Research and Development Technical Report ECOM-0035-F

PROPERTIES OF WIND AND TEMPERATURE AT ROUND HILL, SOUTH DARTMOUTH, MASS.

Final Report

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1. INTRODUCTION

For over a decade, the Massachusetts Institute of Technology operated a micrometeorological research station at Round Hill, South Dartmouth, Mass. Originally directed by E. W. Hewson, the work was taken over later by H. E. Cramer, assisted by Frank Record and J. E. Tillman. Although the research program was at first aimed at the investigation of atmospheric diffusion, a great deal of emphasis was placed on accurate measurement of profiles of wind and temperature and of fluctuation statistics of these variables.

At the time of dissolution of the micrometeorological station at Round Hill, many of the excellent observations remained unanalyzed. They were instead transmitted to the sponsor of much of the work in the later years, the Atmospheric Sciences Research Division of the Electronics Command, U. S. Army, at Fort Huachuca, Arizona. Personnel at this location, particularly James Appleby, Thomas Pries and the late Philip Kaiser, performed a number of computations on the original observations. As a result there exists an unusually complete set of statistics of meteorological variables, including mean winds and temperatures, variances and covariances (thus giving heat flux and Reynolds stress), higher-order moments, and spectra and cross spectra. This report deals with the analysis of some of these data, sometimes in comparison with results obtained from other sites.

The terrain at Round Hill is not particularly homogeneous. Tower A is located on a smooth, grassy site, surrounded by bushes and trees. The terrain around tower B is rough and more nearly homogeneous, but still not suitable for certain meteorological studies requiring exact horizontal homogeneity, such as the evaluation of the "universal" wind profile function in non-neutral air. On the other hand, certain other statistics, such as spectra, appear to be less sensitive to the nature of the terrain. But just because of the unevenness of the terrain, the observations at Round Hill are quite suitable to infer certain properties of the turbulence in air which is not in equilibrium, and thus more representative of conditions usually found. Figure 1.1 shows the topographic features of the Round Hill site.

In order to test the universality of some of the results from Round Hill, observations from other sites were also analyzed. Table 1.1 summarizes the most pertinent information concerning the observations for this study.

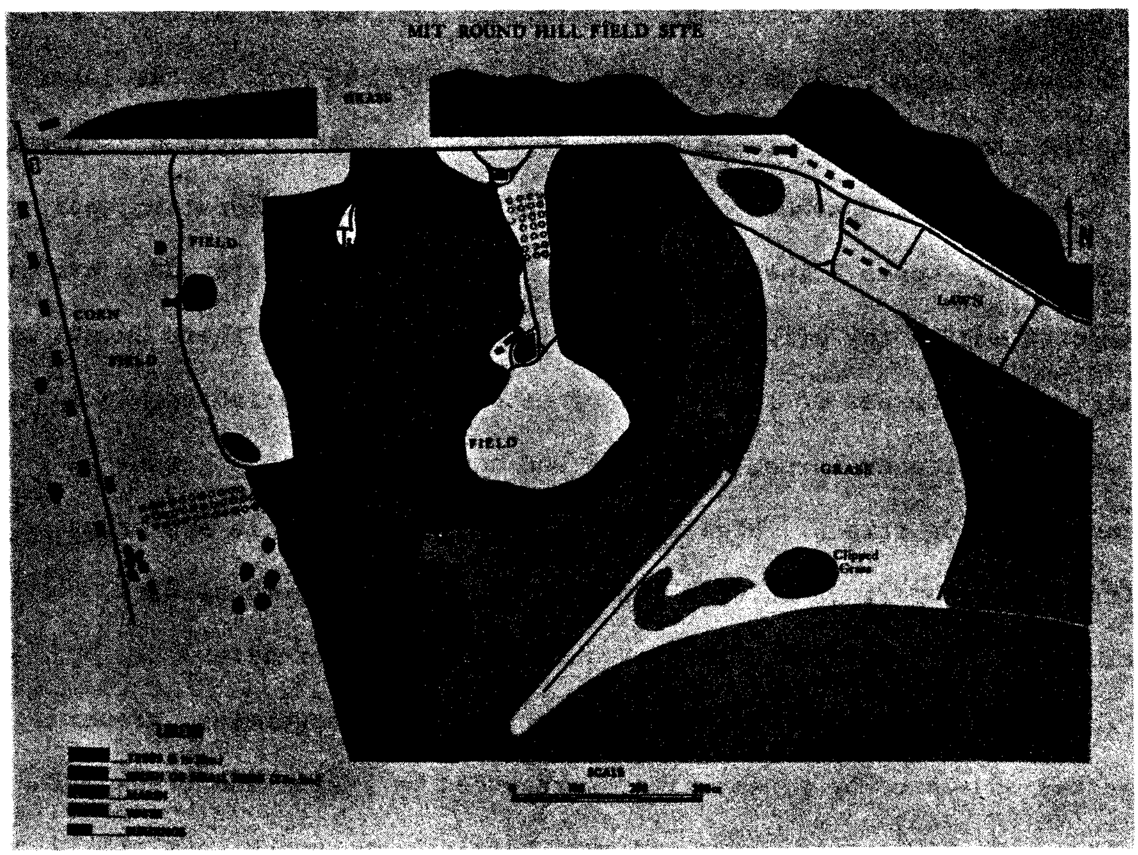

Fig. 1.1 Topographic features of Round Hill site, courtesy of Thomas H. Pries. (T_1 is referred to as tower A, and T_2 as tower B in this report.)

Table 1.1. Summary of observations selected for study.

Location	Round Hill	Hanford	Cedar Hill	Vancouver	Vancouver
Observer	Cramer et al.	Elderkin	Kaimal	Smith	Weiler and Burling
Type of Terrain	Tower A: smooth inhomogeneous Tower B: rough inhomogeneous	arid desert sagebrush fairly homogeneous	gently rolling countryside scattered woods	over sea	over sea
Height (m)	15, 16, 40, 46, 91	3, 6.1	46, 137, 229, 320	1.55 to 4.22	1.68 to 2.70
No. of Runs: Stable	11	4	52	--	3
Neutral	18	7	--	11*	--
Unstable	14	3	100	--	6
Turbulence Quantities Measured	u', v', w', T'	u', v', w'	w'	u', w'	u', w'
Type of Sensors	thermistor anemometers, bivanes, resistance thermometers	heated thermocouple wires	sonic anemometers	thrust anemometers	hot-wire anemometers
Duration of Observations (min)	45-90	13-134 (average 44)	20 or 40 (average 34)	32	>24
Type of Recording	digital	analogue	analogue	analogue	analogue and digital
Type of Analysis	digital	analogue	digital using block averages over 1 sec	analogue	analogue
Profiles: Wind Temperature	cup anemometers resistance thermometers	cup anemometers thermocouples	Aerovanes thermocouples	cup anemometers --	cup anemometers

* stability uncertain

2. COMPARISON OF SPECTRA AT ROUND HILL AND SPECTRA ELSEWHERE

Niels Busch and H. A. Panofsky

2.1 Site properties. Experimental details and data reduction.

2.11 Round Hill. The data used in this study comprise 43 sets of spectra as well as vertical heat and momentum fluxes determined directly from the fluctuation measurements. Spectra of all three velocity components were available for 5 heights (15, 16, 40, 46 and 91 m). The measurements were taken on two different towers.

Tower A (16 and 40 m) is situated about 40 m north of the shoreline of Buzzards Bay in an open area covered with grass. Toward the west and northwest, there is a tidal marsh, and beyond it the terrain changes to woods (Fig. 1.1). The site has been described in detail by Record and Cramer (1966) and Cramer et al. (1961).

Tower B (15, 46 and 91 m) is located about 900 m to the northwest of tower A in an area covered by brush of an average height of 1.5 m. Except for westerly directions, the site is surrounded by woods (average height of about 8 m), the shortest distance to the woods being about 60 m. The topography of the site is relatively flat, except for a low ridge on the west side of the site.

The measurements consisted of one-hour-long recordings of the three fluctuating wind components and temperature and were performed by use of thermistor anemometers, light bivanes and resistance thermometers. A thorough description of the instrumentation and the data-handling system can be found in Cramer et al. (1961).

The data were digitally recorded at equally spaced intervals of 1.0 or 1.2 seconds and analyzed numerically. The computed spectra were corrected for the influence of instrumental time-lag. Another correction was applied to correct for the fact that the original data represented deviations from 301-second moving averages. Correction for aliasing was performed on the basis of an expected -5/3 power law for the portion of the spectra above the Nyquist frequency. It was assumed that the area above this frequency had been folded once about the Nyquist frequency.

Detailed investigation of the data showed that for very small friction velocities u*, the calculated vertical momentum fluxes tended to become numerically very unstable. Hence, it was decided to discard the runs for which $u*^2 < 0.1\ (m/sec)^2$; above this value, $u*^2$ was reasonably stable. Furthermore, inspection of the data showed that in some cases the vertical heat flux computed from deviations from the mean had the opposite sign from the flux computed from deviations from a 301-second moving average. This indicates that the cospectra change sign with frequency and since the physical reason for this is not understood and it well could be a result of the numerical method used, such cases were rejected. Also rejected were runs for which the stability changed sign with height. Finally, for some runs, not all information was available.

Of the 79 runs originally available for this study, 36 were rejected for one or more of the reasons mentioned. Most of the rejected runs were taken under conditions of relatively large stability or during transition periods. In addition, information derived from many other runs was published by Record and Cramer (1966). Some use of these data was made in section 2.3.

<u>2.12 Hanford.</u> Elderkin (1966) reports 14 sets of wind velocity spectra for all three components measured at 3 and 6.1 m at The Battelle Northwest Laboratory, Hanford, Washington. The same report gives a complete description of the instrumentation.

The friction velocity was in each case calculated directly from the fluctuation measurements. Measurements of temperature fluctuations were not obtained; therefore, estimates of the vertical heat-flux were not available. The thermal stability classification of the runs was obtained using gradient Richardson numbers determined from profile measurements.

A description of the site has been given by Barad et al. (1962). It is flat and fairly homogeneous desert-terrain covered with sagebrush of 1 to 2 m height interspersed with desert grasses.

The turbulence data were collected with a fast response sensor utilizing heated thermocouple wires. The data were recorded on magnetic tape and analyzed by use of analogue methods. The duration of the runs varied from 13 minutes to 134 minutes with an average duration of 44 minutes.

2.13 Cedar Hill. In August 1963 a series of vertical-velocity measurement was made on the Cedar Hill tower near Dallas, Texas. Four one-dimensional, two-way sonic anemometers were mounted at levels 46, 137, 229 and 320 m providing simultaneous measurements of the vertical-velocity components.

A total of 40 sets of such simultaneous runs have been reported by Kaimal (1966) who also gives a description of the turbulence instrumentation and data-handling system.

The data were recorded as analogue signals on magnetic tape but later converted into time series consisting of 1-sec block averages over consecutive intervals. The analysis was carried out numerically. The spectra were corrected for the filter effect of the block averaging as well as for aliasing. The duration of the runs was 40 minutes for 28, and 20 minutes for 12 of the runs.

The only turbulence quantity measured was the vertical-velocity component; therefore, direct estimates of Reynolds stresses and heat fluxes were not available. Estimates of the friction velocity were obtained from the relation

$\overline{w^2}/u_*^2 = 1.7$ (see section 2.3) and the stability was judged on the basis of gradient Richardson numbers obtained from profile measurements.

Of the 40 sets of runs reported by Kaimal only 38 are considered in this study. One set was rejected due to change of stability with height. For the other, some statistics were missing. Both sets were measured during transition periods.

A description of the tower and its instrumentation for profile measurements may be found in Gerhardt et al. (1962).

The site is described as gently-rolling countryside with scattered woods (Stevens and Gerhardt, 1959) but appears to be rather inhomogeneous on a larger scale (MacCready et al., 1961).

2.14 Vancouver. Smith (1966, pp. 141-151) reports 11 measurements of the longitudinal and vertical spectra over the sea at the Spanish Banks near Vancouver, B. C. The site has been described by Pond et al. (1966), who also describe the thrust anemometer used to collect the wind data utilized in this study.

The height of measurement varied with the tide from 1.55 m to 4.22 m. The data were recorded as analogue signals on magnetic tape and the spectral analysis as well as the computation of Reynolds stresses were carried out by analogue computer. The duration of the observations was 32 minutes. Measurements of temperature fluctuations were not obtained; therefore, estimation of vertical heat-fluxes was not possible. Wind profiles were measured but not the temperature profiles. A check on the thermal stability of the atmosphere is thus not furnished.

Later, Weiler and Burling (1967) reported spectra of longitudinal and vertical-velocity components obtained at the same site but from measurements by hot-wire anemometers. Reduction of the data was similar to Smith's.

Table 7.1. List of quantities measured, height of measurement and roughness length for each site:

Site	Height (m)	z_o (cm)	Quantities measured
Argus ocean tower	5.5, 7.5	<0.1 (variable)	σ_w
Australia, 1955	30	2.0	σ_u σ_w σ_T
Centerton, N. J.	32	150	σ_w
Marsh site, N. J.	16	3	σ_w
O'Neill, Neb., 1957	1.5, 12	0.8	σ_u σ_v σ_w σ_T
O'Neill, Neb., 1959	2.0	0.8	σ_u σ_v σ_w
South Dartmouth, Mass., 1962	16, 40, 15, 46, 91	7, 30	σ_u σ_v σ_w σ_T
Sterling, Va.	2, 4, 8	<0.1	σ_α
White Sands, N. Mex.	11.7, 17.8	20	σ_u σ_v σ_T

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