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Estimates of Dispersion from Pollutant Releases of aFew Seconds to 8 Hours in Duration

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Air Resources Laboratory Reports

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1. Dispersion Estimates from Pollutant Releases of a Few Seconds to 8 Hours in Duration. David H. Slade. Aug. 1965.

2. A Technique for Estimating Average Airborne Contaminant Concentrations. Jerome L. Heffter. Feb. 1966.

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ESTIMATES OF DISPERSION FROM POLLUTANT RELEASES OF A FEW SECONDS TO 8 HOURS IN DURATION

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ABSTRACT

The purpose of this note is to present a simple method, based on on-site measurements made with a single wind system, for estimating dosage or concentration values, from point sources of pollution at a specific location. The method is based on diffusion theory and experimental evidence. A number of readily rationalized simplifications have been used to develop this system of dispersion specification which is primarily intended for use in constructing dispersion climatologies. A major portion of this paper is reproduced from Technical Note 2-ARL-1 by this author [20].

The method may be used at any location situated in reasonably regular terrain. It should be used with great care, if at all, in areas typified by large, discrete topographic variations such as marked valleys, mountain peaks, and coastal regions.

1. INTRODUCTION

This paper is divided into three basic parts:

(a) Instructions for obtaining the required meteorological measurements.

(b) The estimation of dosage or concentration from continuous point source releases of pollutants. In this section, release or sampling times in the range of 10 minutes to 8 hours are considered.

(c) The estimation of dosage or concentration from quasi-instantaneous point sources. Here, release times are considered to be in the range of from a few to 30 seconds.

The dispersion estimation technique to be discussed here has its origin in the analysis of a series of dispersion experiments referred to collectively as "Project Prairie Grass." These experiments were performed in the summer of 1956 at O'Neill, Nebraska and reports dealing with the measurements have been prepared by Barad [1] and Haugen [8].

In 1957, Cramer [2] presented a series of graphs of measured axial concentration and plume width for distances to 800 m. from the source as a function of a measure of the fluctuation of the wind. These curves were based on some 70 experiments from the Prairie Grass series as well as upon 29 experiments performed at Round Hill, Massachusetts. Cramer's paper showed quite clearly that the standard deviation of the azimuthal wind direction, σ_θ, the wind fluctuation parameter, could be used to describe concentration or plume width with a useful degree of accuracy for distances from 50 m. to 800 m. from the source. He further computed the vertical spreading of the plume from the axial concentration and plume width for various values of the parameter σ_θ.

An effort was made by Pasquill, in an unpublished note the substance of which is contained in a paper by Meade [18] and, again, by Pasquill [19] to develop a simple system of downwind concentration estimation. Pasquill suggested that both the vertical and horizontal standard deviations of the continuous plume concentration distributions, σ_z and σ_y, be estimated in accordance with the suggestions of Hay and Pasquill [10]. The Hay and Pasquill paper presented a convenient method of estimating both vertical and lateral cloud spread from measurements of wind direction fluctuations made with a suitably responsive instrument. Recognizing that the vertical wind direction fluctuation data required by this method were not generally available, Pasquill suggested that the appropriate degree of vertical spreading could be found by the use of the Cramer curves with the σ_θ values called for by Cramer estimated from stability considerations. It was suggested that stability be estimated from wind speed and the degree of insolation. Pasquill further indicated how the lateral spreading of the plume could be estimated from the "range" (width of the wind direction trace from a recording wind direction system) for long (about one hour) pollutant releases. He also suggested a series of wind direction range values to be used in lieu of actual wind measurements for short releases during steady wind direction conditions. These direction range values were related to the same estimates of stability used to infer the vertical spreading.

The Gaussian plume model assumed by Pasquill is similar to that given in Appendix 2 of this paper by the equation for concentration in a continuous plume with the exception that the plume width was given by θ in degrees and depth by h in meters. These are, respectively, twice the angular width of the plume from the plume axis to a point where the concentration is 10 percent of the axial and the vertical extent of the plume, measured from the surface again to the point where the concentration falls to 10 percent of axial. As pointed out by Pasquill and also by Gifford [7], these values of θ and h can be expressed in terms of the dispersion coefficients σ_y and σ_z, of the generalized Gaussian plume model by the relationships

$$\theta/2 \text{ (radians)} = 2.15\ \sigma_y/x \qquad (1)$$

$$h = 2.15\ \sigma_z \qquad (2)$$

(x is the distance from the source) where the numerical coefficient 2.15 is the 10 percent ordinate of the normal distribution curve. Gifford converted the Pasquill values of h into σ_z and the short release time θ estimates into σ_y and presented the resulting curves in the aforementioned note. In Gifford's note, dispersion estimation is achieved by estimating <u>both</u> σ_y and σ_z from the appropriate curves representing the various thermal stability values. These are, in turn, estimated from cloud cover, wind speed, and (by day) insolation intensity.

It is necessary to point out that, to date, no one has systematically related these inferred stability categories to Cramer's σ_θ categories or to values of σ_θ and σ_ϕ (the horizontal and vertical wind direction standard deviation) computed as suggested by Hay and Pasquill in their 1959 paper.

Further, in practice, observations of cloud cover and wind speed are not usually available for the precise location of interest. Therefore, because of the spatial variability of wind speed, cloud cover, and topographic configuration, the use of stability types derived from data taken perhaps tens of kilometers from the location at which dispersion estimates are desired, is open to considerable question. Again, this system of stability estimation is quite sensitive to the wind speed (a difference of 2 $m. sec.^{-1}$ being equivalent to the difference between stable and neutral dispersion conditions on clear nights). The known spatial variability of wind speed and crudeness, for dispersion estimates, of the wind speed observation at conventional weather stations, detracts further from the confidence that can be attached to dispersion estimates made from conventional observations.

In 1964, Fuquay, Simpson, and Hinds [5] extended the methods of Cramer and Pasquill by presenting the results of 46 continuous source dispersion experiments (the Green Glow-30 series) conducted during a variety of stability conditions over a grid extending to greater distances (25.6 km) than had been used in any previous major dispersion experiment. Their program consisted of the direct evaluation of measured dispersion parameters in terms of measured wind fluctuation parameters. Fuquay et al. chose to relate downstream dosage to measures of the product $\sigma_\theta \bar{u}$ (where $\bar{u}$ is the average wind speed during the tracer release). They also measured the thermal stability via a form of the Richardson number which could be expected to be related to the vertical spreading of the tracer. In the use of the Richardson number they went one step further than Cramer who assumed that the horizontal wind statistics were sufficient in themselves to estimate the total result of lateral and vertical plume spreading, i.e., the downstream concentration distribution. The data from this important series of experiments will be incorporated in the simplified dispersion estimation technique described in section 4.

The method of dispersion estimation advanced in this note is intended to provide those who wish to erect an effluent producing system with an objective scheme for estimating the dispersion climatology at their site. The method of this note requires a climatology of wind fluctuation data collected over a period of at least a year. The often heard lament that there are "no data available" for a particular site should not usually be countenanced since there frequently is, or can be, sufficient lead time, in planning for an important facility, to collect a reasonably definitive dispersion climatology, via the approaches of Cramer, Pasquill, Fuquay et al., or that to be presented in the following sections, if the opportunity for data collection is grasped as soon as the requirement is recognized.

Before proceeding to the working sections, the reader should be alerted to the degree of confidence that can be attached to the various topics. The continuous source discussions of sections 2, 3, and 4 are based on many investigations all of which have furnished a reasonably consistent body of information. This material may, therefore, be used with the confidence that future research may modify, but will not drastically alter, the general picture. The method of section 5, dealing with the extension of continuous source dispersion statistics to periods considerably greater than one hour, has rarely been tested and should be used only to furnish a crude estimate in an area where no better working techniques have been promulgated. The topic discussed in Appendix 1, the instantaneous source release, has received considerable attention in the theoretical literature but experimental evidence has but very recently begun to accumulate. Therefore, this information should be considered as quite tentative.

2. THE BASIC METEOROLOGICAL DATA

The meteorological data required by the various methods for estimating dispersion, as noted in section 1, are adequately described in the previously referenced publications. The simplified technique described in the following sections requires certain concepts and data manipulation techniques that are discussed in this section.

The meteorological data required are the average wind speed ($\overline{u}$), the wind direction (θ) and the standard deviation of the azimuthal wind direction (σ_θ) all for a period of <u>30 minutes</u>. These data may be estimated from the analog records of any one of a number of commercially available wind systems.

The sturdy and widely used "Aerovane" type of wind system, available from a number of manufacturers should perform adequately. It is desirable that the recorder be equipped with an extended direction scale, typically, 540°. When the direction recording pen reaches either edge of the chart in systems of this type, it is automatically switched to return 360° toward the center of the chart, thus eliminating ambiguous marginal recording. Variable chart drive speeds of 3 in. per hour and 3 in. per minute are a useful, but not mandatory feature. The 3 in. per hour chart speed is required for all the operations discussed below except as otherwise noted.

The mean wind speed and direction for a 30-minute period (the base observation length for use with this note) may be read directly from the analog traces on the charts by means of a clear plastic overlay scribed with a straight line. The attempted accuracy of the readings should be commensurate with the scale of the charts and the sensitivity and accuracy of the sensors. Direction readings to the nearest 5° and average speeds to the nearest 1/2 to 1 m. sec.$^{-1}$ should be sufficient.

Estimates of σ_θ may be made in a number of ways. Electronic data reduction systems, Jones and Pasquill, [15] that convert the wind vane movements directly into σ_θ values are available. Alternatively, the wind direction data output may be digitized and values of σ_θ obtained by computer processing.

The method suggested for use in this note involves the measurement of the wind direction range (R) over the basic 30-minute period. The method is simply this: one notes the absolute range of the wind direction trace on the analog recording (in degrees) and divides this value by a constant factor, a procedure which converts R to an approximate value of σ_θ. The use of the range to estimate σ_θ is adequate for climatological compilations. A value of 6.0 is suggested for the constant (Holland, [13]; Markee [16]).
A value, perhaps more appropriate to the particular site of interest may be obtained from a trace made with chart speeds of 3 in. per minute. In this case, the raw data consists of 5- or 10-second average direction values (θ) obtained from the analog chart over a 30-minute interval. These values of θ

may then be used to determine σ_θ in the usual way. This process should be repeated for 10 or 20 different 30-minute periods under a variety of wind speed, wind direction, and thermal stability conditions. The resulting σ_θ values may then be compared to the absolute range over each of the intervals. This time consuming calibration procedure may be carried out simultaneously with the actual climatological compilation thus avoiding unnecessary delay in beginning the data collection program.

The sensor should be mounted at the approximate height and location of the expected effluent release. If this is not possible, the sensor should be placed at a location where it would be expected to experience wind characteristics similar to those that would exist at the actual source. The possible pitfalls in locating the sensor are legion and professional meteorological advice may be necessary. This is extremely important since improper placement could invalidate the results of the entire program.

3. STEADY AND NON-STEADY WINDS

In order to properly use the concepts of turbulence theory to estimate diffusion, it is important to distinguish between "steady" and "non-steady" winds. This is necessary regardless of whether σ_θ is determined by automatic electronic manipulation or by estimates made from the wind direction range.

A steady wind direction over a given period of time, a half hour is a good example, may be described as consisting of a well defined mean direction superimposed upon which are random turbulent fluctuations. This concept can be clarified by reference to typical wind direction traces. Consider, first, the daytime traces in figure 1. These range from a very steady case, figure 1(a), associated with comparatively high winds (speeds are in knots on these charts) to the extremely unsteady winds in the last illustration, figure 1(e). The progressive decrease of wind speed and concurrent increasing non-steadiness may be noted.

In figures 1(a) and (b) the wind is defined as steady for the purpose of this note and the wind direction range may be measured simply and unequivocally. Figure 1(c) shows generally steady wind directions except for the change in mean direction between 2:15 p.m. and 2:40 p.m. One would, however, use the range measured in the half hour interval including this change for a σ_θ measurement since a pollutant emitted in this interval would be spread over a comparatively large sector. The large σ_θ values computed from the range, in cases such as this, would furnish a good measure of the combined effects of turbulence and direction meander on spreading the plume laterally and thus reducing average concentrations or total dosages at a downwind point.

The wind direction trace in figure 1(d) can be considered as "steady" and used to estimate σ_θ most of the time if the very transitory wide fluctuations, such as the two in the vicinity of 11:00 a.m. are ignored in measuring the range. This is justifiable since the amount of effluent transported from a continuous source during these extremely brief excursions is minimal. It may be noted that these large direction fluctuations are frequently associated with decreases of the wind speed to values below the threshold of the anemo-

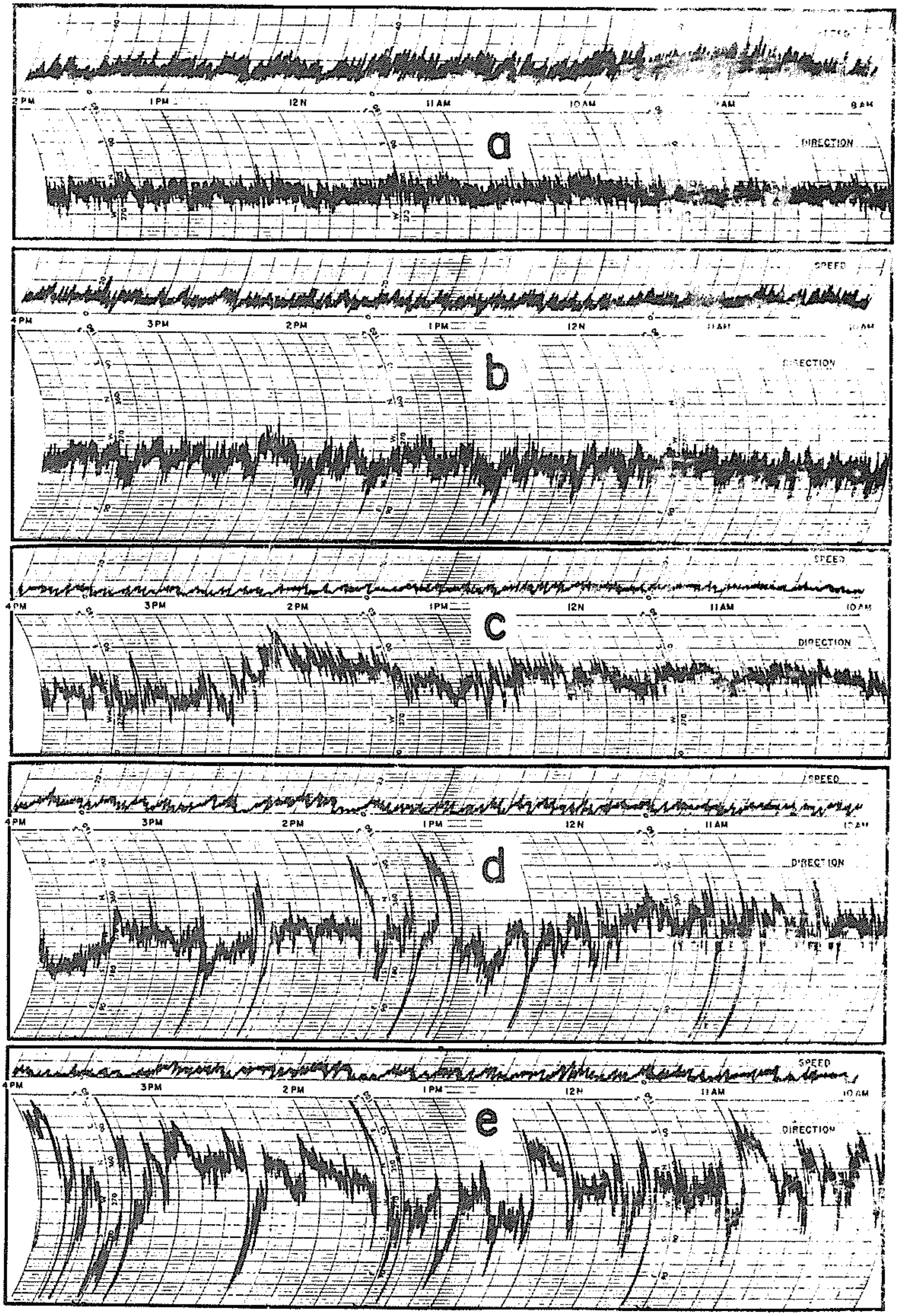

Figure 1. Typical analog wind speed and direction traces observed during the day.

meter. Extreme direction meander is evident in figure 1(e) between 3:00 p.m. and 4:00 p.m. A period such as this should be considered as non-steady. There is obviously some point in the interpretation of wind traces where a subjective decision must be made as to whether the wind direction trace is steady or non-steady.

Low-level wind direction conditions at night are generally somewhat different from those that occur during the day. Three typical traces are shown in figure 2. The first diagram, figure 2(a), illustrates the classic steady wind direction pattern. This pattern is typically composed of a narrow range of turbulent fluctuations superimposed on a slowly meandering mean direction. Wind speeds, while low, rarely fall below the threshold of a well maintained off-the-shelf commercial wind speed sensor. With higher night wind speeds, the meander is reduced while the turbulent fluctuations increase somewhat resulting in a trace not unlike that of a windy day.

Under clear night skies during conditions of generally light, large-scale air movement, the low-level wind pattern is frequently similar to that in figure 2(b). The peculiar square-cornered trace, associated with a below-threshold wind speed, is caused by brief, very gentle puffs of wind moving the vane from one position to another where it languishes until the next puff. Such portions of the direction trace are considered as non-steady in the framework of this note. The remainder of the trace in figure 2(b) is usable for range determination.

The last diagram, figure 2(c), shows an extreme version of the trace type of figure 2(b). Here the wind speed rarely reaches a level sufficient to cause a usable response in the direction sensor and the entire trace is considered as non-steady.

At most sites, the frequency of non-steady daytime winds is low, 10 per cent or less being a typical figure. However, night non-steady winds are much more frequent with occurrences of 50 percent or more of the night hours not being uncommon during the summer and fall at some sites. Since neither theory nor the experiments conducted to date offer much help in assessing dispersion at such times, the meteorologist may have to develop methods different from those discussed here if non-steady winds are a major feature of the wind climatology at a site. In any case, at any site, the ratio of non-steady to steady winds is a statistic of considerable interest since it is a factor in determining the applicability of much existing diffusion theory and practice.

4. THE DISPERSION DIAGRAM FOR CONTINUOUS RELEASES OF FROM TEN MINUTES TO ABOUT ONE HOUR.

In order to construct a dispersion estimation technique which includes the results of experiments not yet accomplished when Cramer and Pasquill constructed their schemes, an approach similar to Cramer's was adopted. Some 200 surface dispersion experiments for which axial concentration and σ_θ measurements were available were used. These included, in addition to the Project Prairie Grass and Green Glow-30 series data noted earlier, all of a series of 33 surface dispersion experiments at the National Reactor Testing Station in

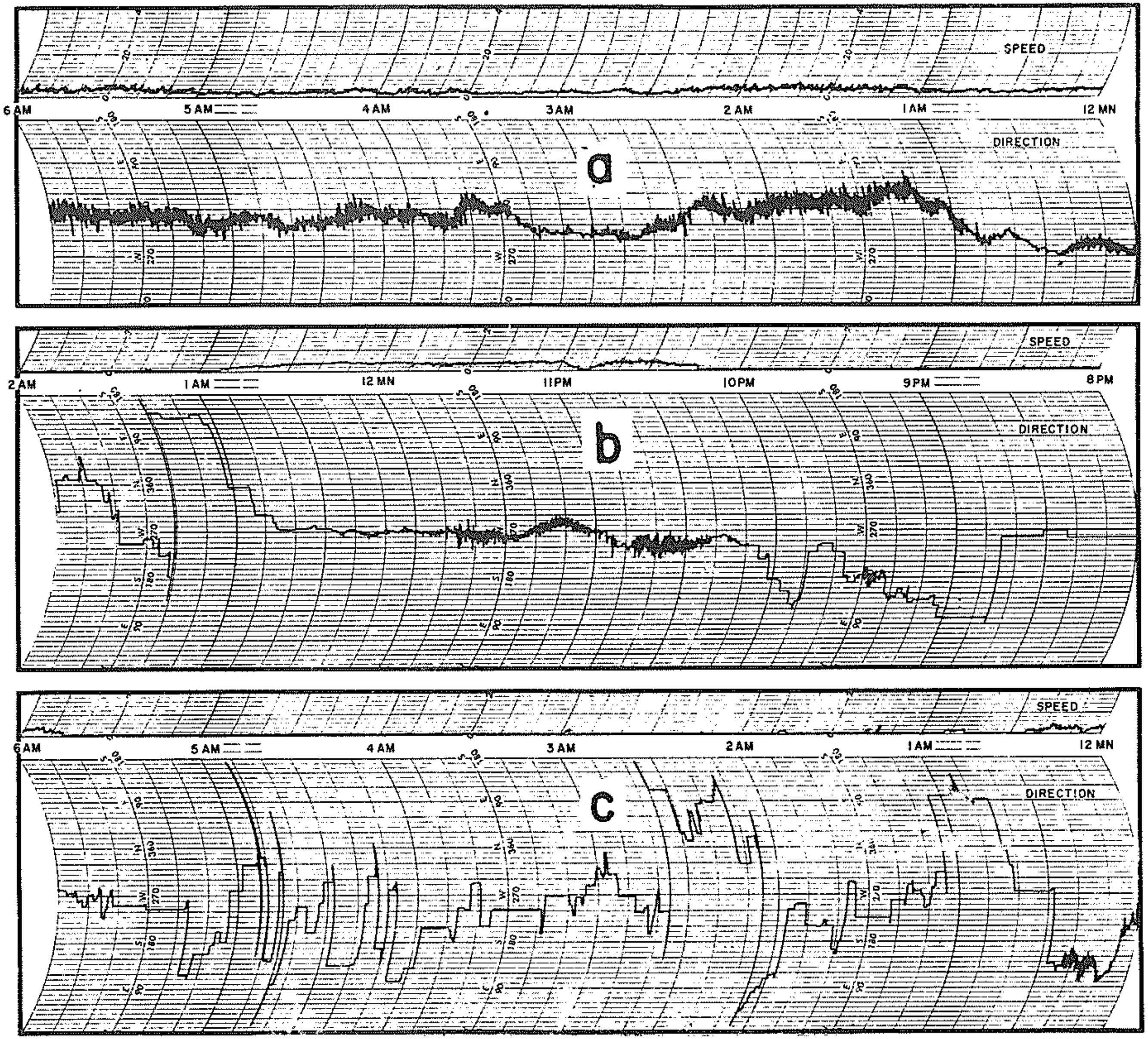

Figure 2. Typical analog wind speed and direction traces observed during the night.

Idaho (Islitzer and Dumbauld, [14]) and a selection of 55 experiments from the "Ocean Breeze" and "Dry Gulch" series (Haugen and Fuquay, [9]). In addition to the direct use of these data, information from a number of other, less definitive, experiments was used to confirm estimates of greatest and least dilution.

A variety of meteorological predictors were used in the various experiments. Specifically, σ_θ (for both fixed and varying averaging times), $\sigma_\theta \bar{u}$, σ_φ, Δ T, Ri, and $\bar{u}$, were used individually or in combination. The fluctuation data were computed for a variety of sampling and averaging times. Vertical temperature difference data were computed over a number of different height intervals originating at different levels above the surface.

From the results of the various experiments, it appears that a measure of the horizontal wind direction fluctuation (σ_θ) can be used to construct a set of diagrams for summarizing diffusion experiment data. Such diagrams are also useful for estimating diffusion directly from the meteorological measurement. The use of σ_θ only results in more scatter than would be expected if some measure of stability or vertical wind fluctuation were included. However, as has been noted in the last paragraph, no variable of this type was measured in a consistent manner in most of the experiments.

Figure 3 shows the relationship between normalized axial concentration and travel distance from the source for approximately 200 individual diffusion experiments selected from the Green Glow-30, Prairie Grass, National Reactor Testing Station, Ocean Breeze and Dry Gulch series. The normalized concentration data for each travel distance were grouped according to the observed σ_θ values and the median values of concentration for each 5° range of σ_θ were plotted. The type "A" and "F" Pasquill categories have been added for comparison. The relationships for $\sigma_\theta \approx 2.5^\circ$ and 25.0° are partially based on extrapolated data since there were few occasions during which measured σ_θ values were either this small or large.

It is evident that the observed data fit the broad band of values postulated by Pasquill quite well except during the more stable conditions (smaller values of σ_θ) at the longer distances. Here the observed values of normalized concentration are almost an order of magnitude smaller than indicated by the Pasquill type F curve. However, it should be recognized that the observed data associated with the smaller values of σ_θ probably reflect the effects of deposition, the results of which should be most in evidence during stable conditions and at the greater distances for the aerosol tracers used in these experiments. The Prairie Grass data, obtained by the use of a nominally non-depositing tracer, are included in figure 3 for the first 800 m. and generally show higher concentrations, for the same meteorological conditions, than the other experimental results.

An illustration of the effect of deposition is given by Simpson [22], for instance, who found that as much as 90% of the initial, surface-released source material was removed by deposition after 3200 m. of travel during a stable, nighttime experiment. Again, a technique for estimating deposition suggested by Gifford [6] and evaluated numerically by Culkowski [4] also indicates reductions of the aerosol concentrations by an order of magnitude at long distances under stable conditions and with a deposition velocity of 0.01 m. sec $^{-1}$. On the other hand, since high aerosol concentrations cannot be maintained near the ground during unstable, turbulent conditions, deposition losses at such times are likely to be small despite perhaps larger values of the deposition velocity.

Thus, if the effect of deposition were to be removed from the observed curves in figure 3, the sense of the displacement would be in the direction of decreasing the difference between the more stable Pasquill curves and the observed stable data. Such a computation, the results of which were presented in an early version of this report (August, 1965), indicated that the observed, corrected concentration curves were in reasonable agreement with the Pasquill curves. Therefore, since the Pasquill curves are in wide use, it was felt that the goals of the present development would be met if the Pasquill curves were additionally labelled with the approximately applicable values of σ_θ.

The relabeled Pasquill curves are presented in the dispersion diagram, figure 4. In this diagram, Q is the source strength (amount per unit time). If Q is given as the <u>total</u> amount of material released, the dosage (D) rather than the average concentration is obtained.

Two other curves have been added. That labeled $F_{(elev)}$ has been estimated from the highest values reported in the literature and may occur with elevated releases during very stable conditions. It is important to recognize that the increase of wind speed with height is greatest during very stable conditions so that these high values of $\chi\bar{u}/Q$ may be associated with wind speeds in the range of 10 to 15 m. sec.$^{-1}$ at heights above 50 m.

The second added curve in figure 4, labeled $A_{(limit)}$, results from a tentative estimate of the greatest dilution likely under conditions of a steady wind. This probably corresponds to σ_θ values of about 35° although direct experimental evidence is lacking.

Values of σ_y, the standard deviation of the cross wind concentration distribution, measured during the same experiments that were used to construct figure 4 were stratified by values of σ_θ and showed good agreement with the Pasquill curves. Thus the various letter categories could again be associated with measured values of σ_θ. This has been done in figure 5. Values of σ_z, the vertical standard deviation, derived from the values of $\chi\bar{u}/Q$ and σ_y for each value of σ_θ from the continuous point source equation for axial concentration, equation (9) are presented in figure 6 and are, of course, identical to the values given by Hilsmeier and Gifford. Thus, the use of figures 4 or 5 and 6 with the continuous source equations of Appendix 2 presents a unified approach to the estimation of downstream concentration or dosage directly from meteorological data measured at a particular site for periods of 10 minutes to about one hour.

As has been noted earlier, the wind direction trace cannot be used to estimate σ_θ during non-steady wind direction conditions. At such times, an effective value of σ_θ for use in figure 4, must be estimated. The classification proposed below is believed to be conservative. All of the necessary

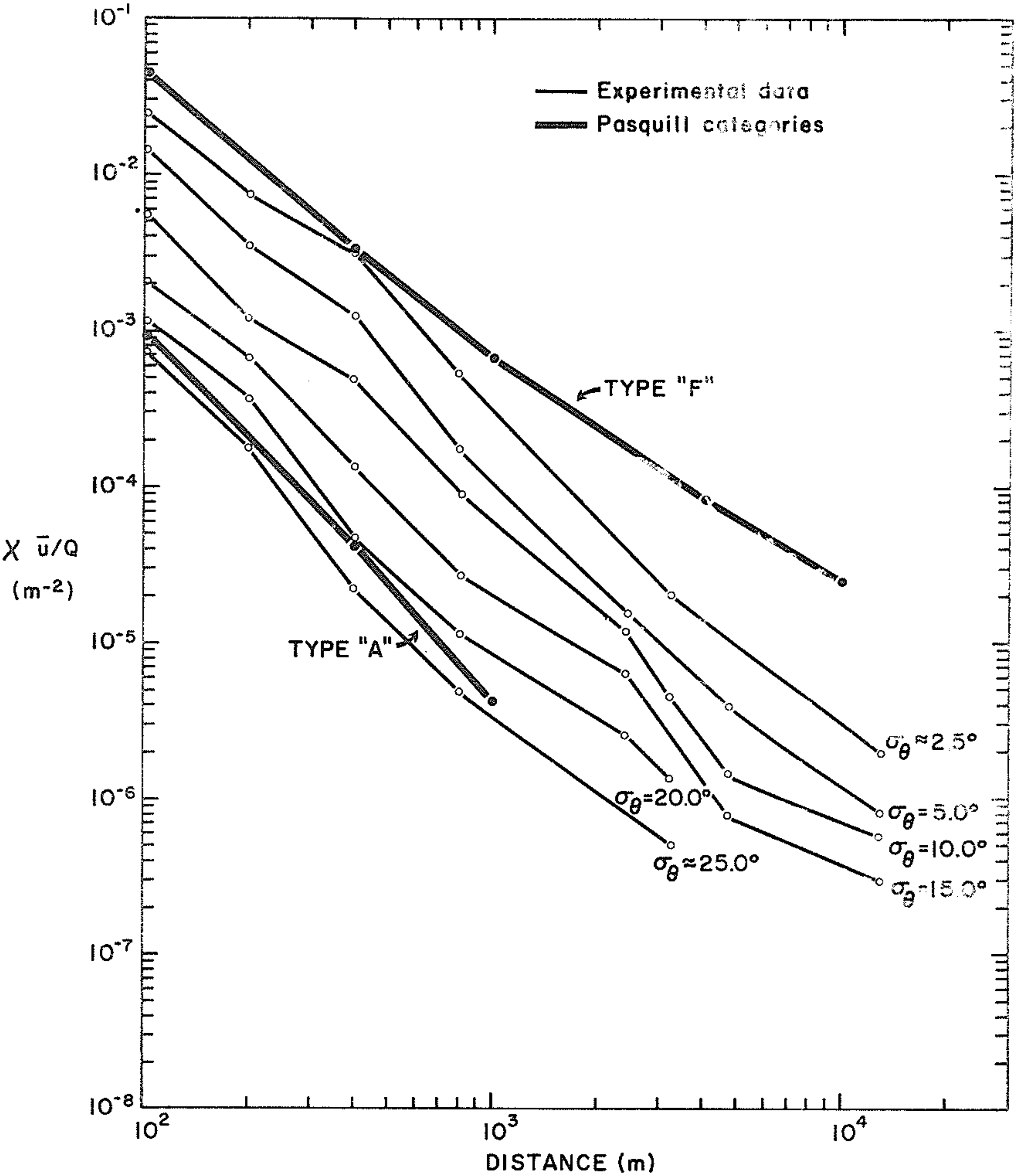

Figure 3. Summary diagram for observed, normalized, surface release, axial concentration measurements. The sloping lines connect median values of concentration for various ranges of concurrently observed σ_θ data.

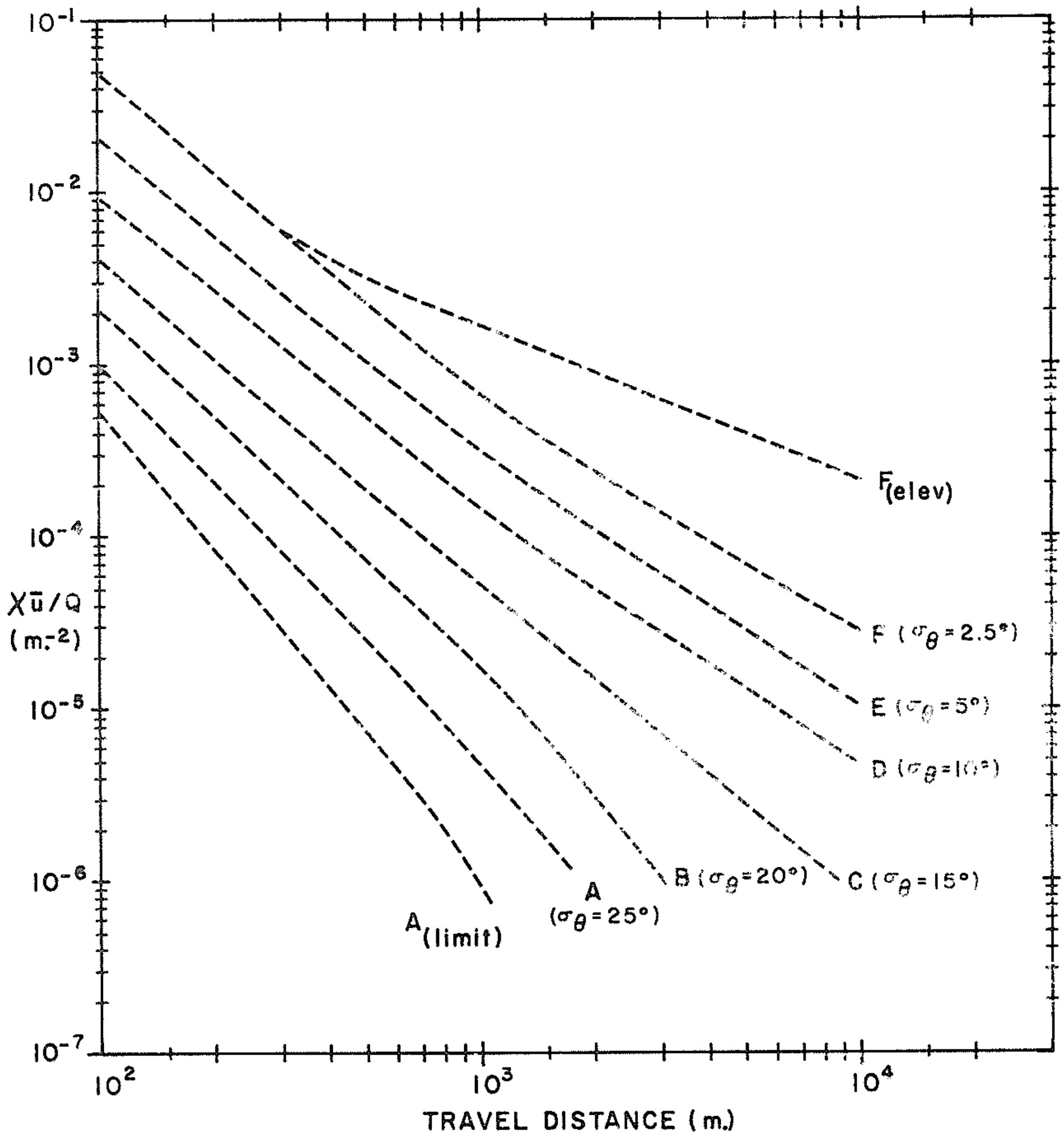

Figure 4. Normalized concentration or dosage as a function of distance from the source for various values of σ_θ; sampling time about 30 minutes.

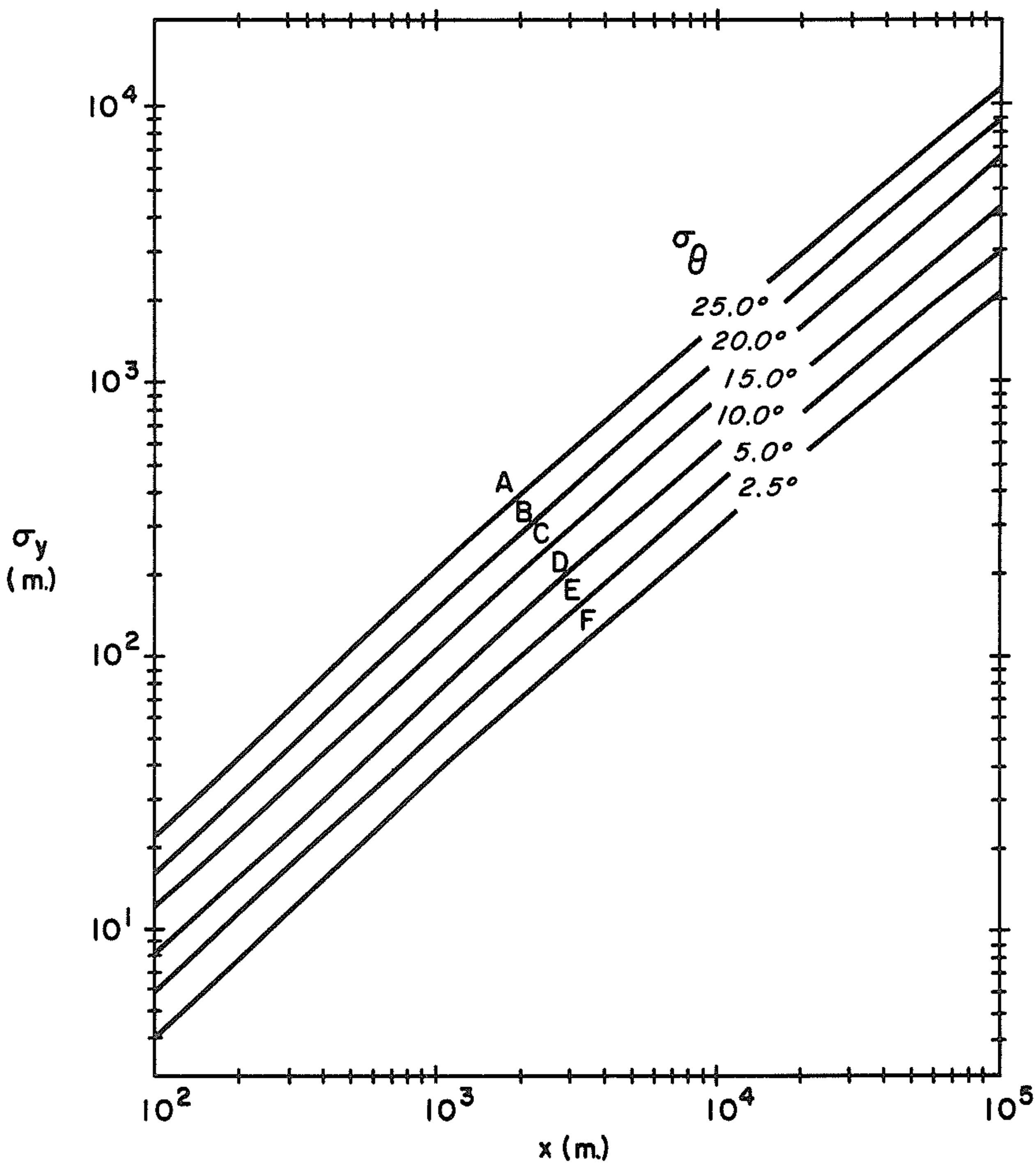

Figure 5. Values of σ_y for a continuous source corresponding to a sampling time of about 30 minutes.

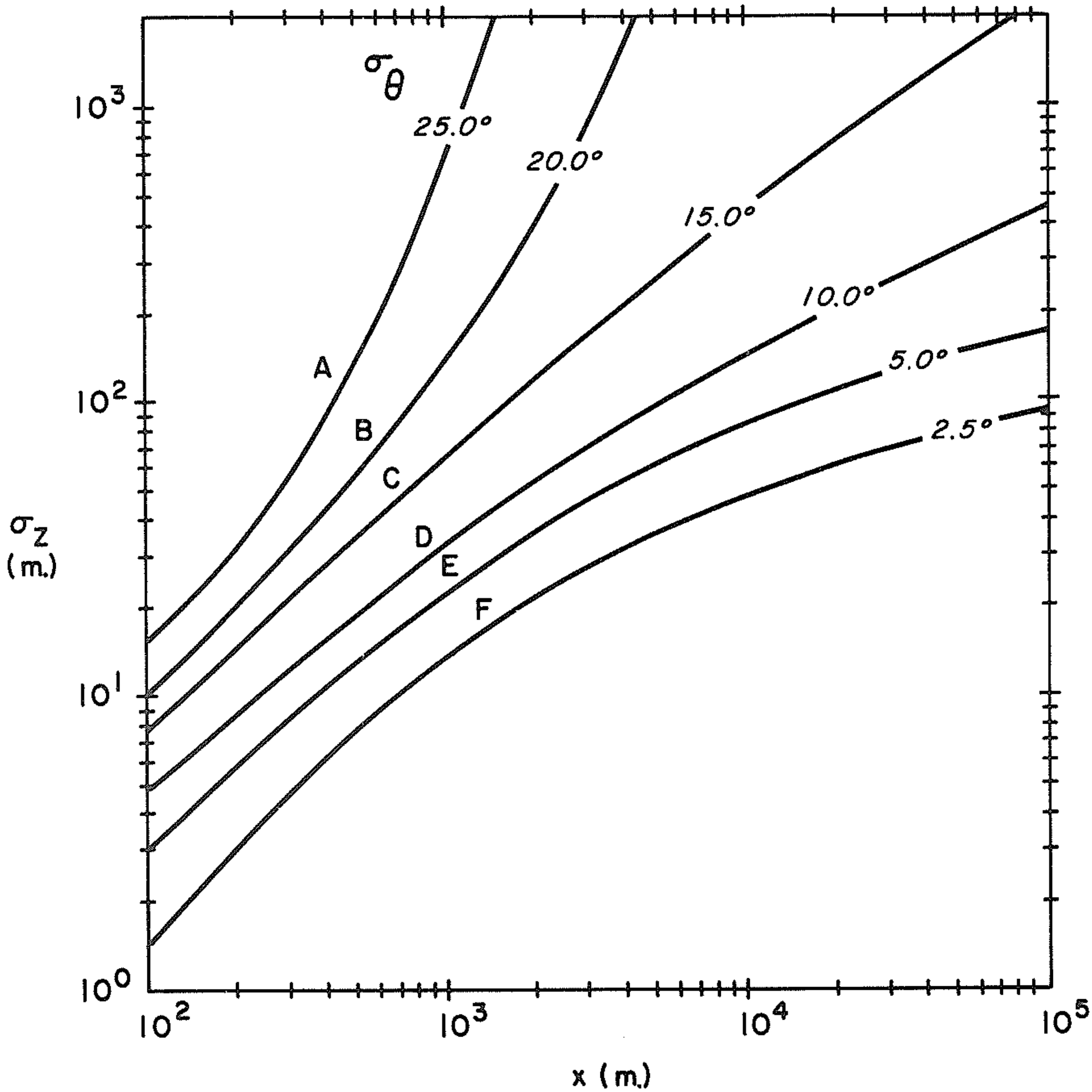

Figure 6. Values of σ_z for a continuous source corresponding to a sampling time of about 30 minutes.

information is contained in the wind charts and a sunrise-sunset table.

If the non-steady wind occurs during the night, defined as a period from one hour prior to sunset to one hour after sunrise, the dispersion conditions should be approximated by the values of $\chi\bar{u}/Q$ between $\sigma_\theta = 5.0°$ and $10.0°$ for both surface and elevated releases. While the non-steady wind indicates a large effective value of lateral spreading (σ_y), the limited vertical dispersion and possibility of local pooling of the effluent suggest the existence of regions of locally high concentration.

If the non-steady winds occur by day, one hour after sunrise to one hour before sunset, the value of $\sigma_\theta = 20.0°$ is suggested as a reasonable estimate for the state of dispersion. Should the sky be clear and the sun high above the horizon, normalized concentration values smaller than those given by $\sigma_\theta = 25.0°$ are likely. However, the sky may not be clear and the sun may not be at its maximum height above the horizon indicating the applicability of a somewhat greater conservatism. The values thus estimated are, of course, subject to much more uncertainty than those for the steady wind case.

These simple rules should suffice for stations at which the frequency of occurrence of non-steady winds is low, perhaps less than 10 percent or 20 percent of all observations. If the frequency is considerably higher, or if a more precise specification of these conditions is necessary for the postulated system or process at the site, more sophisticated concepts, probably based on experimentation are indicated.

5. THE EXTENSION OF CONTINUOUS SOURCE DISPERSION STATISTICS TO PERIODS BETWEEN ONE HOUR AND 8 HOURS.

The formulation

$$\chi(t) = \chi(t_o) \quad (t_o/t)^b, \qquad (3)$$

where $\chi(t)$ is the average concentration over a sampling interval, t, $\chi(t_o)$ some arbitrary reference value of average concentration over a time t_o(assumed to be 1/2 hour if fig. 4 is used for the reference values) and "b" is some factor, can be used to extrapolate the 30-minute sampling time curves of figure 4 to represent sampling times as long as 8 hours. (See Cramer et al. [3] for a thorough discussion of this concept). Since the factor, b, is a function of the turbulent state of the atmosphere, it could be expected to vary with surface roughness, wind speed, stability, and height above the ground. Cramer et al. [3] suggest that b = 1/5 is generally applicable. Values of this factor may be estimated for a particular site by measuring the wind direction range (R) over a basic 30-minute interval and over a variety of sampling times longer than 30 minutes and determining b from the relationship

$$R(t) = R(t_{30}) \quad (t/t_{30})^b \qquad (4)$$

Various values of b obtained from an unpublished study by the author are preand 8 hours during periodsof approximately homogeneous stability conditions, that is, entirely day or night.

Table 1. Values of the factor "b" for two measurement heights.

	Day	Night
4 meters	1/5	1/3
100 meters	1/4	1/2

The site of this study, the top of a small hill near Washington, D.C., experienced very steady winds and it is likely that larger values of the factor may be found at other locations. It is important to note that there has been but little experimental verification of this hypothesis via tracer release experiments for periods up to 8 hours. Cramer et al. [3], however, summarize the results of such experiments for shorter time intervals.

6. THE COMPILATION OF A DISPERSION CLIMATOLOGY

The content of the dispersion climatology for a particular site is intimately related to the meteorology of the site, the population and land usage patterns about the site, and the nature of the effluent-releasing process and system. As such, no simple specification of a preferred climatological content can be suggested. A general discussion of the type of climatological studies possible with the data collection system discussed in this note may, however, be useful.

In order to assemble a climatology of a weather element, it is desirable to make observations at fixed times. The most common and comprehensive reading interval is one hour; that is, the basic one-half-hour observations would be taken once an hour. In order to reduce the data analysis time, readings may be made at less frequent, equally spaced intervals. Eight observations in a 24 hour period are recommended as a minimum.

In mid-latitude locations, most large scale meteorological patterns are annually cyclical. Thus, it is best to collect the data over a period of at least one year. Longer collections add to the confidence of the climatological summaries.

The dispersion parameter, σ_θ, should be used primarily to assess the <u>frequency of occurrence</u> of various classes of dispersion conditions. Any particular dispersion level, as represented by a given value of σ_θ, may, with few exceptions, be found at any site. There is reason to believe, however, that even in comparatively simple terrain significant differences in the frequencies of the various classes of dispersion occur at sites not far removed from each other, probably because of topographical differences the effects of which we can not quantitatively estimate.

While the total frequencies of the various dispersion regimes are an important statistic, the site and source characteristics mentioned above suggest further uses for the collected wind and turbulence data. As a typical instance, the population distribution about a site may be such that only winds from a few directions would move an emitted effluent toward the population center. In this case, the frequencies of the dispersion conditions existing during occurrences of the critical wind directions would be of greatest interest. In addition to wind direction, dispersion statistics can be tabulated by time of day, season, or by the occurrence of other weather elements such as precipitation or pressure change. The joint probability of persistence of certain wind directions and dispersion characteristics would also be a most useful parameter. Since wind speed, direction, and turbulence level are available from the time traces of the unattended wind system, no observing personnel are required to monitor the weather continuously during the period of compilation of any climatology consisting solely of wind statistics.

APPENDIX 1. THE ESTIMATION OF DOSAGE FROM INSTANTANEOUS SOURCE RELEASES

Suggested estimates of σ_y, σ_z and $D\bar{u}/Q$ appropriate for quasi-instantaneous point source releases are presented below. The power functions are applicable in the given range of distances only. Values of σ_x are thought to be similar to those of σ_y.

		100m.	4000m.	Approximate Power function
σ_y (m.)	unstable	10.0	300	$0.14(x)^{0.92}$
	neutral	4.0	120	$0.06(x)^{0.92}$
	very stable	1.3	35.0	$0.02(x)^{0.89}$
σ_z (m.)	unstable	15.0	220	$0.53(x)^{0.73}$
	neutral	3.8	50.0	$0.15(x)^{0.70}$
	very stable	0.75	7.0	$0.05(x)^{0.61}$
$D\bar{u}/Q$ ($m.^{-2}$)	unstable	$2.12x10^{-3}$	$4.81x10^{-6}$	$4.20(x)^{-1.65}$
	neutral	$2.08x10^{-2}$	$5.30x10^{-5}$	$35.5\ (x)^{-1.62}$
	very stable	$3.26x10^{-1}$	$1.30x10^{-3}$	$330.0(x)^{-1.50}$

These data are based on measurements reported by Högström [12], Cramer et al. [3], Smith, Kauper, Berman and Vukovich [23] and from information furnished by the participants in project "Sand Storm" which has been reported upon by Taylor, Tucker and Nou [24]. This and other material is summarized by Slade [21].

The experiments noted above employed release times ranging from 5 to 30 seconds so that the suggested values may differ somewhat from values that would be observed during truly instantaneous releases. Some of these experiments utilized surface releases, some elevated releases, some were close to being point source releases and some were definately volume sources with an initial height of rise. Since, in general, the data necessary to convert the various experiments to a common basis of release length, release height and initial dimensions were not available, the suggested estimates given above must be regarded as tentative. Finally, since a variety of different meteorological predictors, which are not directly comparable, were used by the experimenters, only qualitative estimates of stability may be given. From the descriptions of the experiments given by the various authors, it would seem that the following 30-minute values of σ_θ could be used as an <u>approximate index</u> of the stability conditions:

Stability Category	σ_θ
Very stable	2.5°
Neutral	10.0°
Unstable	25.0°

APPENDIX 2. EQUATIONS AND NOMOGRAMS FOR CONCENTRATION AND DOSAGE DETERMINATION

The assumption is made, in all of these equations, that the receptor is at the surface. The σ values used in the following equations are given in figures 5 and 6, for continuous sources, and in the table on the preceding page for instantaneous sources.

A summary of commonly used concentration and dosage equations follows. A variety of other formulations may be found in AECU 3066, Meteorology and Atomic Energy [25].

Concentration from an instantaneous, point source.

$$\chi = \frac{Q}{2^{1/2}\pi^{3/2}\sigma_x\sigma_y\sigma_z} \exp\left\{-\left[\frac{(x-\bar{u}t)^2}{2\sigma_x^2} + \frac{y^2}{2\sigma_y^2} + \frac{h^2}{2\sigma_z^2}\right]\right\} \qquad (5)$$

where Q = amount (gm., curies, etc.) and h is the source height.

Dosage from an instantaneous, point source.

$$D = \frac{Q}{\pi\sigma_y\sigma_z\bar{u}} \exp\left[-\left(\frac{y^2}{2\sigma_y^2} + \frac{h^2}{2\sigma_z^2}\right)\right] \qquad (6)$$

where Q = amount and dosage (D) = $\int_{T_o}^{T_o+T} \chi dt$

Average concentration from a continuous, point source.

$$\chi = \frac{Q}{2\pi\sigma_y\sigma_z\bar{u}} \exp\left\{-\frac{y^2}{2\sigma_y^2}\right\}\left\{\exp\left[-\frac{(z-h)^2}{2\sigma_z^2}\right] + \exp\left[-\frac{(z+h)^2}{2\sigma_z^2}\right] \qquad (7)$$

where Q = amount $(\text{time})^{-1}$, (gm. sec.^{-1} etc.) If the receptor is at ground level (z = 0)

$$\chi = \frac{Q}{\pi\sigma_y\sigma_z\bar{u}} \exp\left[-\left(\frac{y^2}{2\sigma_y^2} + \frac{h^2}{2\sigma_z^2}\right)\right] \qquad (8)$$

which, if the centerline concentration is of interest, reduces to

$$\chi = \frac{Q}{\pi\sigma_y\sigma_z\bar{u}} \qquad (9)$$

Concentration from an instantaneous, infinite, cross wind line source.

$$\chi = \frac{Q_L}{\pi\sigma_x\sigma_z} \exp\left\{-\left[\frac{(x-\bar{u}t)^2}{2\sigma_x^2} + \frac{h^2}{2\sigma_z^2}\right]\right\} \tag{10}$$

where Q_L = amount (length) $^{-1}$

Dosage from an instantaneous, infinite, cross wind line source.

$$D = \left(\frac{2}{\pi}\right)^{\frac{1}{2}} \frac{Q_L}{\sigma_z\bar{u}} \exp\left(-\frac{h^2}{2\sigma_z^2}\right) \tag{11}$$

where Q_L = amount (length) $^{-1}$

Average concentration from a continuous, infinite, cross wind line source.

$$\chi = \left(\frac{2}{\pi}\right)^{\frac{1}{2}} \frac{Q_L}{\sigma_z\bar{u}} \exp\left(-\frac{h^2}{2\sigma_z^2}\right) \tag{12}$$

where Q_L = amount (length-time) $^{-1}$

Average long period concentration from a continuous point source.

$$\chi_{\text{long term average for each sector}} = \left(\frac{2}{\pi}\right)^{\frac{1}{2}} \frac{0.01fQ}{\sigma_z\bar{u}(2\pi x/n)} \exp\left(-\frac{h^2}{2\sigma_z^2}\right) \tag{13}$$

where f is the frequency (percent) with which the wind blows from a given sector, $2\pi x/n$ is the sector width (n being the number of sectors) at the distance x and Q, σ_z and $\bar{u}$ are average values for the sector over the long time period. Q = amount (time) $^{-1}$.

Average fumigation (trapping) concentration from a continuous point source.

$$\chi_f = \frac{Q}{(2\pi)^{\frac{1}{2}}\sigma_y \bar{u} H} \exp\left(-\frac{y^2}{2\sigma_y^2}\right) \qquad (14)$$

where the plume lies below the level H, the height of the base of the inversion. Q = amount $(\text{time})^{-1}$.

The above equations, in the generalized Gaussian form, may be converted to the corresponding Sutton form through the following identities:

$$\sigma_y^2 = \tfrac{1}{2} C_y^2 x^{2-n}$$
$$\sigma_z^2 = \tfrac{1}{2} C_z^2 x^{2-n} \qquad (15)$$

Formulae for the plume half-width and half-depth are

$$y = \left(2\sigma_y^2 \ln \frac{100}{p}\right)^{\frac{1}{2}}$$
$$z = \left(2\sigma_z^2 \ln \frac{100}{p}\right)^{\frac{1}{2}} \qquad (16)$$

where p is the required percentage of the axial concentration.

Maximum concentration and distance to the maximum from elevated, continuous sources.

For elevated, continuous point sources, the maximum concentrations may be determined directly from figure 7. which is based on equation (8). Concentration and dosage maxima for instantaneous sources may be determined from the instantaneous source σ_y and σ_z values and the appropriate equations.

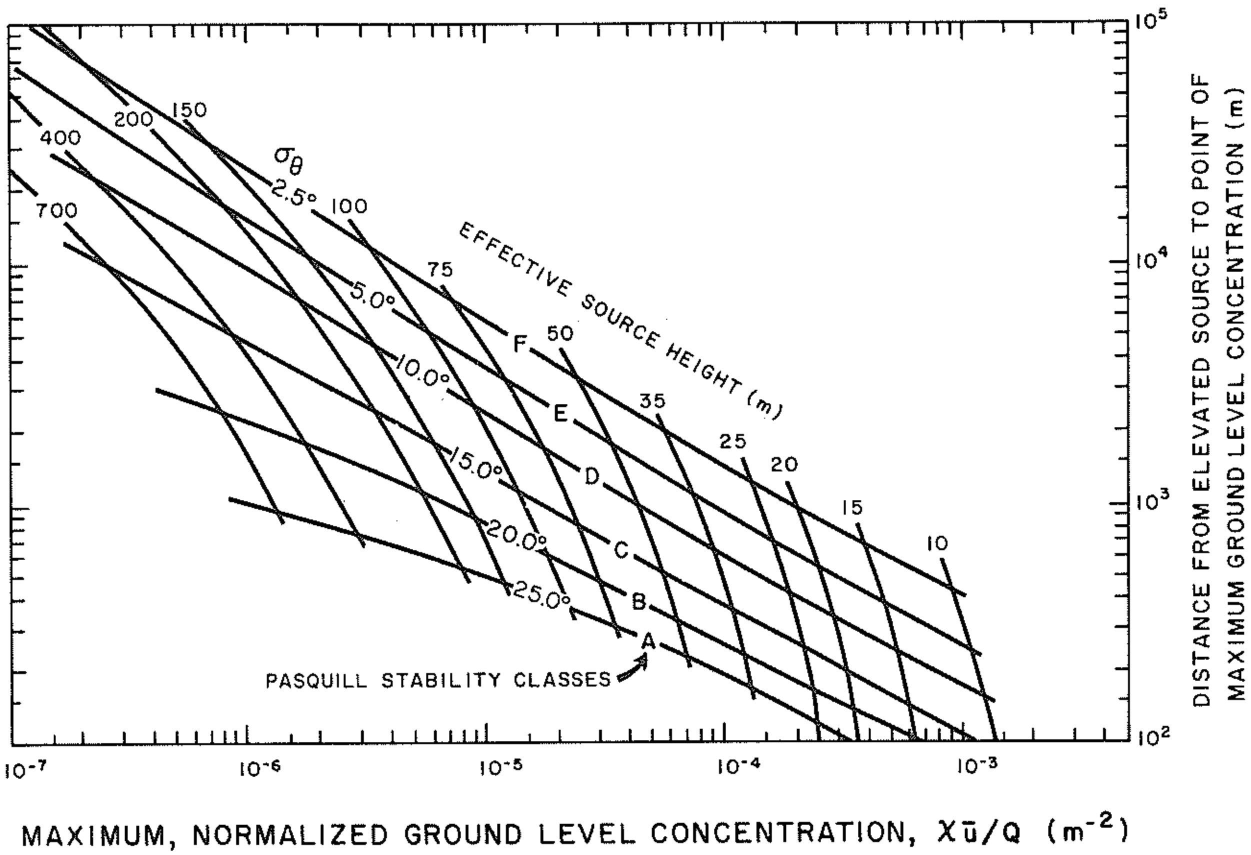

Figure 7. Distances from the source and relative values of maximum concentration for various source heights and values of σ_θ. Martin [17].

Area within a concentration isopleth (continuous, surface source)

The area within a concentration isopleth may be found directly from figure 8 for a given value of σ_θ and the normalized concentration.

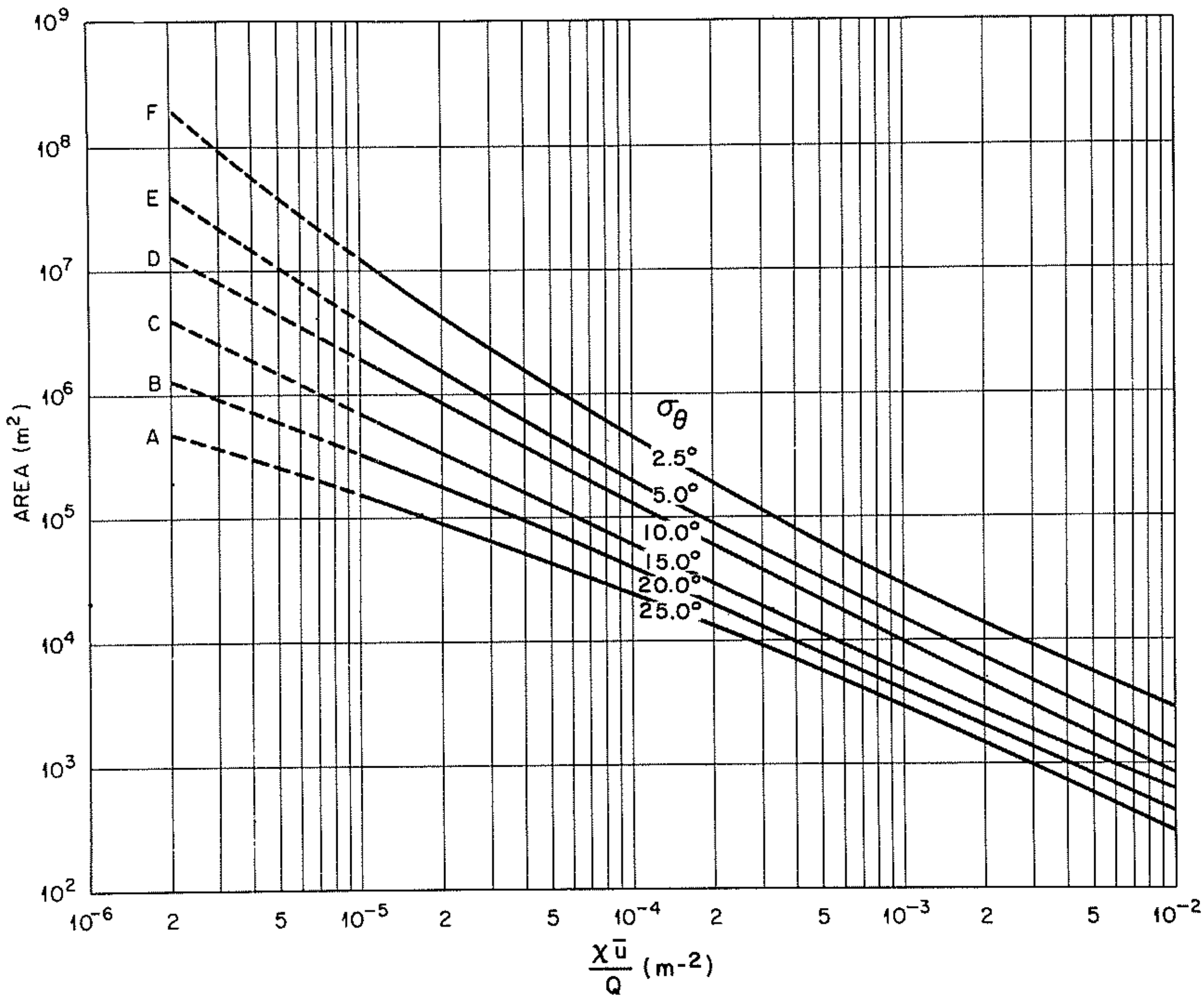

Figure 8. Values of the area enclosed by a ground level concentration isopleth as a function of the normalized concentration. Hilsmeier and Gifford [11].

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