfaced potentiometer burned out in mid-season and was undetected for several days during an unmonitored period.

One unexpected error source occurred in the dry-bulb delta temperature system. After a month of operation we noted that the temperatures being recorded seemed biased by approximately -0.5C. A thorough check showed that a resistor in the thermistor probe had malfunctioned. To minimize the disruption to data collection, another thermistor in a new shield was mounted adjacent to the old instrument. (Post-season calibration indicated that the voltage output for the problem thermistor had shifted an equivalent of -0.5C).

8. QUALITY CONTROL

8.1 General Statements

An important but often deemphasized step in data collection is quality control. Before the advent and extensive use of tape recorders, quality control was relatively simple though probably less effective. Making a few equipment checks and monitoring strip charts usually were enough to insure that outputs remained within desired tolerances.

Tape recorders are useful when large quantities of data are desired.[3] Magnetic tape output implies "recording in the blind," that is, you cannot see

[3] Output of a meteorological signal can be recorded on magnetic tape as a continuous frequency (analog) or incrementally as a binary or hexadecimal impression (digital). The signal of digitally recorded data has been passed through an A/D converter. These data may be processed immediately. The analog data must be passed through an A/D converter before computer processing commences.

what is actually recorded on tape until the tape is removed and listed. An important aspect of data archiving is to develop good quality control techniques that reveal data errors that cannot be seen by a visual scan of the tape listing. When the data set is small, only a desk calculator is necessary; however, collecting data with a tape recorder usually indicates a data set too large for only a calculator. Then a large-capacity digital computer is a necessity. Computer-based quality control takes time and effort to develop and employ. It should be used in as near real time as possible, so that problems can be detected quickly.

For practical purposes, recording should be by strip chart recorders as well as on magnetic tape. As a primary function these recorders provide a quick and easy check of gross features. Figure 14 (a, b, and c) illustrates equipment malfunctions easily detected by the trained eye from the strip charts: 14a, a vertical velocity sensor tilted from the vertical; 14b, the same probe with a broken propeller; 14c, vertical velocity output from a sensor with a faulty bearing. Figure 14 (d and e) shows the expected vertical velocity trace during turbulent and quiescent periods.

At the NSSL tower facility, most signals are recorded on strip chart paper before being recorded on magnetic tape. There is one limiting factor to this procedure. If the signal is weak, a low impedance strip chart recorder may load the circuit enough to create a significant voltage drop. Therefore, during 1972 the temperature strip chart recorders were not used.

Some problems are best detected with specialized quality control routines. The sophistication of the routine is limited by the size of the available computer. For the 1971 and 1972 data collection programs, the size of the readily available computer (IBM 1620) was a restrictive factor.[4]

During both seasons, the same quality control techniques were used. All profiles from the NSSL site were compared with those expected under conditions of a neutrally stratified stationary boundary layer and locally homogeneous terrain. The well-mixed, homogeneous boundary layer will be called the control condition. Lumley and Panofsky (1964) provide information on the behavior of the lower 150 to 200 m of the planetary boundary layer under control conditions. The atmosphere above 200 m is not adequately parameterized, although intelligent guesses may suffice for quality control.

8.2 Quality Control to Determine Deviations from Gross Features

The simplest of all quality controls involves determining the mean. The mean wind speed, wind direction, and temperature were computed and plotted in vertical profiles. Below 100 m, the wind speed profile is logarithmic in neutral conditions (Tennekes, 1973). Above 100 m, the wind speed generally increases slowly with height up to 355 m, then is either constant or decreases

[4]NSSL now has a System Engineering Laboratory Model 8600 computer.

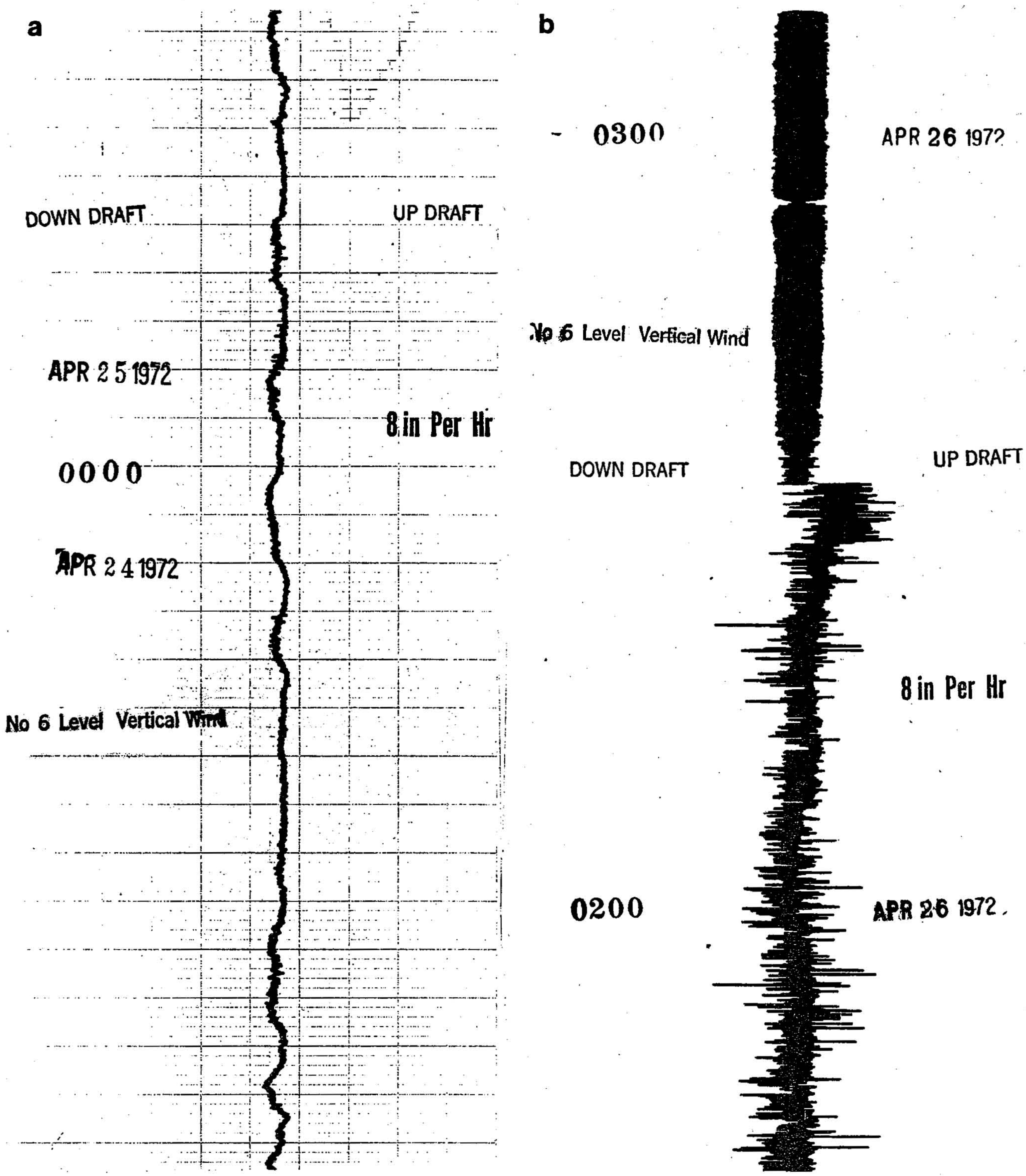

Figure 14. Strip chart data of vertical velocity showing (a) biasing due to improper alignment, (b) broken propellor blade, (c) faulty bearings, (d) normal turbulent periods, (e) normal quiescent periods.

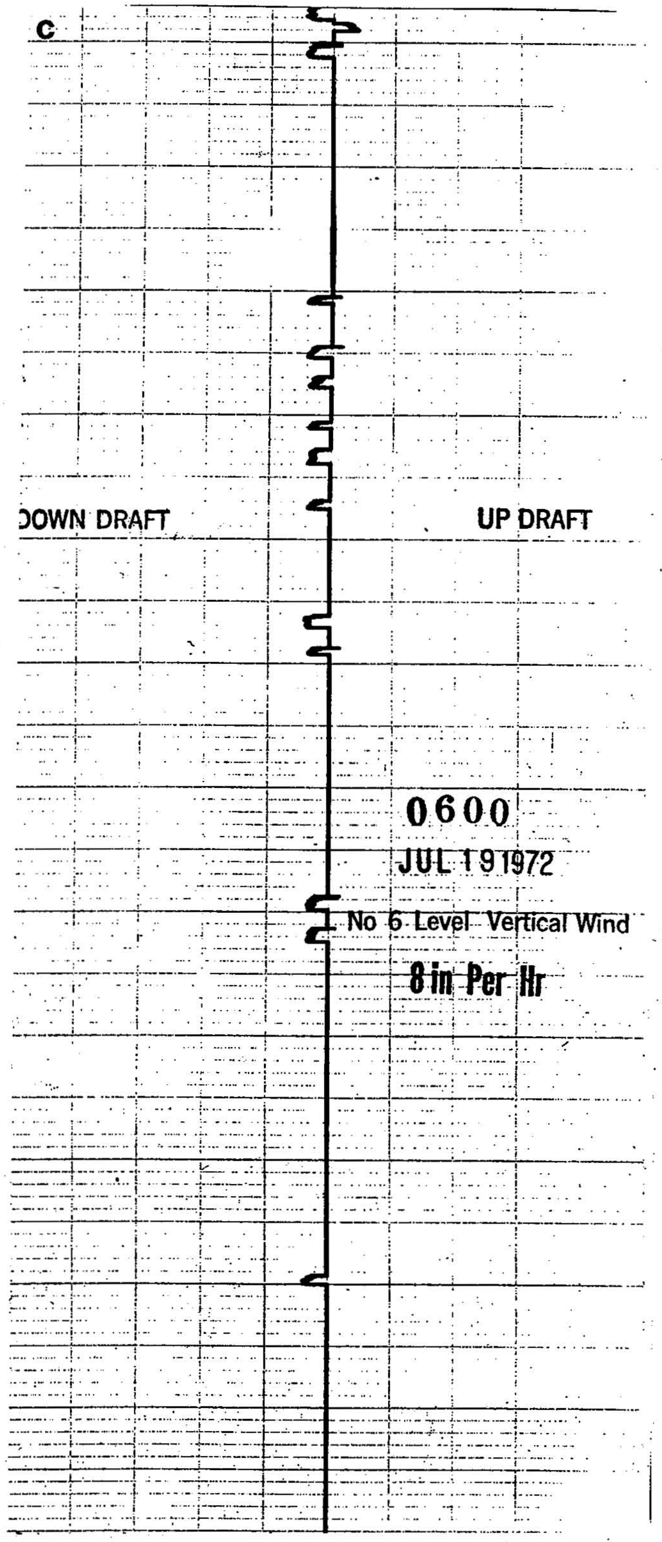

Figure 14c. faulty bearings

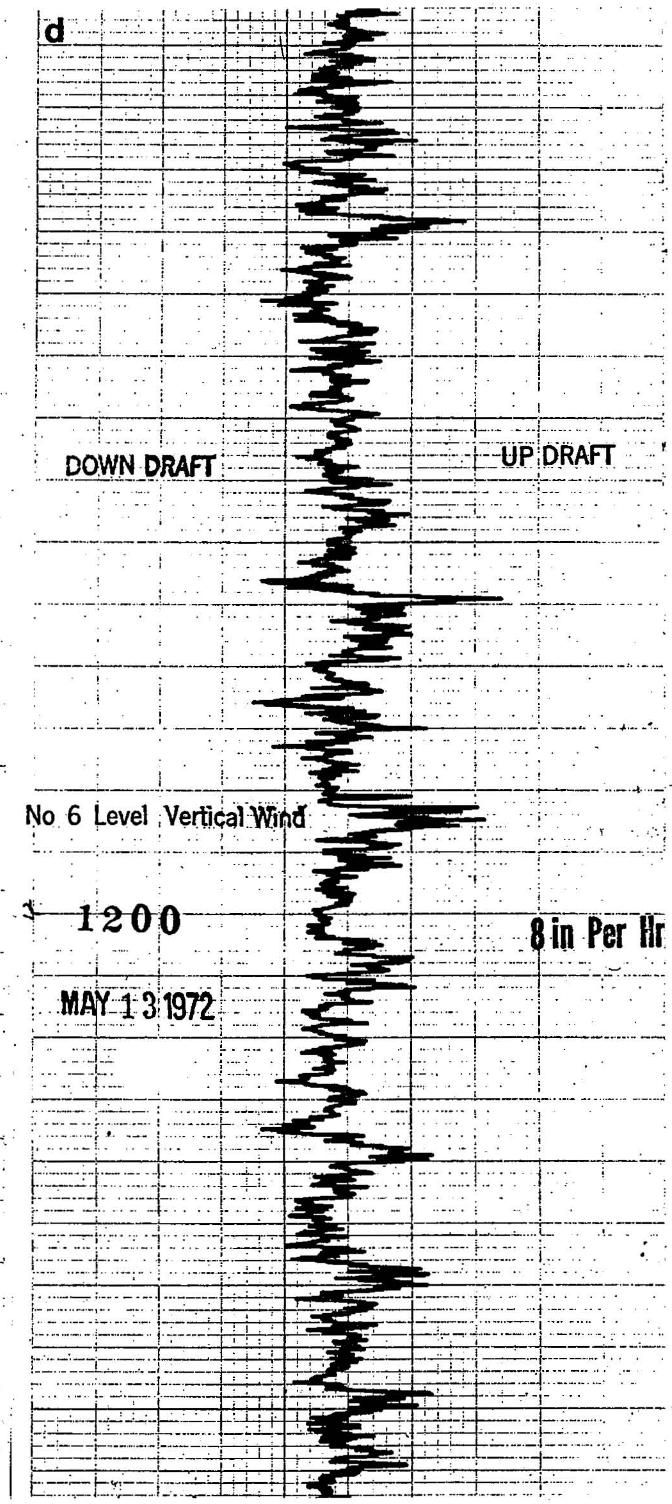

Figure 14d. normal turbulent periods

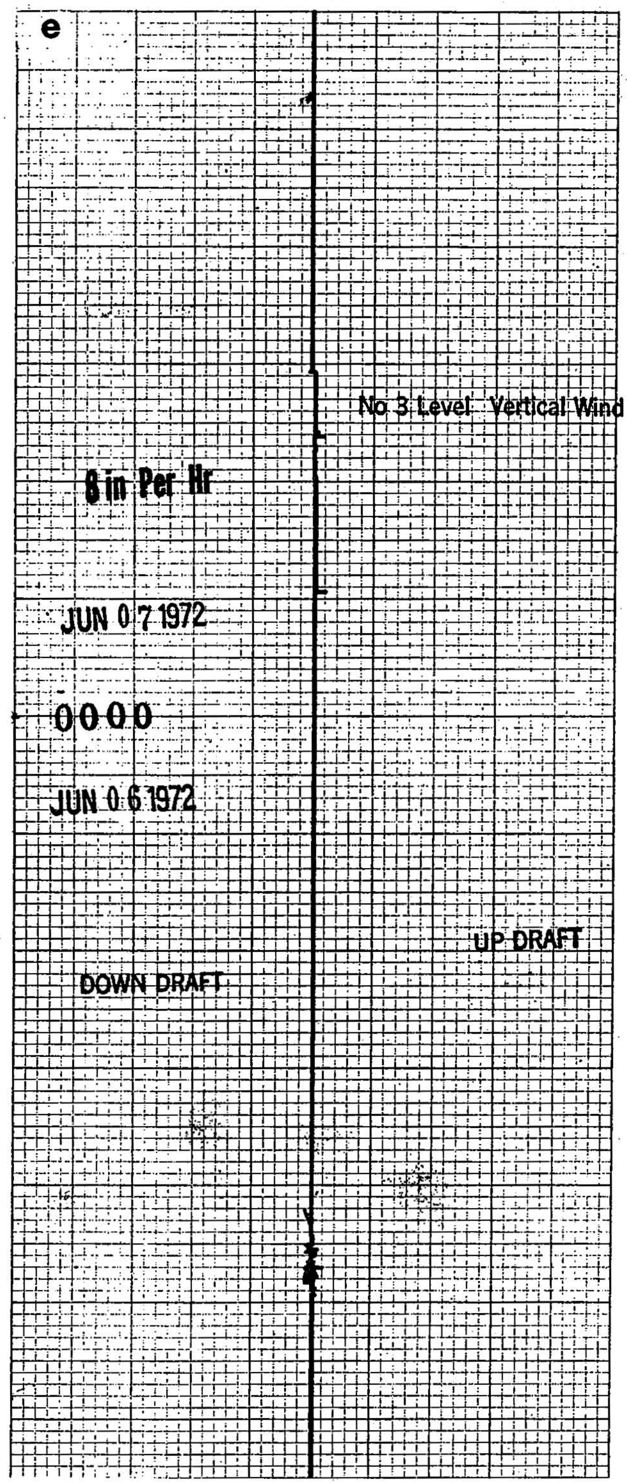

Figure 14e. normal quiescent periods

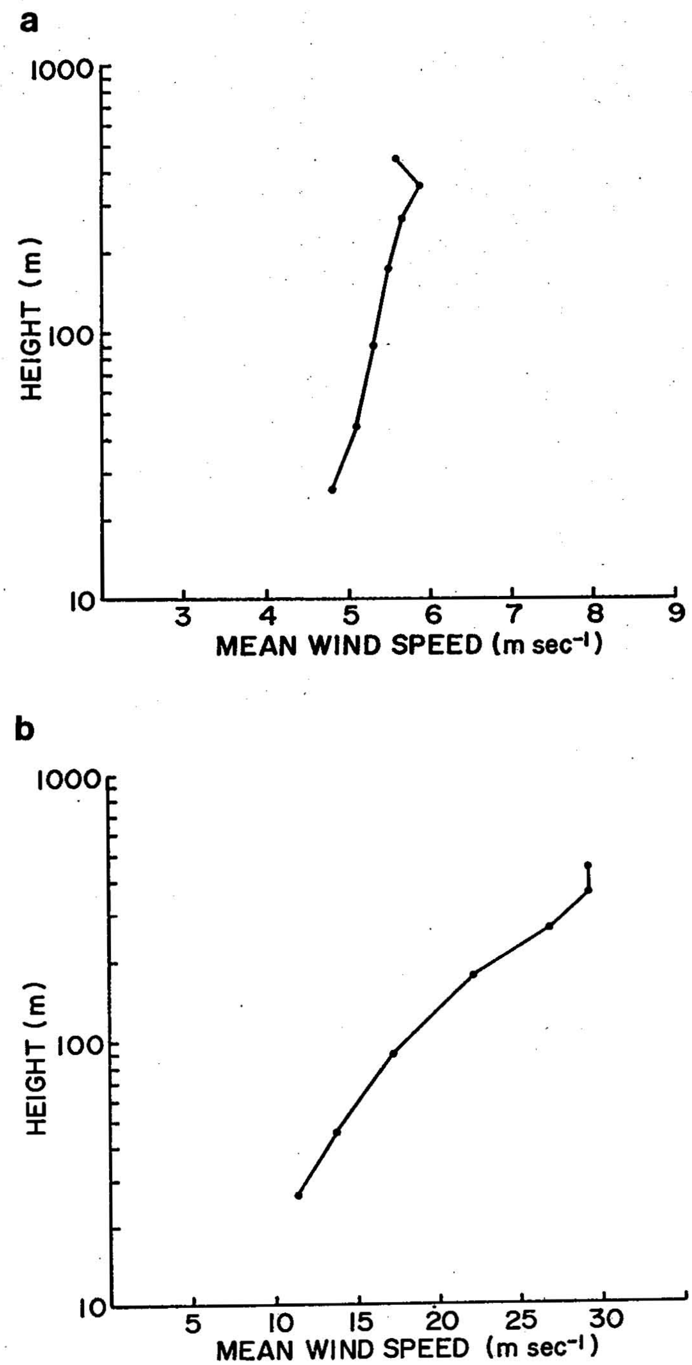

Figure 15. Representative average wind speed profiles on (a) low shear and (b) high shear days.

up to 444 m.[5] Inflection points at lower levels may exist but should not be prominent. If small inflection points appear, they may be due to instrument error but also can be explained theoretically (Peterson, 1972) as evidence of internal boundaries caused by heterogenous terrain. Thus, for quality control, we are concerned with only gross features of the mean wind profile. Figure 15 (a and b) represents averaged (hourly) wind speed profiles on low-shear and high-shear days, under near-neutral conditions.

Generally, the wind direction veers with height up to the gradient wind level, approximating the Ekman spiral. The wind direction instrument includes two sets of synchros that reduce sensor accuracy. Figure 16 (a and b) shows two averaged (hourly) typical wind direction profiles under similar meteorological conditions. The consistently wavy profiles look suspicious, but cannot be improved because they remain within instrument tolerances.

The mean temperature profile is more reliable as a quality check than are the profiles of other parameters. On clear days, especially after a cold front passes, the boundary layer has a very steep unstable lapse rate near the ground, approaches the dry adiabatic rate near 100 m and is nearly dry adiabatic above 100 m (Goff and Hudson, 1972). Figure 17 is a typical profile. Small errors can be detected if a profile differs from Fig. 16 during control conditions.

The mean vertical velocities were computed only to check whether they differed significantly from zero, especially at the lower levels. Other quality control techniques described below are more useful for the vertical velocity.

Usually the wet-bulb depression decreases slowly with height in a well-mixed atmosphere. The profile shape is not generally known in control conditions, so subtle errors are not detected.

The standard deviation of the wind speed σ_U is useful in detecting certain kinds of errors in digital data. Figure 18 suggests that the profile is logarithmic in the tower layer. On days when the profile appears to be smooth, one can use σ_U for checking the bearings in the propellor mechanism. The output from an aerovane with such a problem will have comparatively low σ_U (444 m, Fig. 19).

The behavior of the standard deviation of wind direction σ_α is similar to that of σ_U, but in the tower layer σ_α is much smoother than σ_U if the layer is vertically homogeneous, and thus better indicates faulty equipment. Figure 20 is a typical profile σ_α.

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[5] The decrease of wind speed above 355 m may be caused by the low-level jet (Blackadar, 1957), but the phenomenon appears consistently in all profiles (Crawford and Hudson, 1970). The decrease of the wind from the next to the highest to the highest level was observed on the much smaller 150 m Cape Kennedy meteorological tower (Fichtl, personal communication).

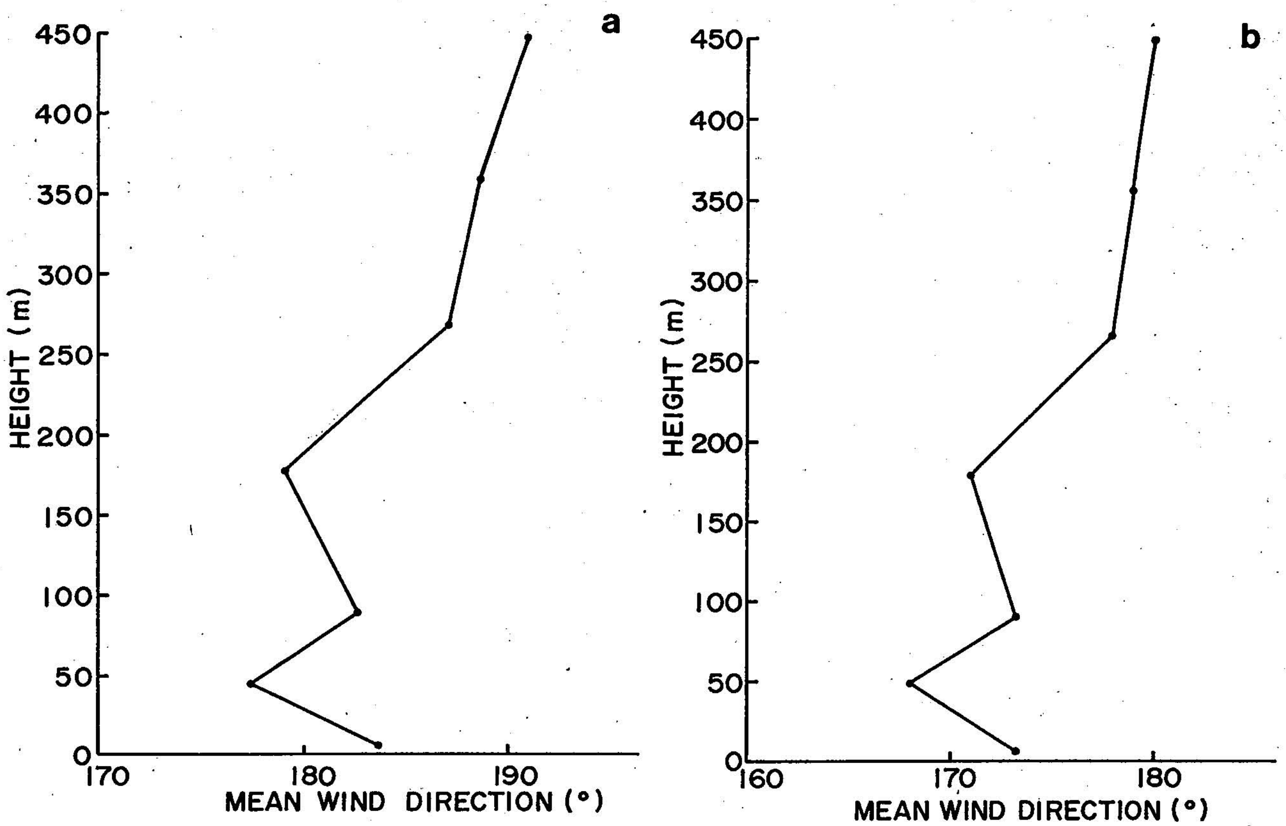


Figure 16. Representative average wind direction profiles on (a) low shear days and (b) high shear days.

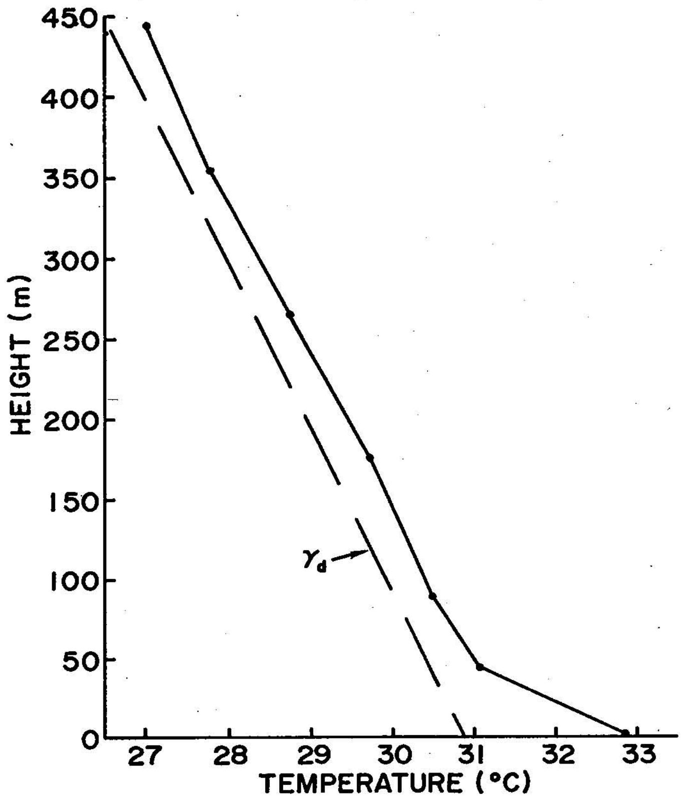


Figure 17. Typical average temperature profile. Dry adiabat (γ_d) indicated.

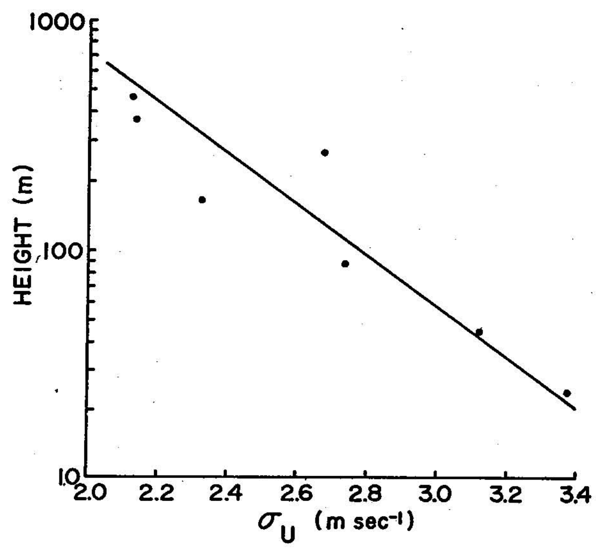


Figure 18. Typical σ_U pfofile.

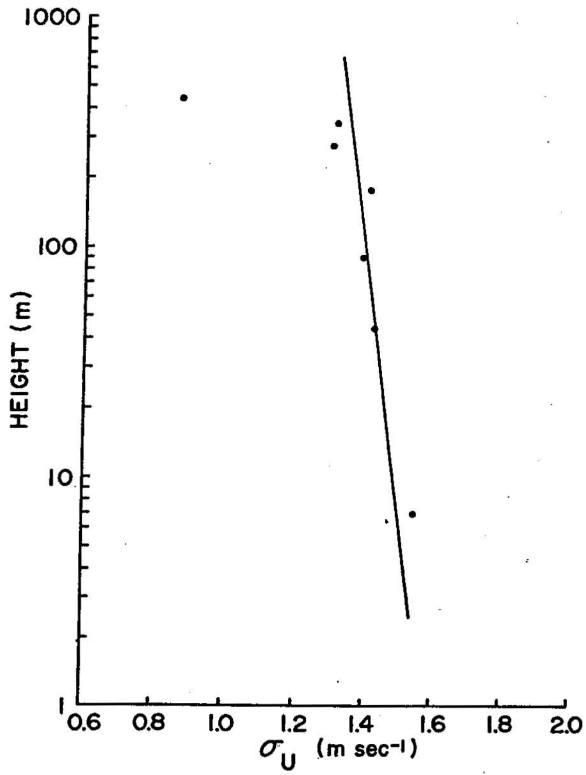


Figure 19. Anamolous σ_U profile.

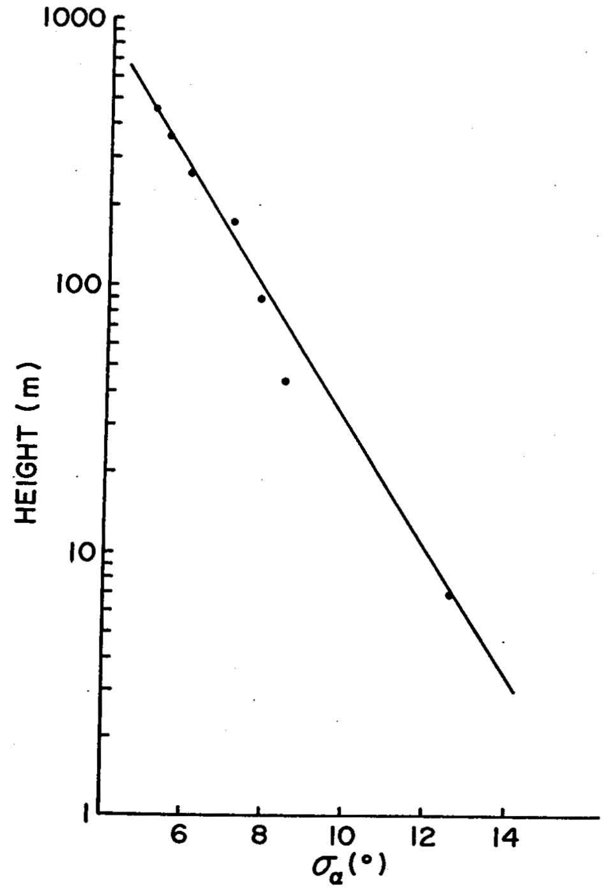


Figure 20. Typical σ_α profile.

Temperature sensors used by NSSL are not sensitive to frequencies above about 0.02 Hz. If the sampling interval is 10 sec, we expect the standard deviation of temperature (σ_T) to be small. It was observed that σ_T decreased approximately linearly with height under control conditions. Deviations from the expected profile were noted and investigated further. Fig. 21 is an example of a σ_T profile when relays in the data acquisition system were not functioning properly.[6] Notice that σ_T for the 2 and 90 m levels is comparatively large.

8.3 Quality Control for Infrequent Transients

Up to now, only the simplest of quality control techniques have been described. Although the mean and standard deviation are useful quality control parameters, they are not conclusive. The mean is helpful in detecting bias type errors. Large and frequent, but sporadic, errors are better detected by the standard deviation parameter and techniques to be explained shortly. When equipment failures occur less frequently or the output has sporadic discrepancies of small magnitude, some quality control technique must be used to isolate bad data rather than to integrate it with the whole sample. Two

[6] In 1970 two temperature sensors were located at 2 m; there were no sensors at 26 m.

simple techniques give the desired results. In one technique, a wind time series is chosen and σ_U and σ_α computed. It is believed that given control conditions, the absolute value of the maximum fluctuation of either parameter will be a function of σ only. In fact, Fig. 21 demonstrates that $|\Delta U|_{max}$ is proportional to σ_U, or

$$|\Delta U|_{max} = C_1\sigma_U \qquad (2)$$

where

$$\Delta U = U_{t+1} - U_t, \; t = 0, 1, 2, \ldots N$$

and N is the sample size. The slope of the best fit linear curve in Fig. 22 indicates that the dimensionless constant (C_1) in (2) is 3.2 for the aerovane and for sampling rates of 10 sec. The "constant" varies for instruments of different sensitivity, and for different sampling rates. The constant appears to be an implicit function of height and time only, that is,

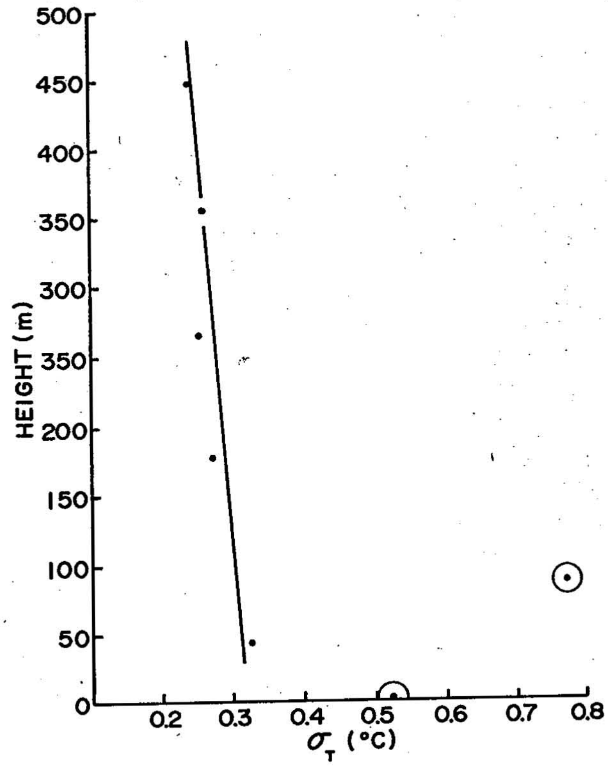


Figure 21. Anamolous σ_T profile (defective thermistors: 2 and 90 m).

$$C_1 = C_1\,[\sigma_U(Z,t)] \qquad (3)$$

with the stipulation that the sampling rate remains constant for a given sensor. We have not determined C_1 for other instruments or sampling rates.

There is an analogous relationship between the wind direction (α) and σ_α. For a time series of size N,

$$|\Delta\alpha|_{max} = C_2\sigma_\alpha, \qquad (4)$$

where

$$\Delta\alpha = \alpha_{t+1} - \alpha_t, \; t = 0, 1, 2, \ldots N.$$

C_2 in (4) was determined to be 4.0 by fitting a linear curve to a scatter diagram of Fig. 23. Notice that at high σ_α, the relationship does not appear

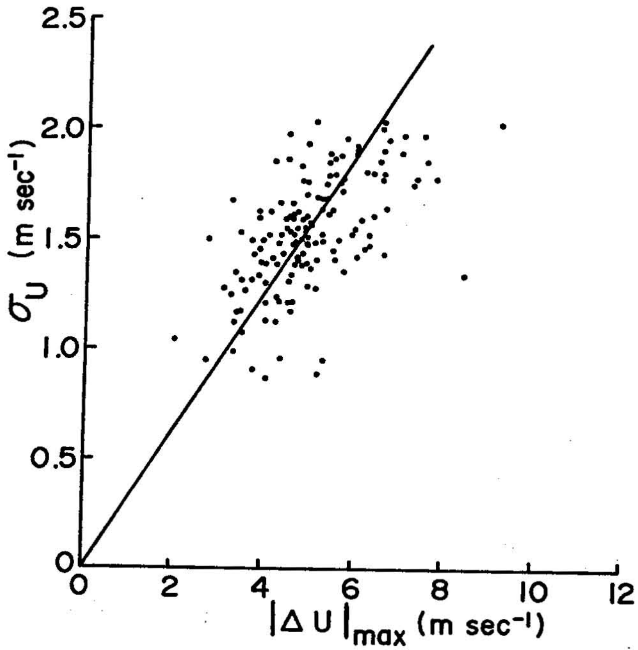


Figure 22. Comparison of $|\Delta U|_{max}$ with σ_U.

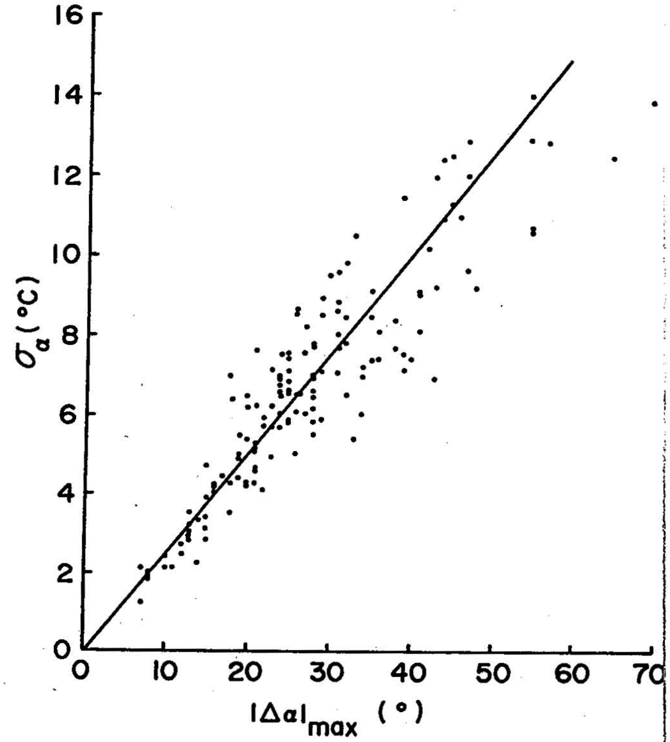


Figure 23. Comparison of $|\Delta\alpha|_{max}$ with σ_α.

to be linear. C_2 also obeys a relation like (3).

With the constants C_1 and C_2 determined for the control data sets, we can use them as quality control parameters for subsequent data sets. We need only determine the standard deviation of the wind speed and stipulate that $|\Delta U|$ not exceed $C_1\sigma_U$ (analogously for wind direction, i.e., $|\Delta\alpha| \leq C_2\sigma_\alpha$).

This technique was used with success for the wind speed and direction, but it was used cautiously on the temperature data.[7] It was not useful for any type of data during thunderstorms, frontal passages, or other phenomena exhibiting unsteady characteristics.

Another simple quality control procedure was the frequency distribution. For example, for the wind speed time series, ΔU was determined and compiled in a distribution over several small intervals. ΔU was chosen instead of U because the range is smaller. Distributions also were determined for $\Delta\alpha$, ΔT

[7]There is no simple relationship between $|\Delta T|_{max}$ and $\sigma_T|\Delta T|$. $|\Delta T|$ may have the same relative magnitude in stable and unstable conditions because (1) in stable conditions the sensor may be influenced by large amplitude, long period gravity wave type oscillations and, (2) in unstable conditions may be influenced by high frequency turbulent fluctuations, albeit the sensor will not respond to the full amplitude of the turbulent eddy if the frequency is high.

and w or Δw. In each case, the distributions should have a bell shape, although they need not necessarily be Gaussian. Bimodal, skewed or other unusual distributions in control conditions were investigated for instrument failure.

8.4 Additional Quality Control Techniques

Quality control is an integral part of the archival procedure of a typical tower data set. Data collected on magnetic tape have units in volts and must be converted to meteorological units. In some cases, the constant of proportionality is unity, and in other cases the factor differs from unity and must be determined in calibration. For temperature data, corrections are non-linear (see Sec. 4). Before correction, the raw data are checked by appropriate quality control techniques. Bad data are marked and logged (see Sec. 9). During the archival process, some additional quality control is done to check for particular problems that otherwise would not be handled. These controls are:

(1) Check and indicate tape channel shifts,

(2) Wind speed: IF(SPEED.LT.0) SPEED=0,

(3) Wind direction:

  (a) IF(DIR.GT.360) DIR=999

  (b) IF(DIR.LT.0) DIR=888

  (c) IF(SPEED.EQ.0) DIR=0

  (d) IF(DIR.EQ.0) AND SPEED.GT.0) DIR=360,

(4) Raingage:

  (a) IF(RAIN.LT.0) RAIN=0

  (b) IF($RAIN_I$.LT.$RAIN_{I-1}$) $RAIN_I$=$RAIN_{I-1}$,

(5) Check and indicate deviation from specified calibration voltages,

(6) Check difference between 26 m thermistors (see Sec. 4).

Data archiving was beyond the capability of the IBM 1620, so the University of Oklahoma's IBM 360/50 was used.

The quality control procedures described are adequate only for the instruments, sampling rates, type of meteorological facility, and computer specified. More sophisticated techniques can be used, and in some cases should be used, for the more sophisticated instruments and faster sampling rates if an adequate computer is available.

9. SUMMARY OF AVAILABLE DATA

9.1 Digital Data

The digital data collected during the 1972 storm season are archived on 2400 ft reels of 1/2 inch seven-track tape at 556 BPI even parity. Each record contains 133 characters, and each archived data tape averages over 20,000 records. Table 2 shows the output format for the consolidated data with sample printout of the data in Fig. 24.

Table 3 represents a user's guide to the 1972 data in a coded format. Each entry indicates a change in the status of the data either in the sampling rate, reliability, or continuity of the data. Starting and ending dates and times for which the status of the data is unchanged. The sampling rate in records per hour is also given. Each parameter is indexed from 01 to 33 (Table 4) and the status categorized as follows:

0 - Data Reliable (no errors were detectable and no problems known to exist).

1 - Data Unreliable (data are unusable and may be denoted by 9's on the archived tape).

2 - Data Suspect (a small error is suspected in the data, but evidence is inconclusive).

3 - Data Unreliable in part (intermittent errors occur but the data are otherwise reliable).

4 - Channel Shorted.

In Table 3 data gaps (minutes) are indicated on the right.

There are several major problems which appear in Table 3: approximately every 10 days maintenance personnel were on the tower to refill the wet-bulb water reservoirs (coded unreliable); the 444 m vertical velocity is coded unreliable in part at the beginning of the data set because of faulty orientation; a system failure on 27 May rendered a large body of data unreliable or unreliable in part; and, no data were collected on channel 24, for the entire season.

Breaks in the data comprise 3.85% of the 90-day sample. Table 5 shows the quality of available data in percent by parameter and Table 6, the overall quality of the data. A resume of digital data on magnetic tape for 1969 through 1971 is given in Appendix A.

Table 2. 1972 Consolidated Tower Output Format.

COLUMN	DATA	UNITS	FORMAT
1-6	Date	MMDDYY	I6
7-12	Time	HHMMSS	I6
13-36	Wind Speeds Levels 0-6,6F	m/sec	8I3 - XX.X
37-57	Wind Directions Levels 0-6	degrees	7I3 - XXX.
58-93	Temperatures Levels 0-6,6F	C	9I4 - XX.XX
94-105	Wet Bulb Temperatures Levels 0,3,6	C	3I4 - XX.XX
106-121	Gill Vanes Levels 0,3,6,6F	m sec^{-1}	4I4 - XXX.X
122-125	Pressure Level 0	mb	I4 - XXX.X
126-125	Rain Gage Level 0	inch	I3 - X.XX

		WIND SPEEDS								WIND DIRECTIONS							GILL VANES			
DATE	TIME	0	1	2	3	4	5	6	6F	0	1	2	3	4	5	6	0	3	6	6F
52472	81400	2.0	00.8	1.0	03.2	7.6	07.0	4.9	04.6	80	88	96	114	92	91	104	-.3	1.1	.2	.0
52472	81500	2.4	02.6	2.4	04.4	7.4	07.4	4.8	04.7	93	89	111	108	93	90	104	-.6	-.1	.2	.0
52472	81600	1.4	01.2	1.9	04.9	6.9	07.4	5.0	04.7	72	90	104	100	93	89	104	.1	.2	.1	-.2
52472	81700	2.1	02.1	3.3	05.1	6.9	07.4	5.2	04.9	109	92	95	103	95	90	104	.0	.0	.0	-.1
52472	81800	2.4	02.6	3.4	04.9	6.9	07.1	5.0	04.8	108	107	101	105	100	91	104	.5	.0	.2	-.1
52472	81900	2.4	01.8	2.9	05.2	6.9	06.7	4.8	04.5	103	92	112	108	100	94	104	.4	.0	.4	.1
52472	82000	2.7	01.7	3.2	04.4	7.5	07.0	4.8	04.6	95	112	121	107	94	95	104	-.1	.1	.3	.2
52472	82100	1.8	01.5	2.4	04.6	7.5	06.9	4.9	04.7	92	97	117	108	93	94	105	.4	.7	.3	.1
52472	82200	1.9	02.8	1.3	03.0	7.3	07.3	4.9	04.6	103	97	120	99	96	93	106	.5	.0	.3	.1
52472	82300	1.8	02.2	2.7	04.6	6.8	07.5	4.8	04.6	94	106	105	98	95	92	106	.3	.7	.4	.3
52472	82400	3.0	03.3	3.3	04.6	7.2	07.1	4.6	04.4	100	102	120	110	99	95	107	.2	.1	.2	.0
52472	82500	1.9	03.2	3.3	03.9	7.1	06.9	4.7	04.4	120	102	108	108	98	94	108	.1	.1	.4	.1
52472	82600	3.1	03.0	3.7	03.0	7.2	07.1	4.8	04.7	112	105	115	123	100	97	108	.0	.4	.2	.1
52472	82700	2.4	03.3	3.8	04.7	6.8	07.2	4.9	04.7	112	113	111	112	98	94	112	-.6	-.2	.2	.0
52472	82800	3.7	03.8	3.8	05.5	6.8	06.0	4.6	04.4	133	122	102	110	96	102	111	.2	-.9	.5	.1
52472	82900	3.9	03.2	3.3	03.7	5.0	07.4	4.7	04.6	90	98	101	116	91	97	111	.9	1.1	.3	.1

		TEMPERATURES									WET BULB TEMPERATURE			PRESSURE	
DATE	TIME	SA	0	1	2	3	4	5	6A	6F	0	3	6	0	RAIN
52472	81400	21.58	21.13	20.85	20.34	19.91	20.30	20.51	21.68	99.99	15.89	13.84	10.99	971.9	.00
52472	81500	21.48	21.12	20.95	20.39	20.01	20.22	20.38	21.68	99.99	15.78	13.63	11.10	971.9	.00
52472	81600	21.58	21.17	21.04	20.46	20.08	20.10	20.15	21.58	99.99	15.99	13.23	11.10	971.9	.00
52472	81700	21.68	21.26	21.08	20.63	20.22	20.10	20.29	21.58	99.99	15.58	13.43	11.10	971.9	.00
52472	81800	21.78	21.43	21.19	20.75	20.21	20.10	20.25	21.58	99.99	15.58	13.53	11.10	971.9	.00
52472	81900	21.88	21.47	21.26	20.69	20.28	20.06	20.37	21.58	99.99	15.58	13.33	11.10	971.9	.00
52472	82000	21.88	21.39	21.22	20.70	20.17	20.01	20.40	21.58	99.99	15.58	13.63	11.10	971.9	.00
52472	82100	21.88	21.38	21.19	20.69	20.12	20.02	20.33	21.58	99.99	15.58	13.84	11.10	971.9	.00
52472	82200	21.88	21.43	21.20	20.70	20.03	20.01	20.21	21.58	99.99	15.68	14.24	11.10	971.9	.00
52472	82300	21.98	21.48	21.25	20.75	20.07	19.93	20.11	21.58	99.99	15.78	14.04	11.10	971.9	.00
52472	82400	22.08	21.56	21.37	20.84	20.10	19.82	20.28	21.68	99.99	15.58	14.04	11.10	971.9	.00
52472	82500	22.08	21.63	21.44	20.84	20.09	19.87	20.31	21.68	99.99	15.68	14.34	11.10	972.0	.00
52472	82600	22.18	21.64	21.44	20.90	20.16	19.88	20.36	21.68	99.99	15.48	14.04	10.99	972.0	.00
52472	82700	22.28	21.69	21.47	20.94	20.25	19.79	20.17	21.58	99.99	15.68	13.74	11.10	972.0	.00
52472	82800	22.28	21.79	21.54	21.03	20.35	19.89	20.71	21.68	99.99	15.38	13.84	11.10	972.0	.00
52472	82900	22.38	21.87	21.71	21.14	20.41	19.77	20.29	21.68	99.99	15.58	14.14	11.10	972.0	.00

Figure 24. Archived tower data sample.

Table 3. User's Guide to 1972 Digital Data.

TP	DATE ON	TIME ON	RPH	DATE OFF	TIME CFF	INDEX 000000000111111111122222222223333 123456789012345678901234567890123	GAP (MIN)
01	041372	162130	060	041472	112930	000000000000000000000000400003300	
01	041472	113010	360	041572	114030	000000000000000000000000400003300	
01	041572	115100	060	041872	033800	000000000000000000000000400003300	11
01	041872	033900	060	041872	145900	000000000000000000000004001003300	
01	041872	150740	360	041972	094340	000000000000000000000004001003300	8
02	041972	095340	360	041972	101300	000000000000000000000004001003300	10
02	041972	101310	360	041972	101640	000000000000000000000004001003301	
02	041972	101650	360	042072	100500	000000000000000000000004001003300	
02	042072	101240	360	042172	005950	000000000000000000000004001003300	7
02	042172	010030	060	042172	151130	000000000000000000000004001003300	
02	042172	151230	060	042172	153130	000000110000000100000014001001100	
02	042172	153230	060	042172	154130	000000000000000000000004000003300	
02	042172	154230	060	042172	155930	000100000001000000010004010013300	
02	042172	160030	060	042172	160230	000000000000000000000004000003300	
02	042172	160330	060	042172	161030	100000001000000110000004100103300	
02	042172	161130	060	042272	072430	000000000000000000000004000003300	
02	042272	074030	060	042672	023130	000000000000000000000004000003300	16
02	042672	023230	060	042672	140030	000000000000000000000004000001100	
03	042672	140130	060	042672	191330	000000000000000000000004000001100	
03	042672	192200	360	042772	003450	000000000000000000000004000001100	9
03	042772	003530	060	042772	134430	000000000000000000000004000001100	
03	042772	134530	060	042772	135930	000000110000000100000014001001100	
03	042772	140030	060	042772	140630	000000000000000000000004000000000	
03	042772	140730	060	042772	140930	000100000001000000010004010010000	
03	042772	141030	060	042772	141430	000000000000000000000004000000000	
03	042772	141530	060	042772	141630	100000001000000110000004100100000	
03	042772	141730	060	042972	100630	000000000000000000000004000000000	
03	042972	102300	060	042972	233000	000000000000000000000004000000000	17
03	042972	233010	360	043072	005130	000000000000000000000004000000000	
03	043072	005230	060	050272	101030	000000000000000000000004000000000	
03	050272	101130	060	050272	102930	000000110000000100000014001001000	
03	050272	103030	060	050272	103730	000000000000000000000004000000000	
03	050272	103830	060	050272	104130	000100000001000000000004010010000	
03	050272	104230	060	050472	093230	000000000000000000010004000000000	
03	050472	094410	360	050572	082450	000000000000000000000004000000000	12
04	050572	083230	060	050672	152930	000000000000000000000004000000000	8
04	050672	153000	360	050772	065940	000000000000000000000004000000000	
04	050772	071100	060	050872	095700	000000000000000000000004000000000	12
04	050872	101300	060	050872	102100	000000000000000000000004000000000	16
04	050872	102200	060	050872	102400	000100000001000000010004010010000	
04	050872	102500	060	050872	122700	000000000000000000000004000000000	
04	050872	134010	360	050972	043440	000000000000000000000004000000000	73
04	050972	044610	360	050972	135140	000000000000000000000004000000000	12
04	050972	135150	360	050972	141840	000000000000000001111114000000000	
04	050972	141850	360	051072	042950	000000000000000000000004000000000	
05	051072	055000	060	051172	160000	000000000000000000000004000000000	81
05	051172	160010	360	051272	080415	000000000000000000000004000000000	
05	051272	082000	060	051272	142700	000000000000000000000004000000000	16
05	051272	142800	060	051272	143400	000000110000000100000014001001100	
05	051272	143500	060	051272	152500	000000000000000000000004000000000	
05	051272	152600	060	051272	154500	000000110000000100000014001001100	
05	051272	154600	060	051372	052400	000000000000000000000004000000000	
05	051372	053600	060	051372	133300	000000000000000000000004000000000	11
05	051372	133400	060	051372	134600	000000110000000100000014001001100	
05	051372	134700	060	051372	154400	000000000000000000000004000000000	
05	051372	154500	060	051372	160000	000000000000000000000004100000000	

Table 3 continued on next page.

05	251372	160100	060	051472	153400	000000000000000000000004000000000	
05	251472	153900	060	051572	081800	000000000000000000000004000000000	5
05	251572	092500	060	051872	093600	000000000000000000000004000000000	67
05	251872	093700	060	051872	095000	000000110000001000000014001001100	
05	251872	095100	060	051872	095900	000000000000000000000004000000000	
05	251872	100000	060	051872	100200	000100000001000000010004010010000	
05	251872	100300	060	051872	100400	000000000000000000000004000000000	
05	251872	100500	060	051872	100800	100000001000000110000004100100000	
05	251872	100900	060	052072	124300	000000000000000000000004000000000	
06	252072	140700	060	052272	150100	000000000000000000000004000000000	84
06	252272	150140	360	052372	090540	000000000000000000000004000000000	
06	252372	094400	360	052472	080750	000000000000000000000004000000000	39
07	252472	081400	060	052472	122300	000000000000000000000004000000000	7
07	252472	122400	060	052472	122600	000000110000001000000014001001100	
07	252472	122700	060	052472	123500	000000000000000000000004000000000	
07	252472	123600	060	052472	123900	000100000001000000010004010010000	
07	252472	124000	060	052472	124500	000000000000000000000004000000000	
07	252472	124600	060	052472	124700	100000001000000110000004100100000	
07	252472	124800	060	052472	214900	000000000000000000000004000000000	
07	252472	215005	360	052572	102055	000000000000000000000004000000000	
07	252572	102200	060	052672	124900	000000000000000000000004000000000	
07	252672	130300	360	052772	104540	000000000000000000000004000000000	14
07	252772	105130	060	052772	132230	000000000000000000000004000000000	6
07	252772	132305	360	052772	152755	000000000000000000000004000000000	
07	252772	215700	060	052872	092100	000000000000000033333334000333300	390
07	252872	092930	360	052872	134930	000000000000000033333334000333300	8
08	252872	142300	360	052972	085430	000000001000000233333334000222200	34
08	252972	085440	360	052972	101450	000000000000000233333334000222200	
08	252972	101500	060	053072	080000	000000000000000033333334000222200	
08	253072	085000	060	053172	101000	000000000000000033333334100000000	50
08	253172	101100	060	060172	085800	000000001000000033333334100000000	
08	260172	085900	060	060172	095800	000000001000001033333334100000000	
08	260172	095900	060	060172	100200	000000111000001033333314101001100	
08	260172	100300	120	060172	103600	000000001000001033333334100000000	
08	260172	103700	120	060172	103900	000100001001001033313334110010000	
08	260172	104000	120	060172	110700	000000001000001033333334100000000	
08	260172	110800	120	060172	111100	100000001000001113333334100100000	
08	260172	111200	120	060172	113240	000000001000001033333334100000000	
08	260172	113300	060	060172	134500	000000001000001033333334100222200	
08	260172	134600	060	060172	210000	000000001000000033333334100222200	
08	260172	210100	060	060272	092800	000000001000000033333334103222200	
08	260272	104930	060	060372	035730	000000001000000000000004003000000	81
08	260372	060330	060	060572	100530	000000001000000000000004003000000	126
09	260572	103200	060	060672	133600	000000001000000000000004001000000	26
09	260672	133700	060	060672	134700	000000110000001000000014001001100	
09	260672	134800	060	060672	135500	000000001000000000000004000000000	
09	260672	135600	060	060672	135800	000100001001000000010004010010000	
09	260672	135900	060	060672	140200	000000001000000000000004000000000	
09	260672	140300	060	060672	140400	100000001000000110000004100100000	
09	260672	140500	060	061072	095800	000000000000000000000004000000000	20
09	261072	101830	060	061072	180930	000000001000000000000004000000000	
09	261072	181025	360	061172	125945	000000001000000000000004000000000	
09	261172	131010	360	061172	132520	000000001000000000000004000000000	10
09	261172	133009	360	061272	094455	000000001000000000000004000000000	5
10	261272	095100	060	061472	003200	000000001000000000000004000000000	6
10	261472	003210	360	061472	152940	000000001000000000000004000000000	
10	261472	154000	060	061572	154500	000000001000000000000004000000000	10
10	261572	154505	360	061672	072015	000000001000000000000004000000000	
10	261672	084000	060	061972	214300	000000001000000000000004000000000	86
10	261972	214330	360	062072	000240	000000001000000333333334000000000	
10	262072	004315	360	062072	084655	000000001000000000000004000000000	41
11	262072	102700	060	062372	082800	000000000000000010000004000000000	100
11	262372	092130	060	062372	200330	000000000000000000000004000000000	53
11	262572	153800	060	062772	092900	000000000000000000000004000000000	2615
11	262772	120000	060	062772	155700	000000000000000000000004000000000	151
11	262772	155705	360	062772	193525	000000000000000000000004000000000	
11	262772	193535	360	062872	064615	000000000000000010000004000000000	
11	262872	122800	060	063072	152300	000000000000000000000004000000000	342
11	263072	152330	360	070172	114250	000000000000000000000004000000000	
12	270172	121230	060	070172	233130	000000000000000000000004000000000	30
12	270172	233200	360	070272	190710	000000000000000000000004000000000	
12	270272	192500	360	070372	090140	000000000000000000000004000000000	18
12	270372	093130	060	070772	085330	000000000000000000000004000000000	30
12	270772	090600	060	071272	084500	000000000000000000000004000000000	13

Table 4. Index of Parameters.

INDEX	METEOROLOGICAL VARIABLE
01	W/S, 26M
02	W/S, 45M
03	W/S, 90M
04	W/S, 177M
05	W/S, 266M
06	W/S, 355M
07	W/S, 444M
08	W/S, 444M, WITH LOW PASS FILTER, F=.05HZ
09	W/D, 26M
10	W/D, 45M
11	W/D, 90M
12	W/D, 177M
13	W/D, 266M
14	W/D, 355M
15	W/D, 444M
16	T, 26M, AMBIENT MODE
17	T, 45M, DELTA MODE
18	T, 45M, DELTA MODE
19	T, 90M, DELTA MODE
20	T, 177M, DELTA MODE
21	T, 266M, DELTA MODE
22	T, 355M, DELTA MODE
23	T, 444M, AMBIENT MODE
24	SHORTED CHANNEL
25	WET BULB TEMP, 26M
26	WET BULB TEMP, 177M
27	WET BULB TEMP, 444M
28	VERTICAL VELOCITY, 26M
29	VERTICAL VELOCITY, 177M
30	VERTICAL VELOCITY, 444M
31	VERTICAL VELOCITY, 444M, WITH LOW PASS FILTER F=.05HZ
32	PRESSURE, SURFACE
33	RAINFALL
CODE	
0	DATA RELIABLE
1	DATA UNRELIABLE
2	DATA SUSPECT
3	DATA UNRELIABLE IN PART
4	DATA NOT COLLECTED THIS CHANNEL

Table 5. Quality of Data by Parameter (Percent).

PARAMETER BY INDEX NUMBER (SEE TABLE 4)	RELIABLE 0	UNRELIABLE 1	SUSPECT 2	UNRELIABLE IN PART 3
01	99.99	.01	.00	.00
02	100.00	.00	.00	.00
03	100.00	.00	.00	.00
04	99.98	.02	.00	.00
05	100.00	.00	.00	.00
06	100.00	.00	.00	.00
07	99.95	.05	.00	.00
08	99.95	.05	.00	.00
09	78.84	21.16	.00	.00
10	100.00	.00	.00	.00
11	100.00	.00	.00	.00
12	99.98	.02	.00	.00
13	100.00	.00	.00	.00
14	100.00	.00	.00	.00
15	99.77	.23	.00	.00
16	95.26	1.60	2.82	.32
17	91.94	1.73	.00	6.33
18	93.61	.06	.00	6.33
19	93.61	.06	.00	6.33
20	93.60	.07	.00	6.33
21	93.61	.06	.00	6.33
22	93.61	.06	.00	6.33
23	93.56	.11	.00	6.33
24	NO SENSOR			
25	98.20	1.80	.00	.00
26	99.98	.02	.00	.00
27	88.63	9.44	.00	1.93
28	95.27	.01	3.85	.87
29	95.27	.01	3.85	.87
30	77.11	1.49	3.85	17.55
31	77.11	1.49	3.85	17.55
32	100.00	.00	.00	.00
33	99.99	.01	.00	.00

Table 6. Percent of All Data Falling Into Each Category

CATEGORY	PERCENT
Data Reliable	92.69
Data Unreliable	1.20
Data Suspect	3.58
Data Unreliable In Part	2.53

9.2 Analog Strip Chart Data

Continuous strip chart data for the horizontal winds are available for all seven levels. Missing data constitute less than 0.5% of the total possible data during the 90-day collection period. Strip chart data for the vertical winds are available for the 26, 177, and 444 m levels until 13 June; after 13 June only for the upper two levels. Missing data for vertical velocities constitute about 1.0% of the total possible excluding the 26 m level after 13 June. One-day pressure traces from a standard U. S. Weather Bureau barograph also are available from 25 April to 13 June. No other strip chart data are available for 1972. Strip chart data before 1972 are listed in Appendix B.

10. SOME INTERESTING METEOROLOGICAL PHENOMENA

10.1 Introduction

The type of instrumentation and the tower height make the NSSL/WKY-TV facility useful for studying frontal characteristics, low-level thunderstorm inflow and outflow, and internal wave phenomena of the stratified boundary layer. Sometimes these events occur concurrently. During the 1971 and 1972 spring seasons (an equivalent of 5 mo of data), 69 significant events of this type were recorded. Many phenomena will be discussed in subsequent studies, but for this report they are briefly summarized.

10.2 Gravity Currents

Gravity currents are shallow bodies of air near the ground associated with fronts and thunderstorm outflow. There are several laboratory models (Bata and Bogish, 1953; Middleton, 1966; Keulegan, 1958; and others), and Charba (1972) has used data from this tower in a recent case study. Colmer (1971) has studied the characteristics of the leading edge of the current (gust front). A case similar to Charba's illustrated in Fig. 25 shows a gravity current associated with an unbroken line of thunderstorms oriented approximately east to west and propagating toward the south. The diagram, crudely taken as a time-to-space conversion, shows two surges of cold air passing the tower at 1905 and 1922 CST. Solid isopleths are lines of constant lapse rate that help delineate the inversion position. The vertical velocity is plotted at 177 and 444 m; zero vertical velocity is the straight line drawn at the two heights; strong updrafts and downdrafts are indicated with plus (+) and minus (-). Since the squall line was oriented east to west, pre-storm flow had a dominant southerly component. Following the leading edge of the outflow, the low-level flow was mostly northerly except in the head where the wind was east or northeast along the frontal axis. The wind shift line (dotted line

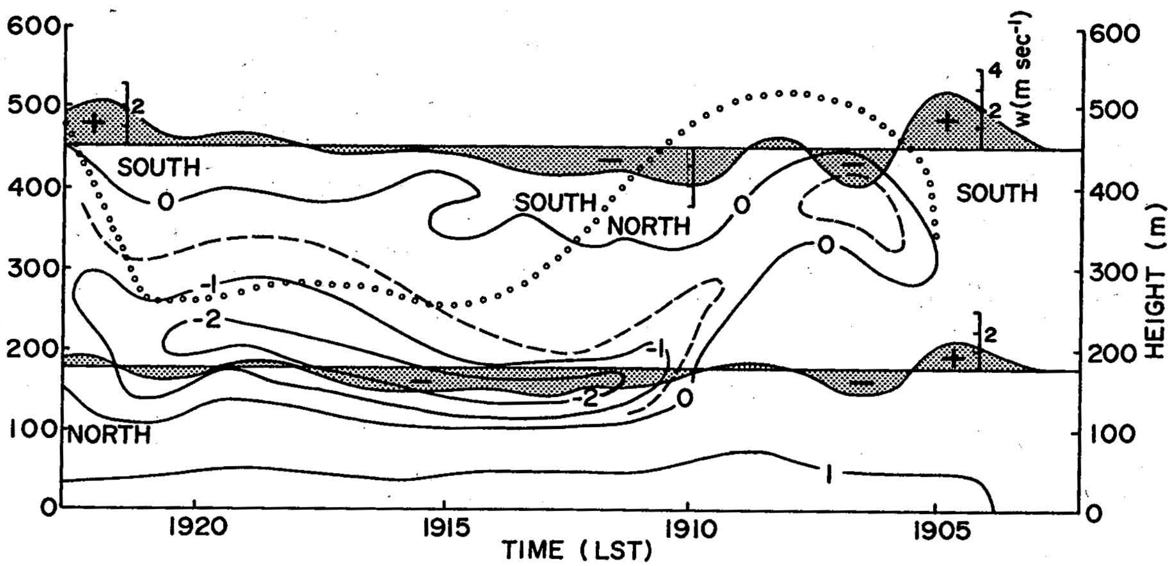


Figure 25. Gravity current associated with a squall line. Vertical velocity plotted at 177 and 444 m (stippled). Winds with north or south components separated by (ooo) line. Lapse rate (C 10^{-2} m^{-1}) solid isolines.

representing an east wind) shows the shallow character of this outflow current.

The two currents at 1905 and 1922 are believed to indicate sudden intensification; i.e., with each cycle of intensification, a new current surges ahead of the squall line. A future study will seek to verify this and discuss turbulence characteristics behind the head with interaction and general characteristics of gust fronts.

10.3 Cold Front Passages

Most fast-moving cold fronts appear quasi-vertical in the tower layer. Occasionally a cold front has a much shallower slope. This seems more likely when the fronts are moving very slowly. Such an event is shown in Fig. 26. The frontal configuration illustrated is midway between the more frequent quasi-vertical front and the gravity current discussed in Section 10.1. The diagram shows small-scale waves along the frontal surface. These may be attributed to tower effects. However, much longer period (∿ 5 to 10 min) wave forms of a meteorological nature have been observed on these shallow sloped fronts.

10.4 Hydraulic (Pressure) Jumps

If the atmosphere, composed of two fluids of different density (in a stable configuration), is impulsively perturbed, a hydraulic, or pressure, jump occurs (Tepper, 1950). Pressure jumps appear as a sudden lifting of an inversion. Figure 27 may be such a pressure jump; here the inversion, initially at 300 m, is suddenly lifted about 200 to 250 m, and thereafter the height fluctuates with a period of 7 to 9 min. Tower observations were extrapolated up some 250 m.

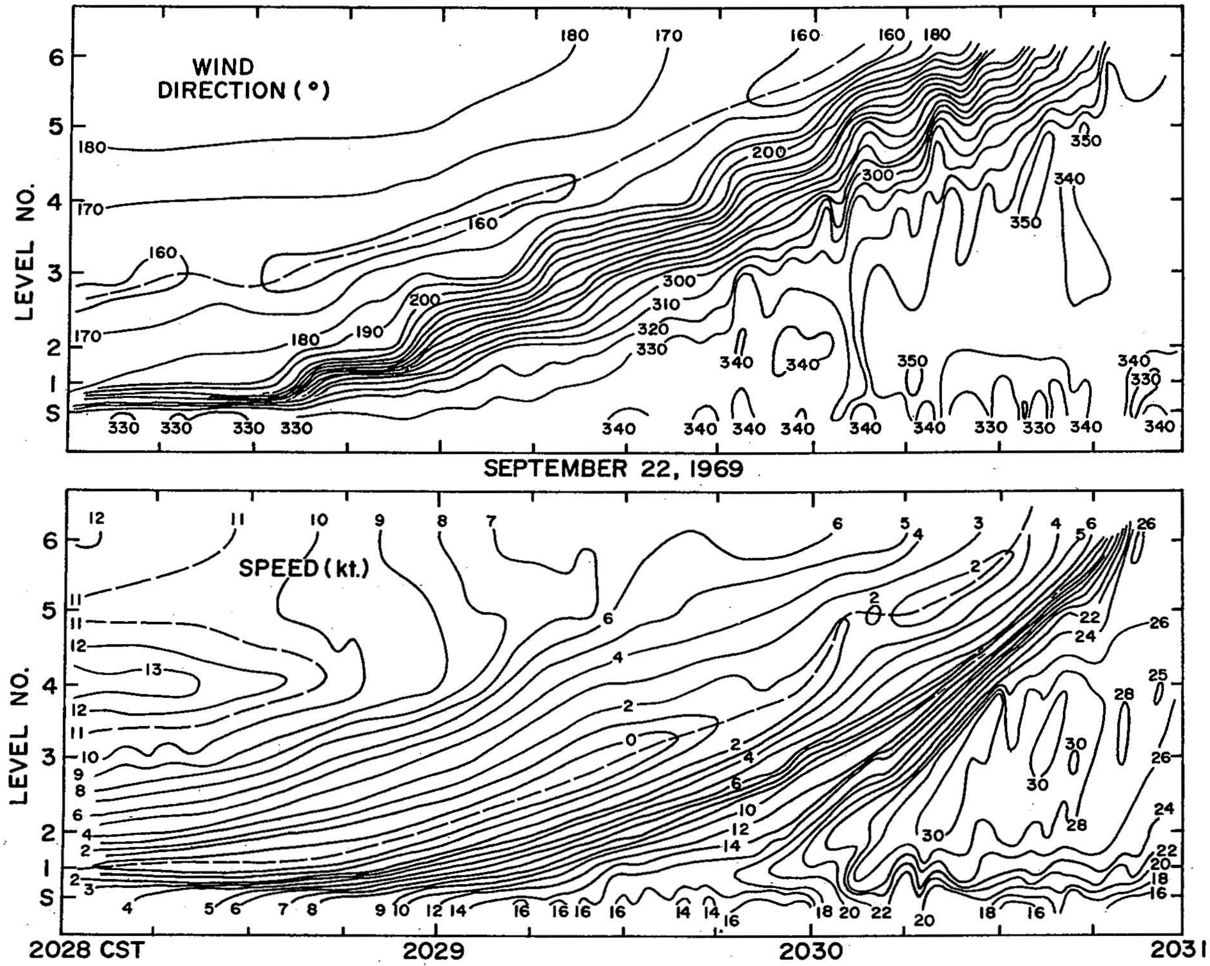


Figure 26. Diagram of shallow cold front (from Sanders, unpublished).

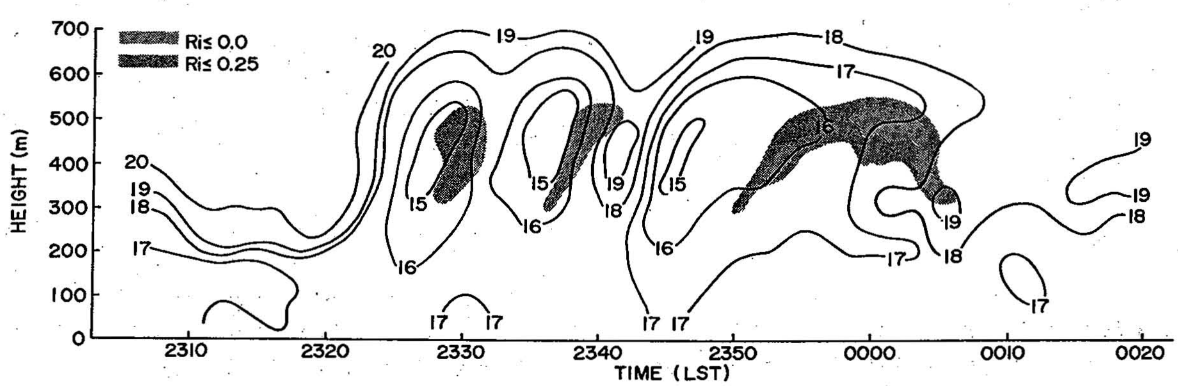


Figure 27. Boundary layer profile of pressure jump. Isolines of temperature (C

10.5 Shear-Gravity Waves

In a stratified atmosphere with strong wind shear, the Richardson number may be sufficiently low such that Kelvin-Helmholtz waves are generated. Several studies of such waves used sensitive radars (Atlas et al., 1969; Browning, 1971; Gossard et al., 1970). A case of shear-gravity waves is illustrated in Fig. 28 (a and b). Shallow dense air behind a thunderstorm has created a strong inversion. There is strong wind shear evident in the accompanying hodograph (Fig. 29). The data in the time-height section have been smoothed somewhat, but even the unsmoothed data are nearly periodic between 0313 and 0321 CST. Notice that the period of these waves is much smaller than those in Fig. 28. Shear-generated waves generally have smaller periods than other mechanically induced fluctuations, although no conclusive statements can be made about their wavelengths with point source data.

10.6 Mesoscale Spectra

The 90-day data sample collected in 1972 will be used to determine the mesoscale kinetic energy spectrum during a typical spring season. Spectra from individual storm days will be compared with the spectrum from the larger sample. Occasionally there is a considerable amount of horizontal kinetic energy in the mesoscale portion of the horizontal wind spectrum (from periods of 30 min to 24 hr; normally an energy weak region) as compared with, say, the Van der Hoven (1957) or Vinnechenko (1970) spectrum in the same frequency range.

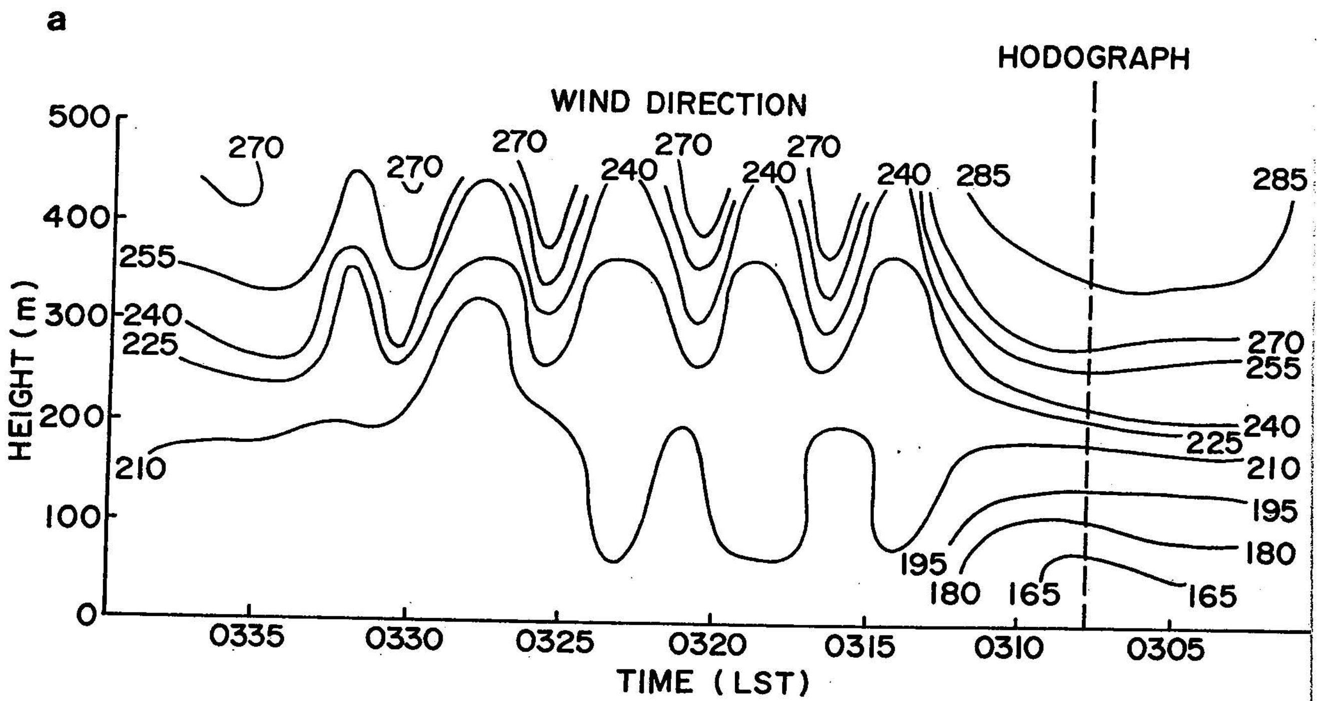
11. SUMMARY AND CONCLUSIONS

A 3-mo sample of nearly continuous data was collected at the NSSL/WKY-TV tower. About half of the data was collected at a 1-min sampling rate. The remainder was collected at a 10-sec sampling rate. The sample probably is unique, because there are few instrumented towers as tall as the WKY tower. Over 90% of the data is considered reliable, i.e., within the tolerances set by quality control procedures.

In 1972 we emphasized electronically digitized data rather than data collected on strip charts. This "improvement" produced several new problems: recording on tape did not allow on-site inspection of the data; at slow sampling rates several days normally elapsed before the tape was removed and data could be checked; the data acquisition system was subject to frequent breakdown (on occasion the malfunction was not detected until the raw data were first inspected); and computer facilities were not adequate for quick processing, although they were improved over previous years.

Some problems were not related to the data collection method. The height of the tower and adverse weather conditions occasionally prevented the immediate repair of faulty equipment. In spite of some handicaps, the spring program was considered a success since data were collected during more than half a dozen thunderstorms and many other mesoscale events.

To save on maintenance costs, reduce manpower needs and improve data, a new recording system was located at NSSL in 1973 with data telemetered from the tower to NSSL over telephone lines. Several tower functions are now



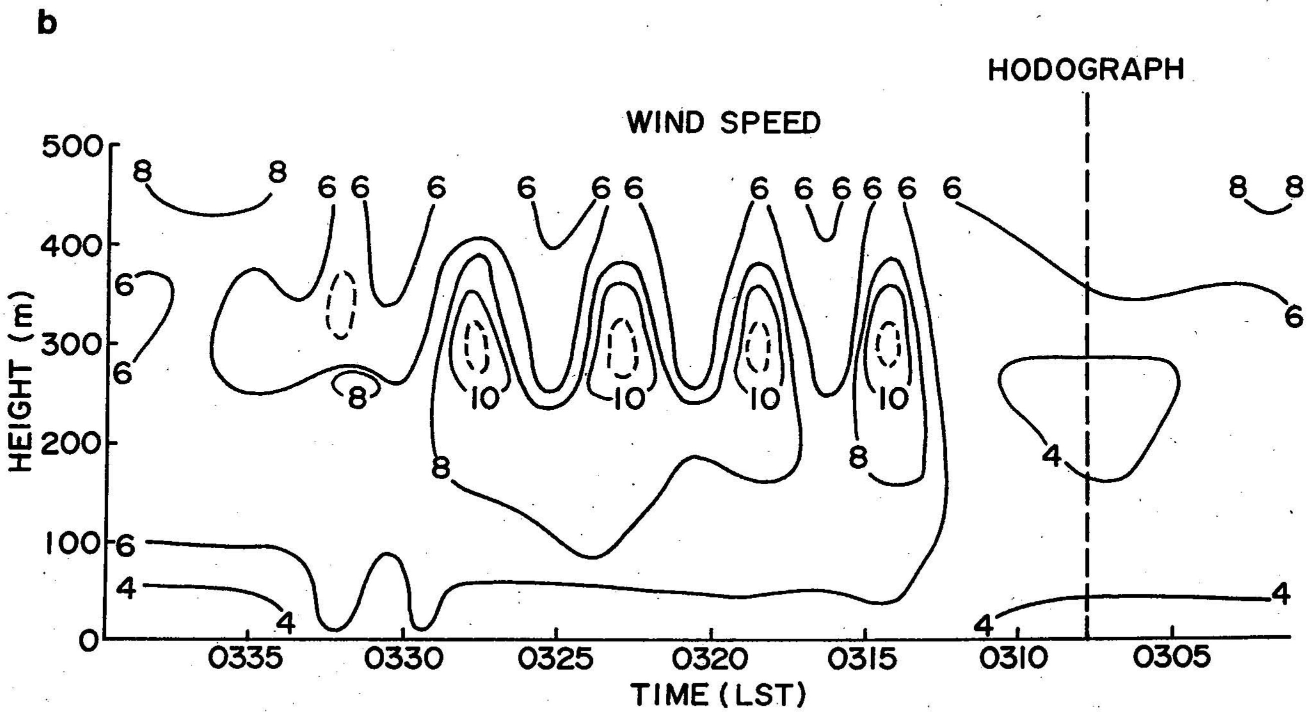


Figure 28. Time/height section of the tower layer showing shear gravity waves. (a) wind direction (°), (b) wind speed (m sec^{-1}).

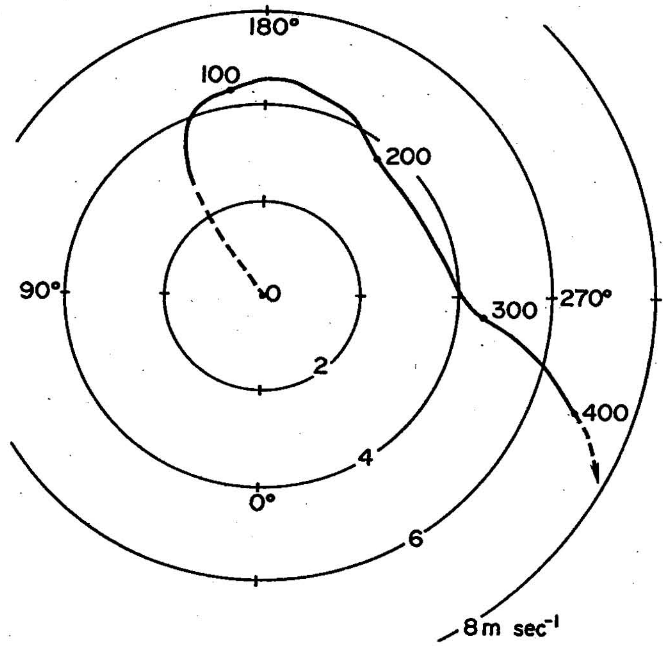


Figure 29. Hodograph of tower layer during shear gravity wave occurrences.

operated by remote control. The new processor streamlines collecting and processing the data and will enhance our research capabilities.

12. ACKNOWLEDGMENTS

The authors appreciate the conscientious efforts of L. Dale Sanders (CEDDA), J. Carter (NSSL), and L. Johnson (NSSL) who were responsible for the design, construction and operation of the tower facility; and M. Weible (NSSL) who assisted in computer data processing.

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APPENDIX A

ARCHIVE TAPE INFORMATION (1969-1971)[8]

Collection Period: 24 October - 30 December 1969

Mode: Digital data collected at 2 sec rates for first 5 min of each hour.

Remarks: Some wind direction data in error; wind speed noisy.

Record Length: 87 characters.

COLUMN	TAPE FORMAT*	DATA
1	1X	Blank
2-7	3I2	Month, day, year
8-13	3I2	Hour, minute, second
14-34	7F3.1	Wind speed (kt) 7 levels
35-55	7F3.0	Wind direction (°) 7 levels
56-87	8F3.0	Temperature (C) 7 levels**

*Tape format indicates position of decimal. Archive tape in I-format.
**2 sensors at surface level.

NSSL TAPE NO.	DATE ON	TIME ON	DATE OFF	TIME OFF
SL0426	24 Oct	160001	27 Oct	100459
SL0428	27 Oct	120003	5 Nov	130459
SL0601	7 Nov	110001	10 Nov	080459
SL0440	14 Nov	090001	21 Nov	100459
SL0580	21 Nov	120005	28 Nov	090459
SL0582	28 Nov	120001	5 Dec	080459
SL0263	5 Dec	160001	9 Dec	090459
SL0258	9 Dec	160001	15 Dec	140459
SL0293	15 Dec	150001	19 Dec	080459
SL0295	19 Dec	090001	22 Dec	114550
SL0386	22 Dec	130001	26 Dec	080459
SL0419	26 Dec	090001	30 Dec	160359

[8] Information for the 1972 data set appears in the text.

Collection Period: 22 April - 12 October 1970

Mode: Digital data collected at 2 or 10 sec rates

Remarks: Questionable data and negative temperatures are specially coded. Code available upon request.

Record Length: 128 characters

COLUMN	TAPE FORMAT*	DATA
1-6	3I2	Month, day, year
7-12	3I2	Hour, minute, second
13-15	F3.2	Calibration voltage (V)
16-36	7F3.1	Aerovane wind speed (kt) 7 levels
37-57	7F3.0	Aerovane wind direction (°) 7 levels
58-78	7F3.1	Cup anemometer wind speed (kt) 7 levels
79-81	F3.2	Calibration voltage (V)
82-89	2F4.1	Vertical wind (kt) 444m
90-92	F3.1	Pyranameter (ly min^{-1}) sfc
93-95	F3.0	Relative humidity (%) sfc
96-127	8F4.2	Temperature (C) 7 levels**
128	I1	Channel change indicator

*Tape format indicates position of decimal. Archive tape in I-format.
**2 sensors at surface level.

NSSL TAPE NO.	DATE ON	TIME ON	DATE OFF	TIME OFF
SL0194	22 Apr	080001	30 Apr	230100
SL0441	1 May	000000	11 May	215040
SL0442	11 May	215050	15 May	134350
SL0216	15 May	134400	28 May	181430
SL0219	28 May	181530	30 May	045630
SL0018	1 Jun	000000	9 Jun	213230
SL0043	9 Jun	213300	13 Jun	083600
SL0215	13 Jun	083602	23 Jun	225800
SL0218	23 Jun	225900	30 Jun	235900
SL0348	1 Jul	000500	14 Jul	220430
SL0431	14 Jul	220530	23 Jul	114910
SL0351	27 Aug	153100	7 Sep	211505
SL0508	7 Sep	211515	24 Sep	033130
SL0044	24 Sep	033230	30 Sep	235930
SL0433	1 Oct	000030	12 Oct	114330

Collection period: 6 May - 1 July 1971

Mode: Digital data collected at 10 sec rates on potential storm days.

Remarks: All 9's and 8's in any field indicates data missing.

Record Length: 131 characters

COLUMN	TAPE FORMAT*	DATA
1-6	3I2	Month, day, year
7-12	3I2	Hours, minutes, seconds
13-42	10F3.1	Wind speed (m sec^{-1}) 7 levels**
43-63	7F3.0	Wind direction (°) 7 levels
64-95	8F4.2	Temperature (C) 7 levels***
96-110	3F5.2	Vertical wind (m sec^{-1}) sfc, 444m
111-116	2F3.0	Relative humidity (%) sfc, 444m
117-119	F3.2	Pyranometer (ly min^{-1}) sfc
120-124	F5.1	Station pressure (mb) sfc
125-127	F3.2	Raingage(inch) sfc
128-130	I3	Channel indicator
131	I1	Channel change indicator

*Tape format indicates position of decimal. Archive tape in I-format.
**Wind speed electronically filtered at sfc, 177 and 444m (breakpoint 0.5 Hz). Filtered data follows unfiltered data in sequence.
***2 sensors at surface level.

NSSL TAPE NO.	DATE ON	TIME ON	DATE OFF	TIME OFF
SL0745	4 May	191015	15 May	154950
SL0968	17 May	160000	23 May	103150
SL0036	23 May	103200	30 May	113000
SL0798	30 May	113010	3 Jun	152850
SL0242	7 Jun	160000	12 Jun	201550
SL0528	12 Jun	201620	1 Jul	072625
SL0784****	18 Jun	133504	18 Jun	143448

****2 sec data.

APPENDIX B

ANALOG STRIP CHART DATA

(1966-1971)

DATE ON	DATE OFF	PARAMETER[3]	HEIGHT OF SENSORS (m)	REMARKS
1 Jun 1966	31 May 1967	U, α	Sfc,44,89,177,266,355,444[1]	For climatological study
9 Dec 1966	31 May 1967	T	Sfc,44,89,177,266,355,444	For climatological study
1 Apr 1968	Sep-Oct 1968	U, α	Sfc,44,89,177,266,355,444	Spring Storm Project
1 Apr 1968	Sep-Oct 1968	T	Sfc,44,89,177,266,355,444	Spring Storm Project
10 Apr 1969	18 Jul 1969	U, α	Sfc,44,89,177,266,355,444	Spring Storm Project
10 Apr 1969	18 Jul 1969	T	Sfc,44,89,177,266,355,444	Spring Storm Project
8 Dec 1969	8 Apr 1970	T	444	Test
22 Dec 1969	8 Apr 1970	T	Sfc,44,89,177,266,355,444	Test
29 Dec 1969	17 Aug 1970	U, α		Spring Storm Project and Special Projects
29 Apr 1970	27 Jul 1970	T	Sfc,44,89,177,266,355,444	Spring Storm Project
4 May 1970	6 Jul 1970	w	444	Spring Storm Project
24 Aug 1970	12 Oct 1970	U, α	Sfc,44,89,177,266,355,444	Special Project
24 Aug 1970	12 Oct 1970	T	Sfc,44,89,177,266,355,444	Special Project
10 Sep 1970	12 Oct 1970	w	266,444	Special Project
16 Apr 1971	1 Jul 1971	U, α	Sfc,44,89,177,266,355,444	Spring Storm Project
19 Apr 1971	1 Jul 1971	T	26,44,89,177,266,355,444[2]	Spring Storm Project
19 Apr 1971	1 Jul 1971	w	26,444	Spring Storm Project
20 Sep 1971	18 Oct 1971	U, α	26,44,89,177,266,355,444	Special Project
22 Sep 1971	15 Oct 1971	T	26,44,89,177,266,355,444	Special Project
18 Oct 1971	16 Nov 1971	U, α	26,44,89,177,266,355,444	Special Project
18 Oct 1971	16 Nov 1971	T	26,44,89,177,266,355,444	Special Project

[1] Surface data were recorded at a site 75 m WNW of the tower base. Wind sensor 7 m; temperature sensor 2m.

[2] A new level at 26 m was added to the tower for 1971 replacing the surface data.

[3] See Table of Symbols.

NATIONAL SEVERE STORMS LABORATORY

The NSSL Technical Memoranda, beginning with No. 28, continue the sequence established by the U. S. Weather Bureau National Severe Storms Project, Kansas City, Missouri. Numbers 1-22 were designated NSSP Reports. Numbers 23-27 were NSSL Reports, and 24-27 appeared as subseries of Weather Bureau Technical Notes. These reports are available from the National Technical Information Service, Operations Division, Springfield, Virginia 22151, for $3.00, and a microfiche version for $0.95. NTIS numbers are given below in parentheses.

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No. 3 Instability Lines and Their Environments as Shown by Aircraft Soundings and Quasi-Horizontal Traverses. D. T. Williams. February 1962. (PB-168209)

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No. 6 Index to the NSSP Surface Network. T. Fujita. April 1962. (PB-168212)

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