Variations of Wind Fluctuations Observed at 10 m over Flat Terrain under Stable Atmospheric Conditions

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(Manuscript received 3 August 1993, in final form 16 November 1993)

ABSTRACT

Turbulence data were collected with the use of a sonic anemometer from October 1988 to September 1989. The study site was situated amid flat terrain near Calgary, Alberta. The data have been analyzed with respect to wind speed and stability. Simple empirical equations have been established that relate median standard deviations of transverse, longitudinal, and vertical wind fluctuations (σ_v, σ_u, σ_w) to wind speed and static stability. One-to-one correlation coefficients between predicted and observed data were typically in excess of 0.90.

Dispersion models utilize the ratios of turbulence parameters to wind speed (i.e., σ_v/U, σ_u/U, σ_w/U). These ratios, referred to as standard deviations of the wind angles, have been derived as functions of wind speed and potential temperature gradients. Values of the standard deviation of the transverse wind angle σ_θ are shown to be independent of stability. Standard deviations of the longitudinal and vertical wind angles (σ_φ, σ_ϕ) have the same exponential dependency on stability at moderate to high wind speeds. Relations between σ_θ, σ_φ, and σ_ϕ and meteorological parameters of wind speed and stability are presented in graphical form.

1. Introduction

Measurements of atmospheric turbulence as expressed by the standard deviations of transverse, longitudinal, and vertical wind fluctuations (σ_v, σ_u, σ_w) are becoming more commonly used in plume modeling exercises (e.g., Weil and Brower 1984; Hanna and Chang 1992). Instrumentation required for measuring and processing data relating to wind fluctuations is specialized and often expensive. There are practical benefits in obtaining simple correlations between values of σ_v and σ_w and more easily collected information relating to wind speed and vertical temperature gradients.

Ideally wind fluctuations over flat terrain should be similar under the same meteorological situations. Experience has shown, however, that values of σ_v, σ_u, and/or σ_w may vary by more than a factor of 2 under what appear to be identical meteorological conditions. This phenomenon may be partially explained as due to localized effects caused by the breaking of internal gravity waves (e.g., Holets and Swanson 1988) or due to moving coherent structures in the boundary layer such as those described by Gao et al. (1989) or Ruscher and Mahrt (1989). Diffusion meteorologists are challenged to find values of σ_u, σ_v, and σ_w that will be representative of dispersion conditions along the full trajectory of a plume. The approach of basing estimates on mean or median values of dispersion as observed for given meteorological conditions has met with general acceptance and success (e.g., Pasquill 1961; Pasquill and Smith 1983; Martin 1979; Briggs 1973; Hanna et al. 1982). Median values of dispersion parameters seem preferable to mean values for representing given conditions. This is because median values give less weight to unusual data that may be caused by lack of stationarity or rare localized phenomena.

Analyses of data relating to the standard deviation of transverse wind fluctuations, σ_v, as reported in the literature for stable conditions, suggests that it tends to be a constant over a wind speed range from 1 to 5 m s^{-1}. The constant depends upon conditions such as averaging time and topography. Hanna (1983) reported an hourly average value of 0.5 m s^{-1} from studies conducted over flat terrain. This is in close agreement with hourly average values of about 0.6 m s^{-1} reported for prairie country by Leahey and Hansen (1985) and Leahey et al. (1988). Values of σ_v tend to increase linearly with wind speeds exceeding 5 m s^{-1}.

Values of the standard deviation of the longitudinal wind fluctuations σ_u are usually assumed to be directly proportional to σ_v. The proportionality constant is assumed to vary from unity to about 1.3 (e.g., Panofsky and Dutton 1984; Leclerc et al. 1988; Caughey et al. 1979).

Investigations and dimensional analyses have shown that standard deviations of vertical wind speed fluctuations, under stable atmospheric conditions, tend to

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vary directly with speed U (e.g., Pasquill and Smith 1983); that is,

$$\sigma_w = B_w U,$$

where B_w is a proportionality constant.

Typical values of B_w for prairie and foothill areas are about 0.06 and 0.14, respectively (Leahey et al. 1988). Application of the above equation with an average wind speed of 4 m s^{-1} gives a value of σ_w for prairie areas of 0.24 m s^{-1}.

When plume dispersion models employ the standard deviations of wind fluctuations they are usually divided by wind speed. The resulting ratios σ_v/U, σ_u/U, σ_w/U, referred to as standard deviations of the horizontal, longitudinal, and vertical wind angles, are denoted as σ_θ, σ_φ, and σ_ϕ. (These parameters are also sometimes referred to as turbulence intensities.) Many values of these parameters are cited in the literature. Gifford (1976) suggests values for σ_θ for slightly and moderately stable conditions of 5° and 2.5°, respectively. Briggs (1973) recommends standard deviations of plume dispersion that effectively assume values for σ_θ of 3.4° and 2.3° for slightly and moderately stable atmospheric conditions, respectively. Both Gifford and Briggs assume that σ_θ is constant with wind speed. Cramer (1957) recommended a constant value for σ_ϕ of one degree for extremely stable conditions. Briggs (1973) effectively assumes the same value but for moderately stable conditions.

There is little information available about σ_φ. Because of the accepted relationships between σ_v and σ_u, which were previously referred to, it is usually assumed to be directly proportional to σ_θ. The proportionality constant varies from unity to about 1.3.

Information considered in this paper relates to half-hourly average values of the standard deviations. Values of σ's for different averaging times are often estimated by the power-law relation:

$$\sigma_t = \sigma_T \left(\frac{t}{T}\right)^p, \qquad (1)$$

where σ_t, σ_T are standard deviations for averaging periods t and T, respectively.

Observations show that for σ_v, the power-law exponent p has a value of about 0.2 for time periods between 3 and 60 min and about 0.28 for time periods between 1 and 100 h (Hanna et al. 1982). Values of σ_w appear to be relatively insensitive to averaging time. For this turbulence parameter the value of p is usually assumed to be zero.

While information is available concerning typical values of σ_u, σ_v, and σ_w, there appear to be very few studies concerning the dependency of these parameters on static stability S. This may be defined as the restoring force to which a unit mass is subjected when displaced vertically by a unit distance. The force per unit mass whose potential temperature θ differs by $\Delta\theta$ from the surroundings on being displaced a distance Δz is (e.g., Scorer 1958)

$$S = -\frac{g}{\theta}\frac{\Delta\theta}{\Delta z}, \qquad (2)$$

where g is acceleration due to gravity. Static stability is negative because it is in the opposite direction to Δz.

Results presented in this paper show relations between wind fluctuation data, wind speed, and static stability that have been obtained using information collected over flat terrain from October 1988 to September 1989 inclusive by the Alberta Energy Resources Conservation Board (ERCB). The information was collected as part of theoretical and observational studies designed to better delineate risks associated with sour gas pipeline ruptures (ERCB 1990).

2. Description of site, instrumentation, and data analyses procedures

Measurements of atmospheric turbulence were conducted at a prairie site located near Kathyrn, Alberta, about 20 km northeast of Calgary. The area was selected with a view to obtaining an observational site characterized by terrain as flat as practically achievable. The general area was very regular for at least 10 km in all directions with gently rolling hills. Within 2 km of the actual observational site the terrain had negligible slopes in the south–north direction. The terrain rose from the east to the west with a slope of 0.015 (0.9°). It was covered with prairie grasses during summer months. The aerodynamic surface roughness varied from about 0.01 to 0.04 m for winter and summer months, respectively (ERCB 1990).

Temperature gradient data were collected between the 10- and 2-m levels using copper–constantan thermocouple junctions. Thermocouple leads were kept at the same length. The sensors were aspirated with R. M. Young motor aspirated ventilation shields. The sensors were confirmed within 0.01°C of each other by immersion in an ice-water bath.

A Kaijo Denki Co. Ltd. model DAT 310 sonic anemometer with the TR61A probe was used for all wind measurements. Sonic anemometers sense the wind by measuring the transit times of acoustic pulses traveling in opposite directions across a known path, which in this instance was 20 cm. The sonic anemometers were three axis units capable of measuring two orthogonal horizontal wind components (U, V) and the vertical wind (W). With the Kaijo Denki probe the horizontal axes are separated by 120°. This orientation has the advantage of sampling the same volume in space. Specifications for the anemometer stipulate a wind accuracy of ±1% with a resolution of 0.005 m s^{-1}.

The sonic anemometer was situated on a 1-m boom on a triangular tower with a face width of 0.5 m. Winds from the east to northeast reached the sensing devices

TABLE 1. Values of indicated percentiles of $\Delta\theta/\Delta z$ (°C m^{-1}) with associated values of the normalized static stability.

Percentile	$\Delta\theta/\Delta z$	S_n	Percentile	$\Delta\theta/\Delta z$	S_n
5	0.006	0.05	55	0.113	1.15
15	0.019	0.20	65	0.150	1.55
25	0.034	0.35	75	0.204	2.10
35	0.058	0.60	85	0.290	3.00
45	0.082	0.85	95	0.490	5.00

after passage through the tower. These winds occurred less than 10% of the time during the study period. Airflow disturbances occasioned by the tower should thus have minimal effects on median values of turbulence discussed in this paper.

The Kaijo Denki probe provides an analog voltage that is proportional to wind speed. Measurements of the wind component on an orthogonal axis were provided at the rate of 10 per second. Signals were converted to digital through the use of a Campbell Scientific 21X data logger. Coordinate rotation was then employed through use of an NEC 386 microcomputer to convert winds to longitudinal and transverse components. This information was used to calculate 3-min mean and variance terms. This averaging time was selected to allow for a need to assess effects of short-term meteorological situations on plume dispersion. It was also considered the maximum time over which meteorological conditions might be reasonably expected to remain constant.

The analysis presented in this paper relates to half-hourly averages of the standard deviations of wind fluctuations.

Thirty-minute average values of mean parameters were estimated using

$$\overline{x(30)} = \frac{1}{N}\sum_{i=1}^{N} x_i(3),$$

where N is the number of 3-min averages available to form the 30-min average ($N \leq 10$). Standard deviations for 30-min periods were evaluated from the equation

$$\overline{\sigma_x(30)} = \left\{\sum_{i=1}^{N}\frac{\overline{\sigma_x(3)_i}^2}{N} + \frac{1}{N}\sum_{i=1}^{N}[x_i(3) - \overline{x(30)}]^2\right\}^{1/2}.$$

The first and second terms provide the contributions of high-frequency (at least one cycle every 3 min) and low-frequency fluctuations (a cycle less than once every 3 min but greater than once every 30 min), respectively.

3. Results of data analyses

This study was restricted to wind fluctuation data collected at the 10-m level during stable atmospheric conditions ($\Delta\theta/\Delta z > 0$). Values of $\Delta\theta/\Delta z$ were derived from temperature differences observed between the 10- and 2-m levels. There were about 11 000 half-hourly average values of each parameter available for analyses.

Potential temperature gradients were determined from temperature gradient data by assuming a dry-adiabatic lapse rate of 0.0098°C m^{-1}. Mean temperatures and potential temperature gradients recorded over the annual observational period were about 3.5°C m^{-1} and 0.10°C m^{-1}, respectively. Application of Eq. (2) shows that such values imply an average static stability (restoring force) of about 0.0032 s^{-2}.

Values of U, σ_u, σ_v, and σ_w were divided into ten subsets according to associated potential temperature gradients. There were approximately 1100 half-hourly average values for each of the turbulence parameters in each subset. The first subset was associated with the 0th- to 10th-percentile values of potential temperature gradients, the second set was associated with the 10th- to 20th-percentile values of potential temperature gradient, etc. The 5th-percentile value of potential temperature gradient should thus be representative of the first subset of data, the 15th-percentile value for the second subset, etc.

Table 1 presents percentile values of the vertical potential temperature gradient $\Delta\theta/\Delta z$ along with the associated static stability S_n as normalized by a representative average value of 0.0032 s^{-2}. Values of S_n have been rounded to the nearest 0.05. As may be seen the observed range of static stability covered two orders of magnitude.

a. Variations of σ_v with wind speed and static stability

Figure 1 presents a plot of median σ_v for three values of S_n (0.05, 1.15, 5.00) as a function of wind speed.

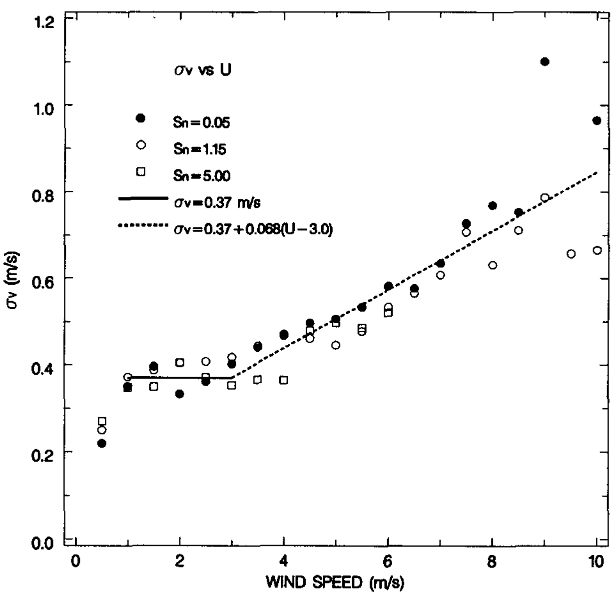

FIG. 1. Median values of σ_v as a function of wind speed for three different static stability conditions. Derived relationships between σ_v and wind speed are shown.

TABLE 2. Mean and standard deviations (SD) of median σ_v values for the wind speed range $1.0 \leq U \leq 3.0$ m s^{-1} under indicated stability conditions.

S_n	Mean	SD
0.05	0.36	0.028
0.20	0.33	0.035
0.35	0.35	0.059
0.60	0.35	0.044
0.85	0.38	0.079
1.15	0.40	0.016
1.55	0.40	0.040
2.10	0.40	0.022
3.00	0.38	0.034
5.00	0.37	0.021

TABLE 3. Values of B_v derived for the indicated stability conditions. Values of the correlation coefficient R are also shown.

S_n	B_v	R
0.05	0.082	0.91
0.20	0.075	0.97
0.35	0.084	0.92
0.60	0.089	0.98
0.85	0.081	0.93
1.15	0.057	0.89
1.55	0.048	0.49
2.10	0.067	0.79
3.00	0.054	0.53
5.00	0.047	0.77

The figure also shows plots of the two lines $\sigma_v = 0.37$ m s^{-1} and $\sigma_v = 0.37 + 0.068(U - 3.0)$. The number of data upon which each median is based was restricted to values equal to or greater than 10. This procedure, adopted for all medians discussed in this paper, was carried out to ensure statistical stability.

Median values of σ_v at very low wind speeds ($U = 0.5$ m s^{-1}) as shown in Fig. 1 tended to be about 0.25 m s^{-1} regardless of static stability. This conclusion was supported by a further analyses of the data for the full range of static stabilities S_n from 0.05 to 5.0. This demonstrated a mean of median σ_v values of 0.25 with a standard deviation of 0.025 m s^{-1}.

For wind speeds from 1 to 3 m s^{-1} values of σ_v tended to be about 0.37 m s^{-1}, as illustrated in Fig. 1. There is no noticeable correlation between σ_v and static stability. The lack of dependency is further illustrated in Table 2, which shows average values of medians for the wind speed range from 1 to 3 m s^{-1} as a function of static stability S_n.

Values of σ_v for winds greater than or equal to 3 m s^{-1} were approximated by the relation $\sigma_v = 0.37 + B_v(U - 3.0)$. Values of B_v were obtained by least-squares methods. They are shown in Table 3 as a function of static stability. As may be seen they did not vary in a systematic fashion with S_n. Table 3 also shows the correlation coefficient between predicted and observed σ_v values associated with each S_n class.

The correlation coefficient R was calculated using the expression

$$R^2 = 1 - \frac{\mathrm{SE}^2}{\sigma^2},$$

where SE is the standard error of estimate and σ is the standard deviation of sample.

The average value for B_v as shown in Table 3 is 0.068. The correlation coefficient between median σ_v values observed over the full range of static stabilities for winds equal to or greater than 3 m s^{-1} and those predicted using the relation

$$\sigma_v = 0.37 + 0.068(U - 3.0) \quad (3)$$

was 0.86. The standard error of estimate was 0.076 m s^{-1}. Comparisons between the 115 predicted and observed values of σ_v are shown in Fig. 2.

b. *Variations of σ_u with wind speed and static stability*

Figure 3 presents a plot of median σ_u for three values of S_n (0.05, 1.15, 5.00) as a function of wind speed. The figure also shows a plot of the line $\sigma_u = 0.41$ m s^{-1} and three lines that describe the increase of σ_u for wind speeds greater than 3 m s^{-1}.

Median values of σ_u at very low wind speeds ($U = 0.5$ m s^{-1}) showed no dependency on static stability. The average value and standard deviation associated with all S_n values were 0.27 and 0.04 m s^{-1}, respectively.

For wind speeds from 1 to 3 m s^{-1} values of σ_u tended to be constant near 0.41 m s^{-1}. There was no

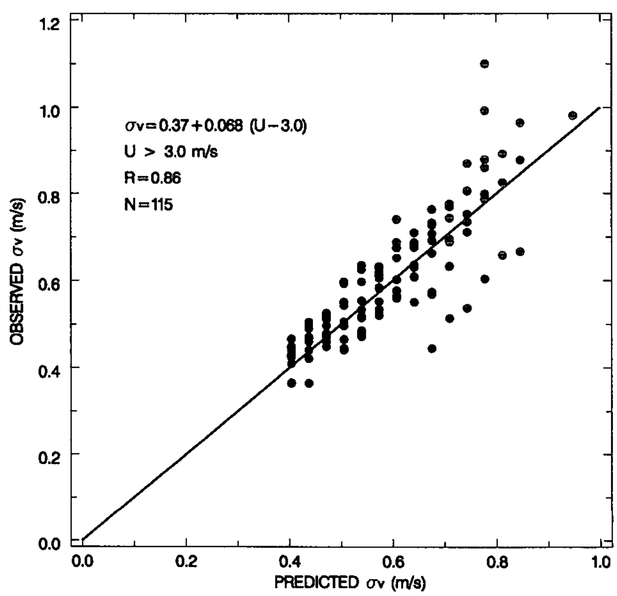

FIG. 2. Comparison between predicted and observed σ_v. The straight line shows the 1:1 relationship.

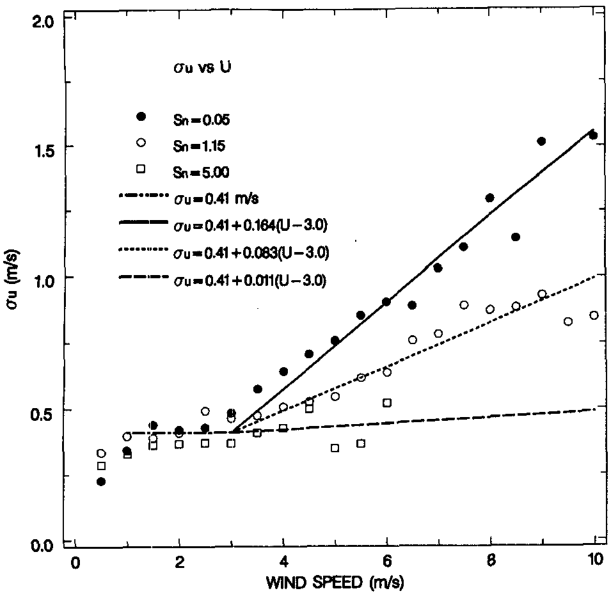

FIG. 3. Median values of σ_u as a function of wind speed for three different static stability conditions. Derived relationships between σ_u and wind speed are shown.

noticeable correlation between σ_u and static stability. This lack of correlation, illustrated in Fig. 3, is also demonstrated in Table 4, which shows average values of medians as a function of static stability S_n.

The straight lines in Fig. 3 that show the increase of σ_u for wind speeds greater than 3 m s^{-1} were obtained by fitting the data in the form $\sigma_u = 0.41 + B_u(U - 3.0)$ by least-squares methods. There were no observed values for $S_n = 5.00$ at wind speeds greater than 6 m s^{-1}.

Derived values of B_u as a function of stability are presented in Table 5. This table also shows the correlation coefficient between observed values of σ_u and those predicted using the straight-line relationship. Values of B_u decrease systematically with increasing stability. The correlation coefficient is very high for all but the most extreme stability conditions.

TABLE 4. Mean and standard deviations (SD) of median σ_u values for the wind speed range $1.0 \leq U \leq 3.0$ m s^{-1} under indicated stability conditions.

S_n	Mean	SD
0.05	0.42	0.05
0.20	0.40	0.04
0.35	0.41	0.05
0.60	0.42	0.02
0.85	0.42	0.06
1.15	0.43	0.04
1.55	0.43	0.05
2.10	0.42	0.04
3.00	0.40	0.04
5.00	0.36	0.02

TABLE 5. Values of B_u derived for the indicated stability conditions. Values of the correlation coefficient R are also shown.

S_n	B_u	R
0.05	0.164	0.97
0.20	0.160	0.99
0.35	0.157	0.96
0.60	0.141	0.99
0.85	0.118	0.99
1.15	0.083	0.91
1.55	0.076	0.71
2.10	0.067	0.89
3.00	0.041	0.63
5.00	0.011	0.00

It was assumed that B_u decreased exponentially with increasing static stability; that is,

$$B_u = C_1 e^{-C_2 S_n}.$$

Values of C_1 and C_2 were derived such that B_u was 0.157 and 0.067 when S_n had values of 0.35 and 2.10, respectively. (This means that C_1 and C_2 were obtained using σ_u data associated with the 25th- and 75th-percentile values of S_n.) It followed that

$$\sigma_u = 0.41 + 0.18(U - 3.0)e^{-0.45 S_n}. \qquad (4)$$

Predictions of σ_u based on Eq. (4) were evaluated against median values of σ_u associated with different wind speeds for 5th-, 15th-, 35th-, . . . , 85th-, 95th-percentile values of S_n. The 25th- and 75th-percentile values were excluded from the evaluation because they were used in deriving the constants C_1 and C_2. Figure 4 shows the comparison between the 94 predicted and

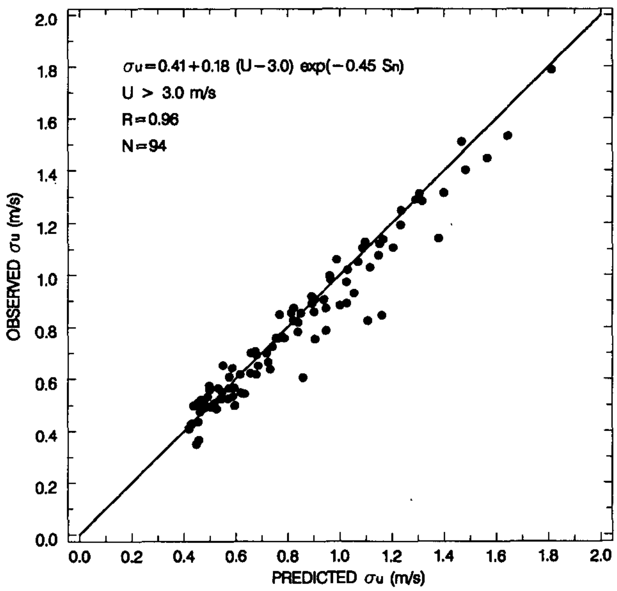

FIG. 4. Comparison between predicted and observed σ_u. The straight line shows the 1:1 relationship.

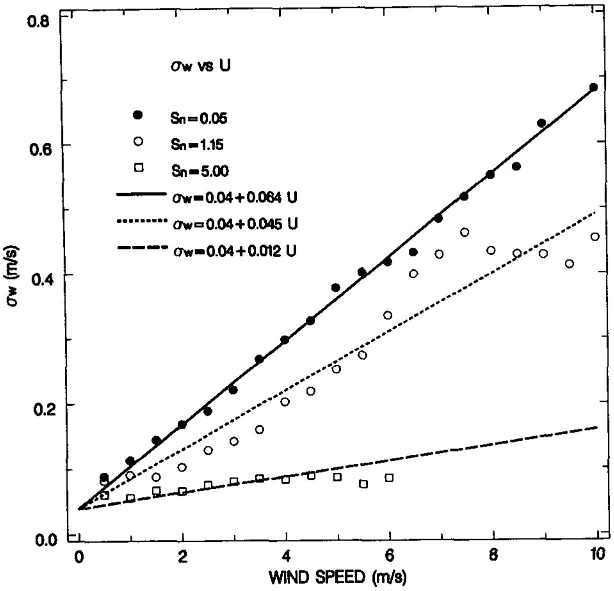

FIG. 5. Median values of σ_w as a function of wind speed for three different static stability conditions. Derived relationships between σ_w and wind speed are shown.

observed values of σ_u. The correlation coefficient was 0.96. The standard error of estimate was 0.081 m s^{-1}.

c. Variation of σ_w with wind speed and static stability

Figure 5 presents a plot of median σ_w for three values of S_n (0.05, 1.15, 5.00) as a function of wind speed. The figure also shows a plot of the three lines that describe the increase of σ_w with wind speed.

The data indicated that σ_w tended to have a constant value at very low wind speeds ($U < 0.5$ m s^{-1}) of about 0.04 m s^{-1}, regardless of the static stability.

The straight lines in Fig. 5 that show the increase of σ_w with wind speed were obtained by fitting the data to the form $\sigma_w = 0.04 + B_w U$ by least-squares methods. There were no observed values for $S_n = 5.00$ at wind speeds greater than 6 m s^{-1}.

Derived values of B_w as a function of stability are presented in Table 6. This table also shows the correlation coefficient between observed values of σ_w and those predicted using the straight-line relationship. Values of B_w tended to decrease with increasing stability. The correlation coefficient is very high for all but the most extreme stability conditions.

It was assumed that B_w decreased exponentially with increasing static stability. Values of the parameters were obtained using σ_w data associated with the 25th- and 75th-percentile values of S_n. [The procedure adopted was thus the same as that employed to derive Eq. (4).] It followed that

$$\sigma_w = 0.04 + 0.075 U e^{-0.45 S_n}. \quad (5)$$

TABLE 6. Values of B_w derived for the indicated stability conditions. Values of the correlation coefficient R are also shown.

S_n	B_w	R
0.05	0.064	0.99
0.20	0.062	0.99
0.35	0.065	0.99
0.60	0.063	0.98
0.85	0.056	0.97
1.15	0.045	0.96
1.55	0.037	0.99
2.10	0.029	0.96
3.00	0.018	0.91
5.00	0.012	0.00

It is perhaps noteworthy that both B_u and B_w have the same exponential dependency on static stability S_n.

Predictions of σ_w based on Eq. (5) were evaluated against observed median values of σ_w for all but the 25th- and 75th-percentile values of S_n. Figure 6 shows the comparison between the 144 predicted and observed values of σ_w. The correlation coefficient was 0.96. The standard error of estimate was 0.046 m s^{-1}. There appears to be a split around the 1:1 line for values of σ_w greater than about 0.4 m s^{-1}. An examination of the data showed that this split was not a consistent function of S_n.

d. Derived values of the standard deviations of wind fluctuation angles

Previous discussions have presented observed variations of the standard deviations of atmospheric wind

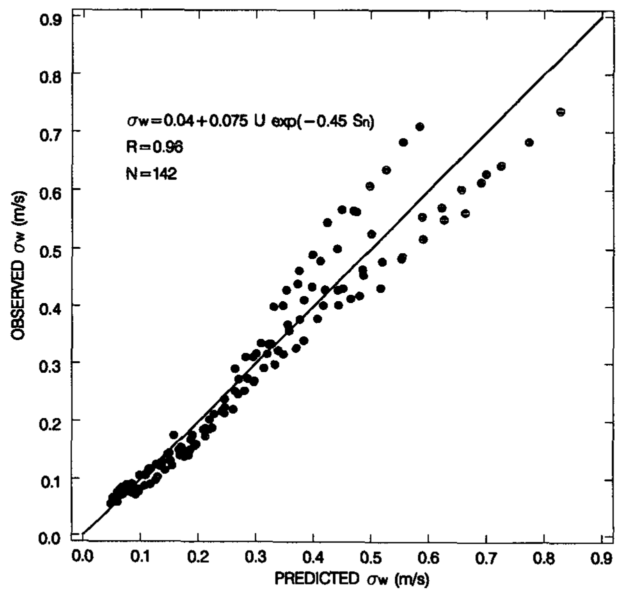

FIG. 6. Comparison between predicted and observed σ_w. The straight line shows the 1:1 relationship.

fluctuations (σ_v, σ_u σ_w). These observed variations have direct implications for corresponding parameters relating to fluctuation angles σ_θ, σ_φ, and σ_ϕ (i.e., σ_v/U, σ_u/U, σ_w/U).

Figure 7 shows derived values of σ_θ (deg) based upon the following assumptions:

$$\sigma_\theta = \begin{cases} \dfrac{14.3}{U}, & U = 0.5 \text{ m s}^{-1}, \\ \dfrac{21.2}{U}, & 0.75 \leqslant U < 3.0 \text{ m s}^{-1}, \\ \dfrac{21.2}{U} + \dfrac{3.9}{U}(U - 3.0), & U \geqslant 3.0 \text{ m s}^{-1}. \end{cases}$$

Values for σ_θ shown for the interval from 0.50 to 0.75 m s^{-1} were obtained by joining the values predicted for these wind speeds using the above equations. All values are independent of stability. They range from about 28° at very low wind speeds to about 5° under stronger wind speed conditions.

Figure 8 presents values of the ratio $\sigma_\varphi/\sigma_\theta$ as a function of wind speed. Values of σ_φ (deg) were based upon the following assumptions:

$$\sigma_\varphi = \begin{cases} \dfrac{15.5}{U}, & U = 0.5 \text{ m s}^{-1}, \\ \dfrac{23.5}{U}, & 0.75 \leqslant U < 3.0 \text{ m s}^{-1}, \\ \dfrac{23.5}{U} + \dfrac{10.3}{U}(U - 3.0)e^{-0.45S_n}, & U \geqslant 3.0 \text{ m s}^{-1}. \end{cases}$$

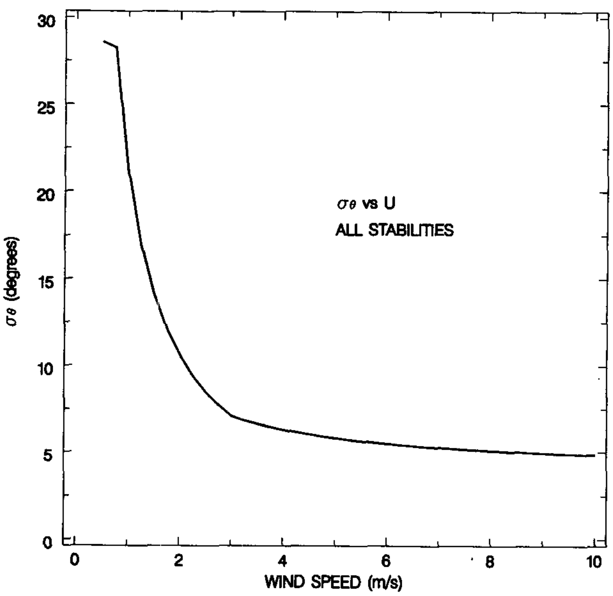

FIG. 7. Median values of σ_θ as a function of wind speed for all static stability conditions.

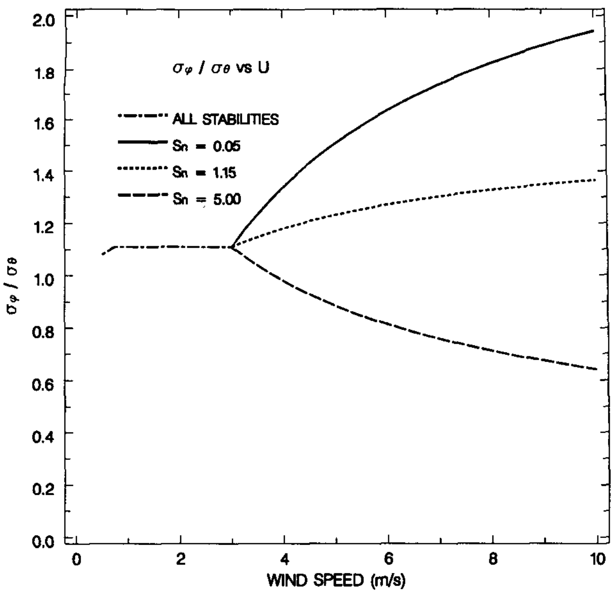

FIG. 8. Median values of $\sigma_\varphi/\sigma_\theta$ as a function of wind speed for three different static stability conditions.

Values for σ_θ shown for the interval from 0.50 to 0.75 m s^{-1} were obtained by joining the values predicted for these wind speeds using the above equations. The ratios are near unity at low wind speeds. At moderate to high wind speeds they can be greater or less than unity depending upon whether the degree of stability is slight or strong. As previously indicated, extremely stable conditions (S_n = 5.00) probably do not exist at wind speeds greater than about 6 m s^{-1}. This means that values of the ratio $\sigma_\varphi/\sigma_\theta$ will always tend to be greater than 0.8.

Figure 9 presents values of σ_ϕ (deg) for three stability conditions (S_n = 0.05, 1.15, 5.00). They are based on the expression

$$\sigma_\phi = \frac{2.3}{U} + 4.3e^{-0.45S_n}, \quad U \geqslant 0.5 \text{ m s}^{-1}.$$

When wind speeds are greater than about 2 m s^{-1}, values of σ_ϕ tend to be functions only of atmospheric stability. Under extremely stable conditions (S_n = 5.00) and moderate wind speeds, σ_ϕ has a value of about 1°. As previously discussed, these extremely stable conditions probably do not exist at wind speeds greater than about 6 m s^{-1}.

4. Discussion

The nature of turbulent fluctuations at very low wind speeds (U = 0.5 m s^{-1}) appears to be independent of static stability. Values of σ_u, σ_v, and σ_w are about 0.25, 0.25, and 0.04 m s^{-1}, respectively.

For wind speeds between 1 and 3 m s^{-1} half-hourly average values of σ_v have been found to be about 0.4

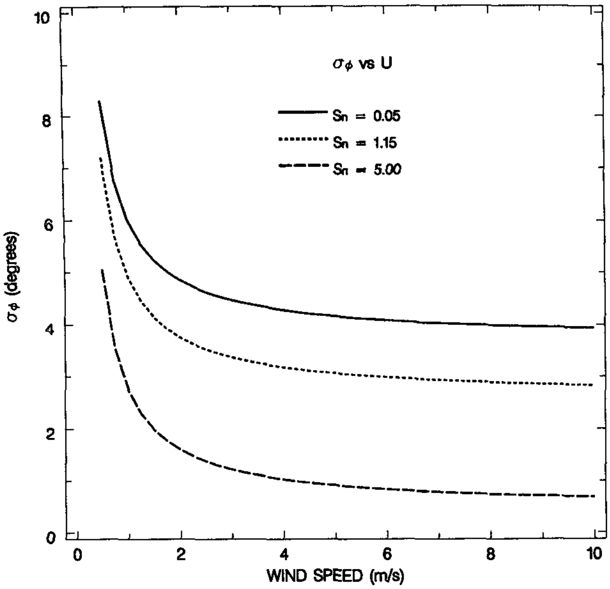

FIG. 9. Median values of σ_ϕ as a function of wind speed for three different static stability conditions.

m s^{-1}. Equation (1) may be employed together with a p value of 0.20 to show that this value is comparable to an hourly average value of 0.46 m s^{-1}. It is thus similar to hourly average values of σ_v reported by Hanna (1983).

Table 6 indicates that half-hourly average values of B_w under typical stable atmospheric conditions (i.e., S_n = 1) are about 0.05. Values of σ_w are usually considered to be insensitive to averaging time. [It is for this reason that changes with averaging time for predicted plume dispersion are assumed to be entirely dependent on changes in σ_y (e.g., Hanna et al. 1982).] It follows that for a wind speed of 4 m s^{-1}, σ_w will be 0.24 m s^{-1}. It is therefore identical to that reported at the same wind speed by Leahey et al. (1988).

It appears that the data analyzed for this paper is generally similar to that reported in the literature by other authors. The method of analysis with respect to static stability is, however, somewhat unusual. It has shown that the two simple meteorological parameters, wind speed and static stability, should be sufficient for estimating turbulence behavior.

Data presented in this paper concerns median values of turbulence parameters. Turbulence data are not necessarily normally distributed. This is because they may reflect nonstationarity and nonhomogeneity conditions. Therefore the median of the product of two parameters may not be the same as the product of the medians. For example the median of the product $\sigma_\theta\sigma_\phi$, which is often employed in dispersion analysis, will not necessarily equal the product of the median σ_θ and the median σ_ϕ. It is the latter product that should be more representative of atmospheric turbulence.

Turbulence information described in this paper was obtained from data collected at the 10-m level. Its use to assess ground-level concentrations resulting from the dispersion of plumes at much higher elevations should lead to overestimations. This is because σ_v and σ_w tend to increase and decrease, respectively, with height above ground (Leahey and Hansen 1985).

Analyses have shown that vertical turbulence decreases with increasing static stability and that horizontal turbulence is a function only of wind speed. These conclusions are not applicable to regions of rough terrain. This is because increased static stability and irregular topography will tend to initiate katabatic wind flows that will create both horizontal and vertical turbulence (e.g., Leahey and Halitsky 1973).

The fact that for wind speeds greater than 3 m s^{-1} both σ_u and σ_w have the same exponential dependency on static stability suggests that both components of turbulence react to mechanical forces in a similar manner. It would be challenging to derive a functional relationship from physical laws that would make the reasons for this similarity apparent.

Acknowledgments. The assistance and cooperation of Ian Dowsett of the Alberta Energy Resources Conservation Board was very helpful for the completion of this study. It is a pleasure to acknowledge the constructive criticisms of Profession David Wilson, Mechanical Engineering Department, University of Alberta.

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