RELATION OF GUSTINESS TO OTHER METEOROLOGICAL PARAMETERS

By Irving A. Singer and Maynard E. Smith

Brookhaven National Laboratory [1,2]

(Manuscript received 21 October 1952)

ABSTRACT

Two years of data have been processed to show relationships between wind gustiness and other meteorological parameters. The gustiness classification used at Brookhaven National Laboratory is defined by the range and appearance of the horizontal wind direction trace. The seasonal and diurnal variations are presented. Gustiness is closely related to lapse rate and solar radiation, while its association with wind speed and Sutton's index of turbulence is not as distinct.

1. Introduction

The meteorological control program developed at Brookhaven National Laboratory requires some simple means of classifying atmospheric turbulence, so that the dispersion of cooling air from the nuclear reactor may be measured and forecast on a routine basis. The first approach to the problem, described by Smith [1], was based on the variations of horizontal wind direction as measured by a standard Bendix-Friez *Aerovane*, mounted 355 ft above ground. The time interval used was one hour. The original system has proven satisfactory in most respects, and is still in daily use.

The purpose of this paper is to relate the gustiness classifications to (1) lapse rate and wind speed, (2) seasonal and diurnal variations, (3) radiation and cloud cover, and (4) Sutton's index of turbulence. Hourly averages of the most accurate and complete data have been analyzed for a two-year period (April 1950–March 1952), and the results are summarized. During this period, 96 per cent of the record is complete in all respects. Only the major aspects of the relationships are considered here, and many details which are relatively unimportant to the reactor control-program have been deferred for future investigation.

2. Gustiness classifications

The original separation of wind gustiness into typical categories [1] was based on a brief record. Four classes were recognized, and were designated A, B, C and D in order of decreasing amplitude of the fluctuations of the horizontal wind direction. Additional data suggested the need for a fifth category, and the B classification is now divided into B_1 and B_2. The current classifications are defined below, and sample sections of the 355-ft wind records are shown in fig. 1:

A: Fluctuations of the wind direction exceeding 90 deg.

B_2: Fluctuations ranging from 45 to 90 deg.

B_1: Similar to A and B_2, with fluctuations confined to 15- and 45-deg limits.

C: Distinguished by the unbroken solid core of the trace, through which a straight line can be drawn for the entire hour, without touching "open space." The fluctuations must reach 15 deg, but no upper limit is imposed.

D: The trace approximates a line. Short-term fluctuations do not exceed 15 deg.

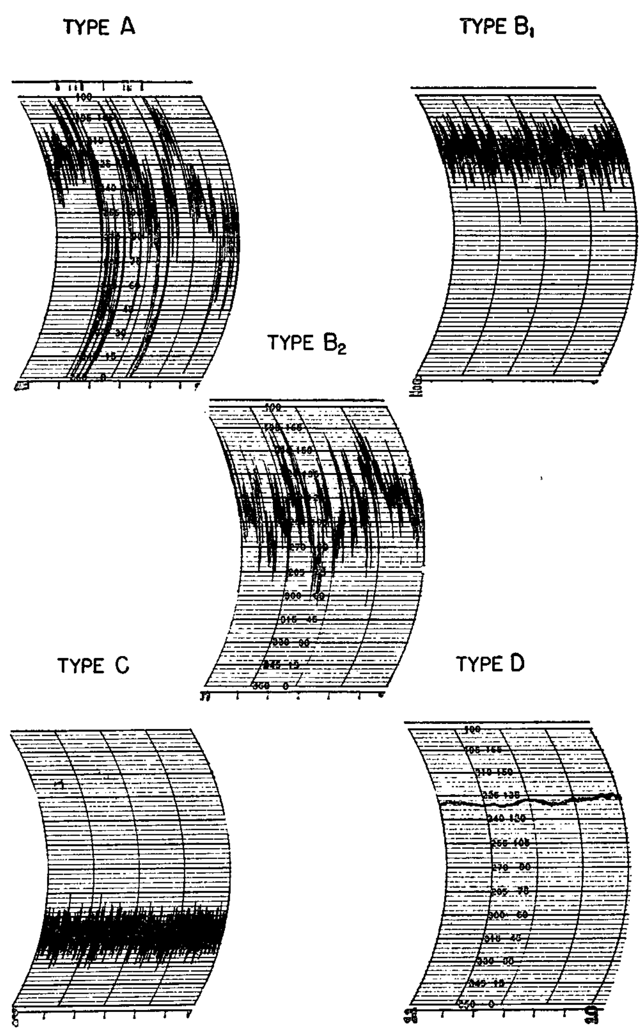

FIG. 1. Gustiness classifications.

[1] Research carried out under the auspices of the U. S. Atomic Energy Commission.

[2] Paper presented at 117th National Meeting of the American Meteorological Society, Buffalo, New York, 3 July 1952.

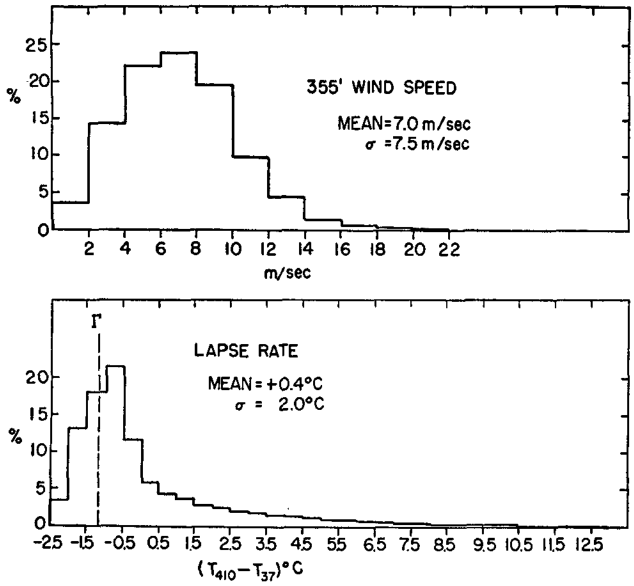

FIG. 2. Percentage frequency distribution of wind speed and lapse rate. (σ for wind speed should read 3.5, not 7.5 m/sec.)

3. Relation of gustiness to lapse rate and wind speed

Turbulence in the atmosphere is basically either convective or mechanical in origin. The former must be related to the lapse rate, the latter to the wind speed. It is therefore desirable that the frequency distributions of these two variables be presented for the period studied.

The percentage frequency of the mean hourly temperature-difference (deg C) between 410 and 37 ft is shown in fig. 2. The range of temperature difference during the period was 15.5C, with a mean of 0.4C and a standard deviation of 2.0C. Inversion conditions prevailed for 39 per cent of all hours. Similar data for the 355-ft wind speed are shown. The range was 22 m/sec, with a mean wind speed of 7.0 m/sec and a standard deviation of 3.5 m/sec.

The gustiness categories are closely related to the lapse rate. Type B_2 is associated with the most unstable lapse rate, followed by A, B_1 and C in order of decreasing instability. All the lapse cases have approximately the same standard deviation, as can be seen from the similarity of their curves in fig. 3. The small percentage of A, B_2, B_1 and C cases associated with inversions probably results from transient conditions, in which the turbulence and the lapse rate are changing rapidly. The D gustiness has a much larger standard deviation, and is found with both inversions and unstable lapse rates. The latter cannot be explained solely by transient conditions, and is discussed further in section 5.

In general, the relationship between gustiness and wind speed shown in fig. 4 is less precise. The most common gustiness classes, types B_1 and D, are found with a wide range of wind conditions. Types A and B_2, however, are associated with light winds, and type C with strong winds. A more marked relation between D cases and light winds might be anticipated, since this is the stable gustiness class. This would be true close to the ground, but at levels of 300 ft or more the maximum wind speeds are usually found at night with stable conditions.

By combination of figs. 3 and 4, the gustiness classes can be associated with the two main types of turbulence, convective and mechanical. This is shown in fig. 5, where the dot in each rectangle represents the appropriate mean of wind speed and lapse rate for the indicated gustiness class, and the dimensions of the rectangles represent the distances of the standard deviations from the means.

Types A and B_2, the light-wind, unstable cases, are mainly convective in nature. Type C is primarily mechanical in origin, and is associated with strong winds and neutral stability. The combination of convective and mechanical turbulence is shown in the B_1 case, with average winds and unstable lapse rates. Type D, which is found with stable lapse rates, reflects very little turbulence.

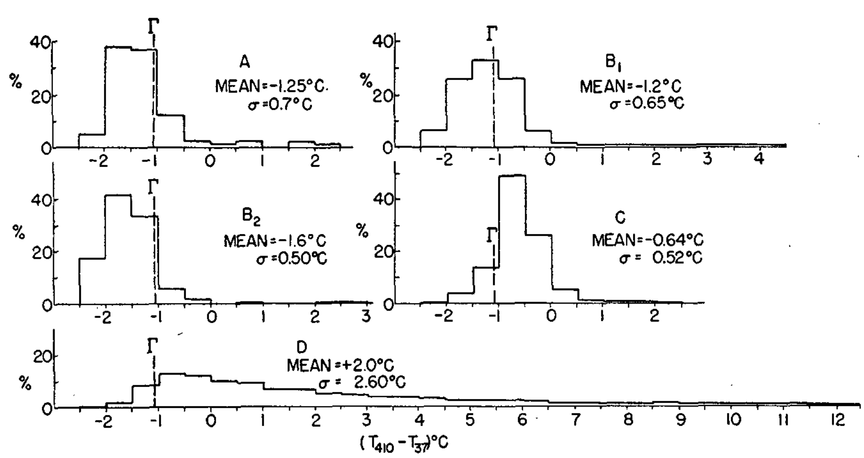

FIG. 3. Percentage frequency of gustiness classes by lapse rate.

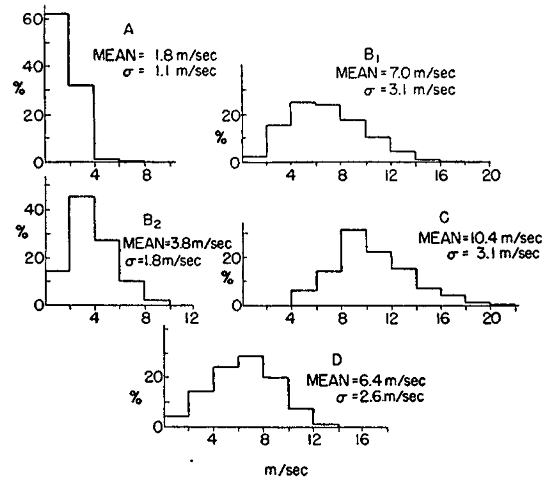

FIG. 4. Percentage frequency of gustiness classes by wind speed.

4. Seasonal and diurnal variation of gustiness

The mean percentages of occurrence of the gustiness classes were as follows:

B_1: 42 per cent
D: 40 per cent
C: 14 per cent
B_2: 3 per cent
A: 1 per cent

An interesting feature of this distribution is the high frequency of the D cases. It is not felt that this result is peculiar to the Brookhaven area, since the terrain conditions and general climate are not particularly unusual except for the sea breeze, which would have little influence on the frequency of low-level temperature inversions.

Fig. 6 shows the monthly percentage frequency of gustiness classes. There is little seasonal variation. One would expect a larger percentage of occurrence of the convective types, A and B_2, during the summer; but their absence probably can be attributed to the sea breeze, which prevents extended periods of low wind speed on summer afternoons. One might also expect a larger percentage of D cases in winter, but the seasonal balance is maintained because the stable cases occur less frequently in winter, as can be seen in fig. 7. From this figure, it is also evident that the D type is predominately a nocturnal case, and the A, B_2 and B_1 types are found during the daylight hours. The C case has a minimum in the early afternoon.

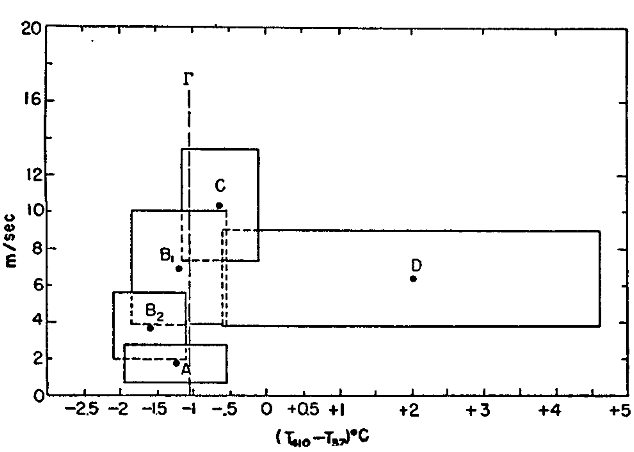

FIG. 5. Means and standard deviations of gustiness classes.

5. Relation of gustiness to radiation and cloud cover

Since the gustiness is strongly influenced by the vertical temperature structure, one would also expect to find a close relationship with both solar and terrestrial radiation. The former is measured at Brookhaven by an Eppley pyrheliometer, and long-wave radiation must be roughly approximated by sky cover. The hours 0100 to 0500 EST and 1100 to 1500 EST have been chosen for an analysis, in an attempt to eliminate transient conditions.

The most outstanding feature of the relationship is the strong predominance of D and B_1 cases, regardless of radiation or season. It is quite clear from fig. 8 that other cases are of minor importance, as far as any average turbulence regime is concerned. From the point of view of atmospheric-dispersion conditions, a new concept of the "average" appears desirable, since the D and B_1 cases represent markedly different forms of dispersion.

The distributions of A and B_2 cases are approximately what would be expected from previous data and consideration of the physical processes involved. They are associated almost entirely with strong insolation and thermal instability.

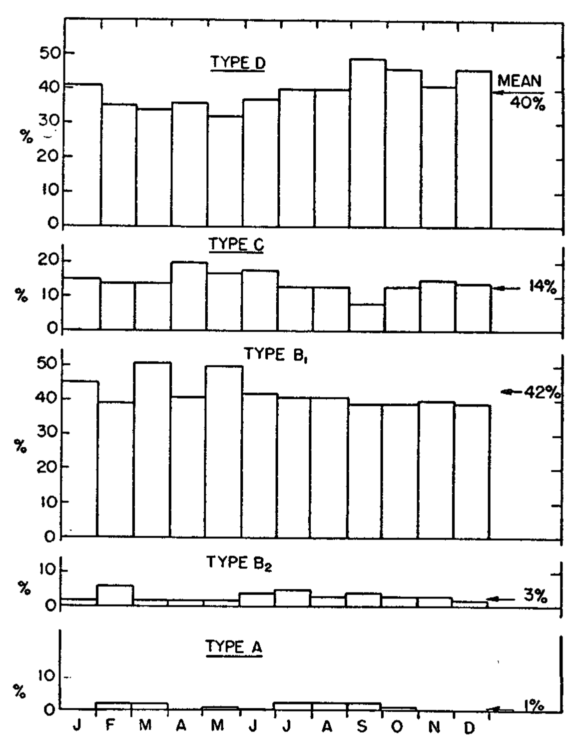

FIG. 6. Monthly percentage frequency of gustiness classes.

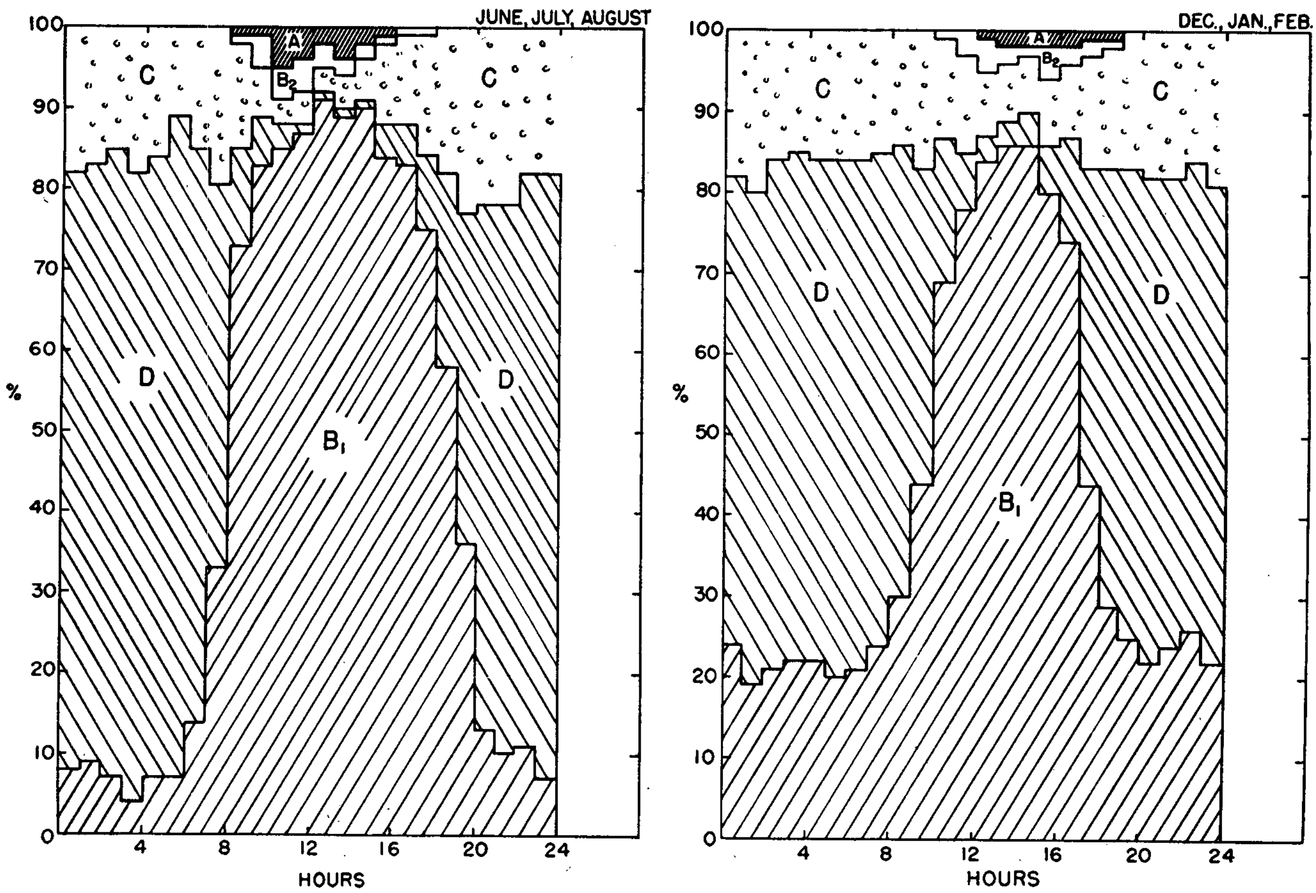

FIG. 7. Percentage frequency of gustiness classes by hours.

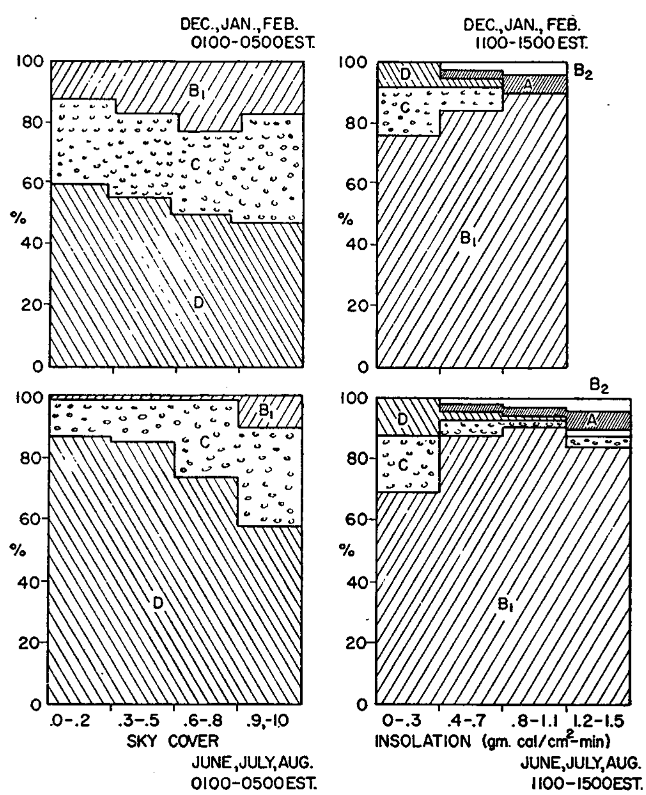

FIG. 8. Percentage frequency of gustiness classes by sky cover and insolation intervals.

The distribution of the C type gustiness is also relatively uncomplicated. In both summer and winter, it is associated with small insolation during the daylight hours, reflecting heavy cloudiness. The nocturnal C case is less common in summer than in winter. It is felt that the greater frequency of high wind speeds during the winter accounts for the difference. Similarly, the greater frequency of B_1 cases in the winter nights is probably associated with cold advection.

Fig. 8 reveals two interesting features of the D gustiness class. Although primarily associated with stability, a very significant portion of D traces is found with a cloud cover of 6/10 to 10/10. Also, a small percentage is associated with solar heating of low intensity. Inasmuch as 36 per cent of the D cases were found to be associated with lapse or isothermal conditions, a further investigation was undertaken. The data for one year (April 1950 to March 1951) were carefully scrutinized, to determine the detailed relationship of D cases to cloudiness and time of day.

The data, presented in fig. 9, show clearly that the D cases associated with inversions have a very different relationship with cloud type and sky cover than those associated with lapse conditions. The inversion D cases show the greatest single percentage occurring with clear skies, and a small secondary maximum with 9/10 to 10/10 low cloud. With lapse D cases, the

$T_{410}-T_{37}$ = +0.1 TO +15.0°C

SKY COVER	CLOUD TYPE: LOW	MIDDLE	HIGH	
.9-1.0	13	8	3	
.6-.8	3	6	5	
.3-.5	2	5	8	
.1-.2	2	4	5	
CLEAR				36

% OF TOTAL D CASES = 75 %

$T_{410}-T_{37}$ = 0.0 TO −2.0°C

SKY COVER	CLOUD TYPE: LOW	MIDDLE	HIGH	
.9-1.0	40	15	3	
.6-.8	5	6	5	
.3-.5	2	2	4	
.1-.2	2	2	2	
CLEAR				12

% OF TOTAL D CASES = 25 %

FIG. 9. Percentage frequency of D cases by sky cover and cloud type, April 1950–March 1951.

relationship is reversed; 60 per cent of them occurred with 9/10 to 10/10 low and middle clouds, and 12 per cent with clear skies. A study of the D cases associated with lapse conditions (fig. 10) reveals that, for the cases with 0 to 8/10 sky cover, a pronounced peak is found in the late afternoon hours, whereas no significant peak occurs with overcast skies. It should be noted that the latter are not transient cases. Every hour of a night with 10/10 low cloud may show the D gustiness.

These data, taken together, suggest that there are three groups of D gustiness classifications: (1) those associated with clear skies and low level inversions, (2) those found with a heavy cloud deck and nearly isothermal conditions, and (3) a transitory group occurring in the late afternoon, but not in the early morning. Further investigation is beyond the scope of the present paper, but it will be important to determine whether there are several processes resulting in typical stable flow, or whether an intermediate classification between C and D exists.

6. Relation of gustiness classes to Sutton's index of turbulence

The gustiness classification system used at Brookhaven is empirical, and is intended for a specific problem at this site. For the general solution of problems in turbulence, an adequate theory is required. Inasmuch as the Sutton [2] approach is used as a theoretical model for the work at Brookhaven, a detailed analysis of the relation of the parameter n and the gustiness classifications has been completed.

n is computed by the following formula:

$$u/u_1 = (z/z_1)^{n/(2-n)}.$$

Here u = wind speed, and z = vertical distance.

The range of n is normally from 0 to 1; the smaller the value of n, the greater the turbulence. Sutton's n was computed hourly for a two-year period, using the heights of 410 and 150 ft. The comparisons are shown in fig. 11. In general, the value of n increases as the gustiness classes become more stable; but n computed in this manner is not sufficiently precise to warrant use in individual cases. For example, the D gustiness in fig. 11 has values of n from 0 to 0.70.

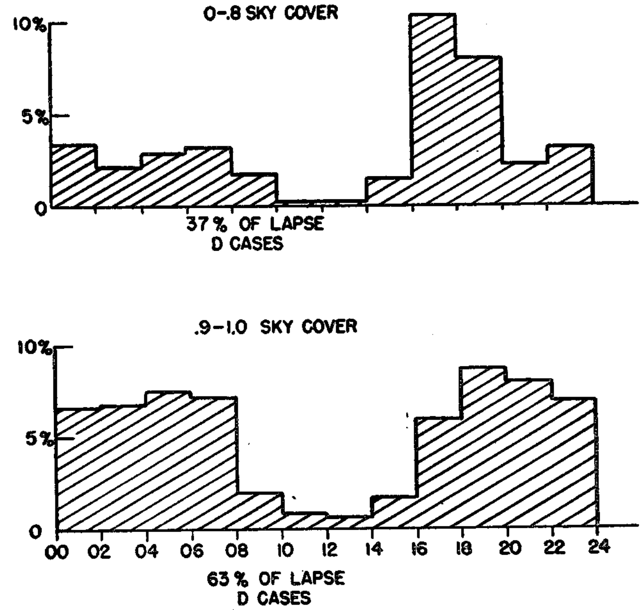

FIG. 10. Percentage frequency of D cases with $T_{410} - T_{37}$ = 0.0 to −2.0C, by sky cover and time of day.

7. Applicability of data

It is advisable to review some of the more important features of the data, to insure clear understanding of their limitations. The basic parameter of the study, the wind gustiness, has been obtained from a standard Bendix-Friez *Aerovane*, which has a period of 12 sec at a wind speed of one meter per second, and a damping factor of 0.042 at one foot per second. The chart speed for the Esterline-Angus recorder is 3 in/hr, resulting in a pen trace which itself is 30 sec to one minute in width. It should be clear that use of an instrument having a different sensitivity and chart speed might necessitate some changes in the definitions of the gustiness categories, because a different portion of the eddy spectrum would be measured.

It is also important to keep in mind that these

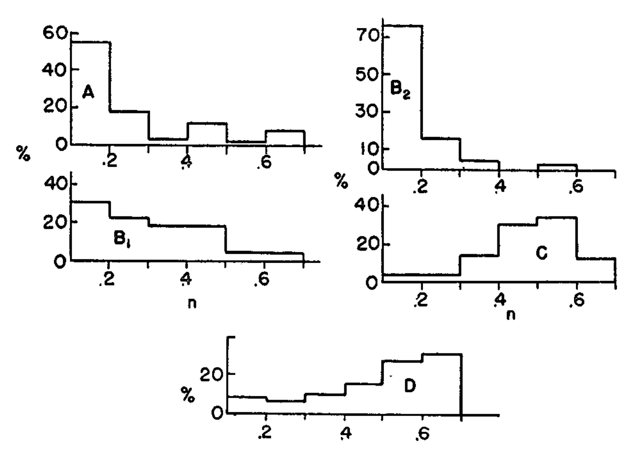

FIG. 11. Percentage frequency of gustiness classes by intervals of Sutton's n.

records were obtained at a relatively high level, at which the stability, turbulence and wind-speed regimes are different from those near ground level. For example, the definitions of gustiness used in this paper apply equally well to 300, 355 and 410 ft, but would require alterations for lower-level measurements. In a lapse situation, the angular width of the trace increases as one approaches the ground level, although the general appearance of the trace remains the same. During most inversions, the wind near ground level is too light to keep the *Aerovane* in motion.

As a final point, some consideration should be given to the more general aspects of the Brookhaven climatology, to assess the over-all value of the data. In many respects, the location is typical of any middle-latitude station having flat terrain. The most obvious departure from a so-called "normal" is the sea breeze, which affects the area to a significant degree during the warm half of the year. This not only gives a predominance of southwest winds during the summer, but reduces the probability of light, horizontal wind speeds during summer days.

8. Summary

The data presented in this paper have shown that the wind gustiness is closely related to the lapse rate of temperature, while the relation to wind speed is not as distinct. Surprisingly, little seasonal variation is found in the frequency of gustiness classes. This results primarily from the inverse relation between the duration and the frequency of inversion situations.

Most of the gustiness categories seem to be suitable, in the sense that they delineate groups having relatively specific limits in terms of lapse rate and, in some cases, wind speed. The D classification stands out as an exception, since a substantial percentage of D cases are found with unstable lapse rates. Further study is indicated to determine whether the definition is inadequate, or whether there is more than one situation associated with stable flow.

Gustiness exhibits a rough relationship with the Sutton index of turbulence, obtained from the wind profile, but this is not sufficiently precise to recommend the use of specific values of n for individual case studies.

Acknowledgments.—The writers are indebted to Mary Geideman and George Potts of the Meteorology Group staff for their invaluable assistance in the preparation of the data. Peter E. Kraght prepared most of the data included in fig. 8, in a preliminary study of the problem, and Prof. Bernhard Haurwitz, Philip Lowry and Daniel Mazzarella each contributed a number of valuable suggestions during the progress of the work.

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2. Sutton, O. G., 1947: The theoretical distribution of airborne pollution from factory chimneys. *Quart. J. r. meteor. Soc.*, **73**, 426–36.