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TITLE: STABILITY-CLASS DETERMINATION: A COMPARISON FOR ONE SITE

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STABILITY-CLASS DETERMINATION:
A COMPARISON FOR ONE SITE

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I. INTRODUCTION

As part of the Environmental Surveillance Program at the Los Alamos National Laboratory, meteorological data have been collected routinely for over three years. The data provide a means for predicting airborne concentrations of radioactive or other hazardous materials from potential accidental releases to the atmosphere.

An estimate of horizontal and vertical dispersion of a puff or plume is needed to accurately predict downwind air concentrations. The well known Pasquill horizontal (σ_y) and vertical (σ_z) coefficients are widely used as dispersion estimates and are included in air pollution handbooks such as Workbook of Atmospheric Dispersion Estimates (Turner, 1969) and Meteorology and Atomic Energy (Slade, 1968). An advantage of Pasquill dispersion estimates is that they can be applied to sites where a limited amount of meteorological data are available. The estimates, based on actual field experiments, can be determined using the Pasquill method based on solar insolation and wind speed. These data can be derived from local National Weather Service stations.

The purpose of this paper is to compare the Pasquill method of determining stability class at a site with irregular terrain with other commonly used methods: (1) vertical temperature difference (ΔT), (2) Richardson number (Ri) and Bulk Richardson number (Ri_B), and (3) horizontal standard deviation of wind (σ_θ) and vertical standard deviation of wind (σ_ϕ). Also, the indirect methods of measuring turbulence, such as the Pasquill method, are compared to direct measures of turbulence, σ_θ and σ_ϕ. This paper is based on other studies that compare various stability methods with the Pasquill stability method: Luna and Church (1972) and Sedefian and Bennett (1980).

II. METHODOLOGY

A. Siting and Instrumentation

The Los Alamos National Laboratory is located on the Pajarito Plateau on the eastern flanks of the Jemez Mountains. The Sangre de Cristo Mountains are nearly 20 km to the east. The Plateau slopes from the base of the Jemez Mountains (~2500 MSL) east southeastward down to the Rio Grande River (~1700 MSL), over a distance of 25 km. There are numerous alternating "finger" mesas and canyons running along the slopeline of the Plateau. The canyons are 50-100 m deep and 200-600 m across, while the mesas vary in width from 100-200 m.

The data presented in this paper were collected at the State Road 4 station. Wind direction and speed were measured at 1.3, 4.0, and 12.0 m; temperature at 1.3 and 12 m; and solar radiation at 4 m. The tower stands on the edge of a smooth, sandy mesa top. Short grass and brush (~0.5 m) and a few juniper and piñon trees (~3 m) grow in the vicinity. A canyon 600 m wide and 100 m deep lies about 50 m to the south. The site elevation is 2140 MSL. The other site, the Occupational Health Laboratory (OHL), has a 23 m tower on a one story (4 m) building. The building is surrounded by paved parking lots and a paved roadway. However, ponderosa pine trees (~20 m) stand in all directions, making this a relatively rough site. In addition, a canyon approximately 250 m wide and 50 m deep lies 50 m to the south. The OHL site elevation is 2250 MSL. Wind direction and speed are measured at 23 m and temperature is measured at 22 m and 1.2 m. Total solar radiation is also measured at the site.

Identical instruments at the two sites measured horizontal wind speed and direction, vertical wind velocity, and temperature. An anemometer measured the three components of the wind. Thermistors equipped with blowers measured the air temperature. Pyranometers were used to measure total solar radiation.

B. Data

A year of 15-minute averaged meteorological data (September 1981-August 1982) were used from both sites in this study. Results from the OHL site were similar to those at the State Road 4 site; therefore, only data from State Road 4 were included in this paper. Each variable was measured every 3.5 seconds by a Los Alamos designed and built microprocessor. The microprocessor averages each variable for 15-minute periods. In addition, 15-minute averaged standard deviations were computed for the U, V, and W components of the wind. The averaged horizontal wind speed and direction, along with the horizontal wind standard deviation, σ_θ, were then computed analytically from the U and V components. The standard deviation of the vertical wind direction (σ_ϕ) was estimated from the following:

$$\sigma_\phi = \sigma_w/U.$$

The Richardson number (Ri) was calculated for the State Road 4 site at 4.0 m from the temperature and wind speed at 12.0 and 1.3 m:

$$Ri = \frac{g(\Delta\theta/\Delta z)}{T(\Delta U/\Delta Z)^2}$$

The Bulk Richardson number (Ri_B), or Stability number, was calculated from the upper wind speed and both temperature levels at both the State Road 4 and OHL sites:

$$Ri_B = \frac{g(\Delta\theta/\Delta z)\overline{z}^2}{TU^2}$$

C. Pasquill Class Determination

The well known Pasquill categories were determined from the surface wind speed at the 10 m level, time of day (night or daylight), and type and amount of cloud cover. An objective method was used in this study to determine the stability class for specific 15-minute periods; Table 1 shows this method. Note that all time periods with wind speeds <0.5 m/s were deleted from the data; these light winds accounted for about 10% of all data. Also, a solar radiation value of 0.05 ly/min was used as a cutoff for daytime and nighttime.

Table 1. Key to Stability Categories

Wind Speed (m/s)	Day: Incoming Solar Radiation (ly/min) >1.0 (strong)	0.5-0.1 (mod)	<0.5 (slight)	Night: Negative ΔT	Positive ΔT
0.5-2	A	A	B	F	F
2-3	A	B	C	E	F
3-5	B	B	C	D	E
5-6	C	C	D	D	D
7-6	C	D	D	D	D

III. ANALYSES AND DISCUSSION

A. Pasquill Categories vs ΔT

The ΔT method is commonly used as a stability indicator and is one of several methods recommended by the U.S. Nuclear Regulatory Commission (NRC) in NRC Safety Guide 1.23 (1974). In this study, ΔT distinguishes stable, neutral and unstable conditions remarkably well. Figure 1 shows the cumulative frequency of ΔT for each Pasquill stability class. It is clear that ΔT

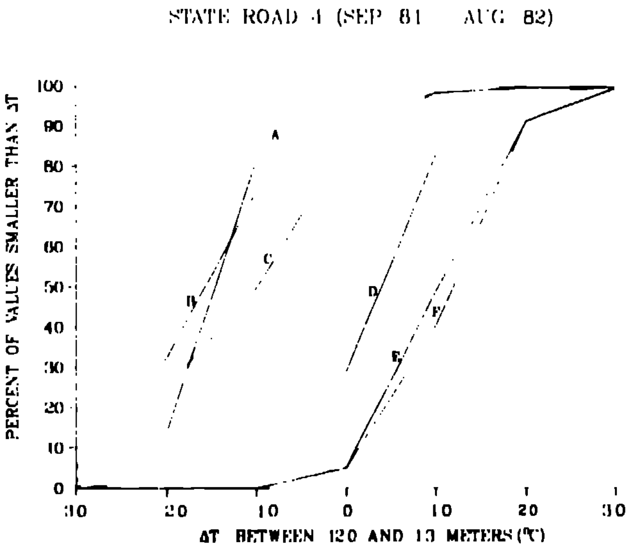

Fig. 1. Cumulative frequencies of ΔT for each Pasqual stability class.

poorly distinguishes the individual unstable (A, B, C) and stable (E, F) categories. A cumulative frequency of ΔT for each category determined by Ri (not shown) shows similar results as in Fig. 1.

B. Pasquill Categories vs Ri

The Ri is a much better indicator of individual stability classes than ΔT. Figure 2 shows the cumulative frequency of Ri for each Pasquill stability category. Note that the values of Ri become larger as the stability becomes more stable (i.e., A→F). Unlike ΔT, Ri does distinguish the individual unstable (A, B, C) and stable (E, F) categories. Note the large grouping of near 0 values of Ri for the neutral D category. Also, for each category A-F, the 75% frequency value of Ri corresponds to less than 25% for the

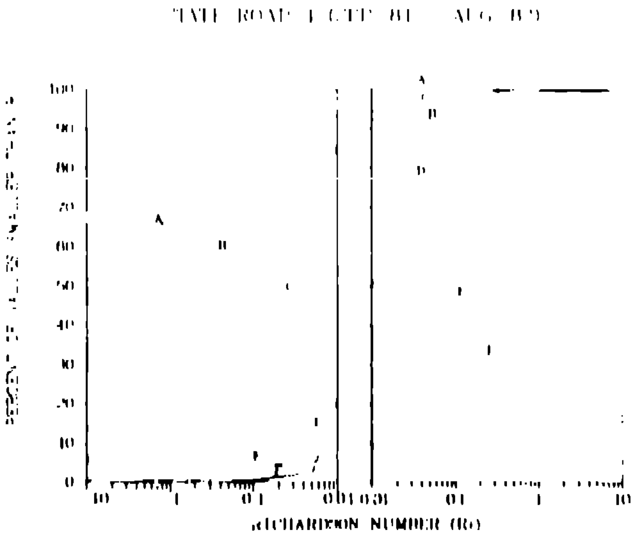

Fig. 2. Cumulative frequencies of Ri for each Pasquill stability class.

next most stable category. A comparison of Pasquill categories vs categories determined by Ri is shown in Table 2. Note the high percentages of simultaneous occurrences for both methods. The categories are coincident about 65% of the time while they are within one category 96% of the time.

Table 2. Percentage Occurrence of Pasquill Stability Class vs Stability Class Determined by Ri*

Pasquill → Ri ↓	A	B	C	D	E	F	Total
A (<-1)	5.0	3.1	0.1	0.0	0.0	0.0	8.2
B (-1- -0.1)	1.9	13.5	4.5	0.1	0.1	0.6	20.7
C (-0.1- -0.05)	0.0	1.9	7.8	3.9	0.2	0.3	6.7
D (-0.05- +0.07)	0.0	0.5	2.6	23.1	2.5	0.9	37.0
E (0.07- +0.25)	0.0	0.0	0.4	0.3	4.1	5.1	11.8
F (>0.25)	0.0	0.6	0.1	0.4	4.1	10.6	15.8
Total	6.9	20.0	15.4	31.6	12.0	14.3	100.0

*The range of values for Ri were determined from this study.

The values of Ri used in this study to determine stability categories are lower in absolute value than any values seen in the literature. This is especially true for the unstable categories. For example, (Businger, 1973) suggests an upper limit for Ri of -5 for the A category compared to -1 in this study.

The good agreement of Pasquill stability category with Ri and Ri_B (not shown) in this study differs from the results of Luna and Church (1972). The difference may be that the Ri_B was calculated from temperature data at 3 m, 40 m, and from wind speed at 40 m in their study.

C. Pasquill Categories vs σ_θ and σ_ϕ

A true test of the usefulness of stability parameters is the degree to which they can predict the dispersion capability of the atmosphere. The standard deviations of the horizontal and vertical wind direction (σ_θ, σ_ϕ) are directly related to atmospheric turbulence. They are also commonly used as stability themselves. The NRC (1972) recommends using a set of ranges of σ_θ to determine the stability category. Likewise, the Environmental Protection Agency (EPA) recommends the use of σ_ϕ to determine the stability category (1980).

The cumulative frequencies of observed σ_θ for each Pasquill category are shown in Fig. 3. The median values of σ_θ decrease as the Pasquill category goes from A to D. However, the σ_θ values actually become larger for the stable categories E and F. This is due to the

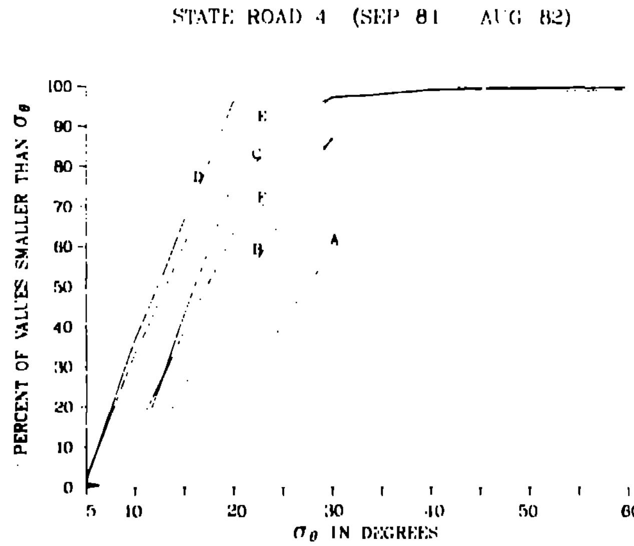

Fig. 3. Cumulative frequencies of σ_θ for each Pasquill stability class.

predominance of wind meander during stable conditions over the complicated terrain. Even for the categories A-D, σ_θ does not correlate with the Pasquill categories as well as Ri and Ri_B. For each category A-C, the 65% frequency level of σ_θ corresponds with the 35% level of the next more stable class.

The cumulative frequency of σ_ϕ for each stability category are presented in Fig. 4. As for the case of σ_θ, the medians for categories A-D decrease linearly while categories E and F show an increase in σ_ϕ over category D. The σ_ϕ correlates slightly better with the stability categories than σ_θ over the mid-cumulative frequency range. Also, note how well σ_ϕ predicts A stability.

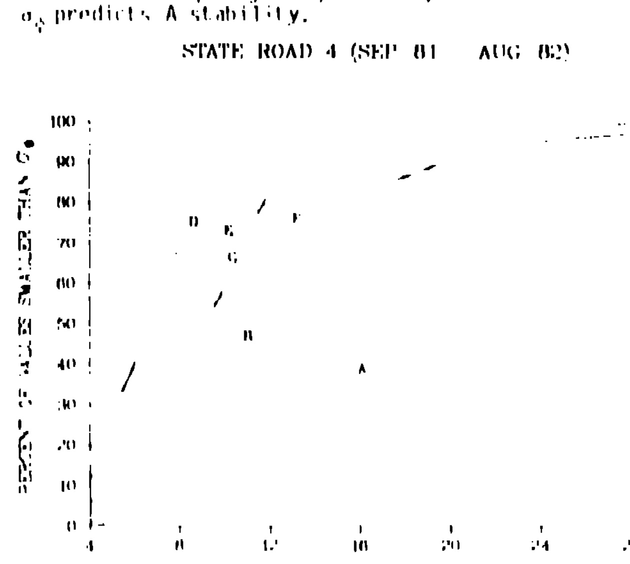

Fig. 4. Cumulative frequencies of σ_ϕ for each Pasquill stability class.

A big problem in predicting the Pasqu[illegible]l category with σ_θ or σ_ϕ is wind meand[illegible]. The EPA (1980) has p[illegible]ed a method to account for wind meander when u[illegible] σ_θ to predict Pasquill category. Tabl[illegible] shows this method along with the ranges of σ [illegible]r each

Table 3. Nighttime Pasquill Stabi[illegible]y Categories Based on σ_θ

If the σ_θ stability class is	and if the 10 m speed, U, is (m/s)	then the stability σ_z is
A ($\sigma_\theta \geq 22.5$)	$U < 2.9$	F
	$2.9 \leq U < 3.6$	E
	$3.6 \leq U$	D
B ($22.5 > \sigma_\theta \geq 17.5$)	$U < 2.4$	F
	$2.4 \leq U < 3.0$	E
	$3.0 \leq U$	D
C ($17.5 > \sigma_\theta \geq 12.5$)	$U < 2.4$	E
	$2.4 \leq U$	D
D ($12.5 > \sigma_\theta \geq 7.5$)	wind speed not considered	D
E ($7.5 > \sigma_\theta \geq 3.8$)	wind speed not considered	E
F ($3.8 > \sigma_\theta$)	wind speed not considered	F

stability class. The σ_θ values were used in determining Pasquill categories according to this method. Table 4 shows the results. Note the good correlation between coincident σ_θ and Pasquill categories. Nearly 49% of the time both methods produce the same stability categories. However, the two methods are within 1 category about 90% of the time. There is a tendency for σ_θ to indicate slightly more unstable conditions.

IV. SUMMARY AND CONCLUSIONS

Various methods for determining stability class are analyzed and compared with the Pasquill classification scheme at 2 sites with irregular terrain. The Pasquill categories were estimated objectively and compared with other stability indicators for 15-minute periods over a year.

Table 4. Percentage Occurrence of Pasquill Stability Class vs σ_θ Stability Class

Pasquill • σ_θ	A	B	C	D	E	F	Total
A	4.7	1.1	0.7	0.3	0.0	0.0	6.8
B	7.7	5.8	4.5	1.7	0.2	0.0	19.9
C	2.0	4.2	5.9	3.1	0.4	0.0	15.6
D	0.2	1.1	3.5	22.3	4.3	0.1	31.5
E	0.0	0.0	0.0	6.9	3.4	1.7	12.0
F	0.0	0.0	0.0	3.1	4.4	6.7	14.2
Total	14.6	17.2	14.6	37.4	17.7	8.5	100.0

The results show that near-surface AT distinguishes the neutral D category very well. However, it does not differentiate the specific stable and unstable categories very well. Both the Ri and Ri_B, indicators of both thermal and mechanical turbulence, correlate very well with and distinguish the different stability categories.

The standard deviations of horizontal (σ_θ) and vertical (σ_ϕ) wind direction are also shown to be good indicators of Pasquill Stability for categories A-D. For stable categories E and F, both σ_θ and σ_ϕ become larger due to wind meander. However, the good correlation for σ_θ extends to the stable E and F stability categories when an EPA proposed method for correcting nighttime wind meander is used.

It is concluded that the use of Ri, Ri_B, σ_θ, and σ_ϕ are all rather good indicators of Pasquill Stability Category at a site with irregular terrain. The ranges of Ri and Ri_B used for stability class, however, are quite different from others in the literature. The Pasquill method, therefore, appears to be a good indicator of turbulence over irregular terrain.

Due to the irregular terrain, the various methods of determining stability may be even better indicators of turbulence and diffusion if the wind direction were taken into account. It is suggested that further study investigate the methods by wind direction.

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