ATMOSPHERIC TURBULENCE INTENSITY AND DIFFUSION PARAMETER OVER COMPLICATED TOPOGRAPHY OF EASTERN GUANGDONG

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ABSTRACT

Based on observations by a dual-theodolite anemometer tracking balanced balloons and an American Gill UVW anemograph for complicated underlying surface in Meizhou, eastern Guangdong, turbulent fluctuations of the Lagrangian and Eulerian systems are determined for the area. Following the Taylor formular in respect to a few reference frames, horizontal and vertical turbulence intensity and atmospheric diffusion parameters σ_y and σ_z are then computed and compared with those obtained by the PG method and BNL experiments. It is found that within heights less than 100 m above the ground σ_y and σ_z are larger than values of PG and BNL with all conditions of stability and stratification.

Key words: complicated topography, atmospheric diffusion parameter, turbulence intensity

Ⅰ. INTRODUCTION

For an atmospheric diffusive model, the key treatment is to describe the process of turbulent diffusion in a reasonable way. The atmospheric diffusive parameter is importantly incorporated in the Guassian plum model that is widely used. The results computed with the PG methods and those under field conditions with flat topography by the Brookhaven National Laboratory, United States, cannot be simply used as diffusive parameters for the city of Meizhou in eastern Guangdong, an area with complicated underlying surface.

Meizhou is located in a southward sloping hilly area south of the Wu Ling Mountains Ranges with the Yinna Mountains transversing across it. The heighest peak is the Wu Zhi Feng (Five Fingers Peak) which is 1300 m above the ground. The area is 77.5 m above the sea level in average and underlied with complicated surface.

By releasing balanced balloons at heights of 100～200 m which were tracked with a dual-theodolite anemometer and installing a UVW anemograph on top of a building, a large amount of fluctuating turbulent momentum data were obtained. Downwind distributions of atmospheric diffusive parameters with various conditions of stability are computed using relevant Taylor formula and they are then compared with PG function computations and BNL experimental results, which are meaningful for practice.

Ⅱ. OBSERVATIONAL DATA AND COMPUTATIONAL METHOD

During separate periods (6～16 January 1987, 20 June～10 July 1992, 6～19 January and 25 July～8 August, 1995), observation was made of fluctuating turbulent momentum using dual-theodolite anemometer tracking balanced balloons released 100～200 m above the ground and mounting a Gill UVW anemograph on a supporting rod of 6 m high atop of a building (about 16 m in height), at selected sites around the Meizhou Power Plant , the Dongfeng Cement Factory and Jingta (Golden Tower) Cement

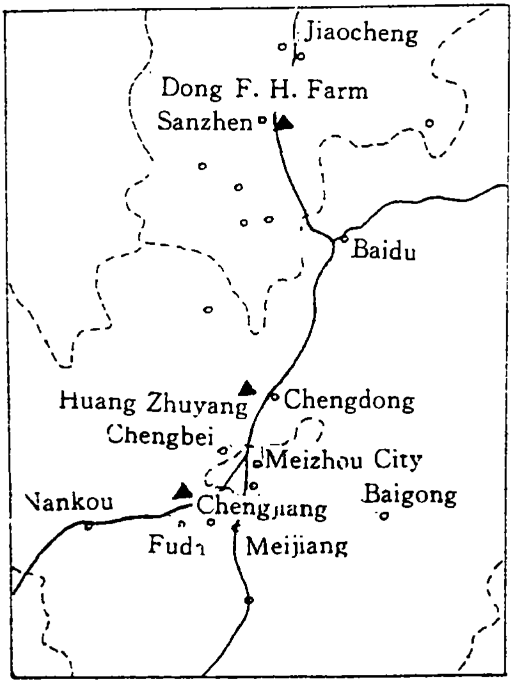

Fig. 1. Schematic chart of field observation location. △: location of observation points.

Company.

To neutralize the lifting force and gravity, the balloons (No. 20) used in the observation were loaded with wood blocks or sand bags after filling the hydragen gas so that the state of liftless drifting in the air could be as long as 30 minutes or more. The aerial position of the balanced balloons were tracked and determined by dual-theodolite anemometers base-lining 300 to 1000 m in between along a direction basically perpenticular (normal) to local prevailing winds. The smallest scale on the anemometers are 0. 05 degrees and finest estimated readings are by 0. 01 degrees. The reading was taken once every 15 seconds in each 30-minute long observation. During the experiment, more than 130 balloons were released and only over 80 of them were providing useful data after deletion for inaccurate records due to ineffective balanced state of the balloons from less appropriate loading, gas leakage or solar radiation.

The UVW anemograph automatically collects wind components along the three directions and temperature over different length of duration and intervals, and stores the raw data and real-time processed computation and prints them. The sampling here was 30 minutes in duration and 1 second at interval. Comprehensive processing (computation and analyses) were not done for the data set until all of the sample were removed with obvious irrational data.

1. *Categorization of atmospheric stability*

(1) With the improved methods of Pasquill classification, the atmospheric stability is determined by wind velocity and solar radiation intensity, the latter is categorized by solar azimuthal altitude and cloud amount.

(2) The stability is determined in degree by standard deviation of horizontal wind fluctuations in reference to the practice of D. H. Slade.

2. *Computation of turbulence intensity*

With transient winds of u, v, w and their variations in x, y, and z directions which are measured automatically and continuously, corresponding variances of velocity fluctuations $\overline{u'^2}$、$\overline{v'^2}$ and $\overline{w'^2}$ are derived and the turbulence intensity is determined by the expression followed:

$$I_u = \left(\frac{\overline{u'^2}}{\overline{u}^2} \right)^{1/2} = \frac{\sigma_u}{\overline{u}},$$

$$I_v = \left(\frac{\overline{v'^2}}{\overline{u}^2}\right)^{1/2} = \frac{\sigma_v}{\overline{u}},$$

$$I_w = \left(\frac{\overline{w'^2}}{\overline{u}^2}\right)^{1/2} = \frac{\sigma_W}{\overline{u}},$$

or by the expression of

$$I_u = \sigma_u/u^*,$$
$$I_v = \sigma_v/u^*,$$
$$I_w = \sigma_w/u^*.$$

Obviously, the difference between the two expressions lies in the values taken for u and u^*.

3. *Computation of frictional velocity* u^*

By definition, the frictional velocity u^* is derived in

$$u^* = \sqrt{\frac{\tau}{\rho}}.$$

4. *Estimation of ground roughness* Z_0

The ground roughness Z_0 is estimated in

$$Z_0 = Z_r/30,$$

where Z_r is the mean height per unit of roughness computation. Results show that the ground roughness Z_0 is 0.5~1.5 m in the area of our atmospheric detection.

5. *Formula estimating diffusive parameter*

Based on the Taylor formular, Pasquill proposed the following expression to estimate atmospheric diffusive parameters:

$$\sigma_y = \sigma_A x f(x),$$
$$\sigma_z = \sigma_E x f(x),$$

where σ_A and σ_E are standand deviation of velocity fluctuations in the horizontal and vertical, x is the downwind distance (m) and $f(x)$ the universal function. Corresponding results for high-mounted sources in field experiment of diffusion have been obtained by Pasquill (Li et al., 1985).

As atmospheric diffusive parameters in Lagrangian system in which pollutants diffuse are estimated from turbulence data observed in Eularian system, a relation between the two systems needs to be established. The computation based on UVW anemograph records and dual-theodolite anemometer tracking data theoretically originates from Taylor's basic idea on diffusion. The spectral function of the Taylor formular is expressed in

$$\overline{Y}^2 = \overline{v'^2}T^2 \int_0^\infty F_L(n) \frac{\sin^2(\pi n T)^2}{(\pi n T)^2} dn, \tag{1}$$

where n is the frequency of individual harmonic components decomposed from the velocity of irregular fluctuation v', $F(n)$ is the function of spectral intensity for v' and T the time of particle diffusion. Similar expressions are found with $\overline{Y}$ being replaced by $\overline{X}$ or $\overline{Z}$.

As the temporal scale of Eulerian auto-correlation is β times from that of Lagrangian system, for the Eulerian turbulent fluctuation the expression above is changed to

$$\overline{Y}^2 = \overline{v}'^2T^2 \int_0^\infty F_L(n) \frac{\sin^2(\pi nT/\beta)^2}{(\pi nT/\beta)^2} dn. \quad (2)$$

Part of the right hand side (r. h. s.) of Eq. (1) can be shown as

$$(\overline{v}'^2)_{\tau,T} = \overline{v}'^2 \int_0^\infty F_L(n) \frac{\sin^2(\pi nT)^2}{(\pi nT)^2} dn. \quad (3)$$

The r. h. s. of (3) is the variance of turbulent fluctuation that is measured in the Lagrangian system at τ sampling time over T smoothed mean duration. The r. h. s. of (2) in the Eulerian system can also be rewritten as

$$(\overline{v}'^2)_{\tau,T/\beta} = \overline{v}'^2 \int_0^\infty F_L(n) \frac{\sin^2(\pi nT/\beta)^2}{(\pi nT/\beta)^2} dn. \quad (4)$$

If the UVW anemograph-measured data is used in the computation, the smoothed mean duration should be changed into T/β . That is to say, when the balanced balloon is used as marked track-displaying particle, its diffusive parameter is written as

$$\sigma_y = T^2(\overline{v}'^2)_{\tau,T},$$

$$\sigma_z = T^2(\overline{w}'^2)_{\tau,T},$$

while the computation based on UVW anemograph data is expressed as

$$\sigma_y = T^2(\overline{v}'^2)_{\tau,T/\beta},$$

$$\sigma_z = T^2(\overline{w}'^2)_{\tau,T/\beta}.$$

Ⅲ. COMPUTATIONAL RESULTS, ANALYSES AND DISCUSSION

1. *Characteristics of atmospheric stability*

It is shown from field observations (Table. 1) that the mean frequency of the atmospheric stability over the complicated underlying surface of Meizhou is dominated by neutrality (Type D) when classified with Pasquill radiative intensity; the stratification is 53.9% for Type D, 14.2% for Type B (unstable), 5.7% and 7.8% for Type A (very unstable) and Type C (slightly unstable), respectively, and 14.2% and 4.2% for Type E (slightly stable)and Type F(stable), respectively. When another standard of classification, Slade's method of variance of horizontal fluctuation σ_A, is used, the stratification is 36.2% neutral (Type D), 17.0% unstable (Type B) and 26.2% slightly unstable (Type C). Each of Types A, E, and F (denotation as above) takes up less than 10%. Mean winds less than 1 m/s occur up to 46.1% of chance in this area. It is shown in the observations and computation above that Slade's variance of horizontal fluctuation is reasonable in classifying atmospheric stability.

Table 1. Standards for classification of different stability and distribution for corresponding frequency of atmospheric stability.

	Frequency-distribution by PQ radiative intensity			Frequency-distribution by Slade horizontal fluctuation		
	Wind velocity		Total	Wind velocity		Total
	≥1m/s	<1m/s	(%)	≥1m/s	<1m/s	(%)
A	5.7	—	5.7	5.0	1.4	6.4
B	8.5	5.7	14.2	13.5	3.5	17.0
C	7.8	—	7.8	14.9	11.3	26.2
D	26.2	27.7	53.9	17.7	18.5	36.2
E	5.7	8.5	14.2	2.8	6.4	9.2
F	—	4.2	4.2	—	5.0	5.0
Total	53.9	46.1	100.0	53.9	46.1	100.0

2. *Relationship between standard deviation of wind direction and wind velocity*

Fig. 2 shows the relationship between the standard deviation of transversal wind σ_v computed for UVW anemograph observation and wind velocity 28 July through 7 August, 1995. It is understood that the relationship gets weaker and weaker as the stratification changes from unstable to neutral and further to stable conditions. With all conditions of stability, the linearity is much weaker between the standard deviations σ_u in the direction of wind (longitudinally), σ_w in the vertical and wind velocity than that between the standard deviation in the transversal direction σ_v and wind velocity (Figure omitted).

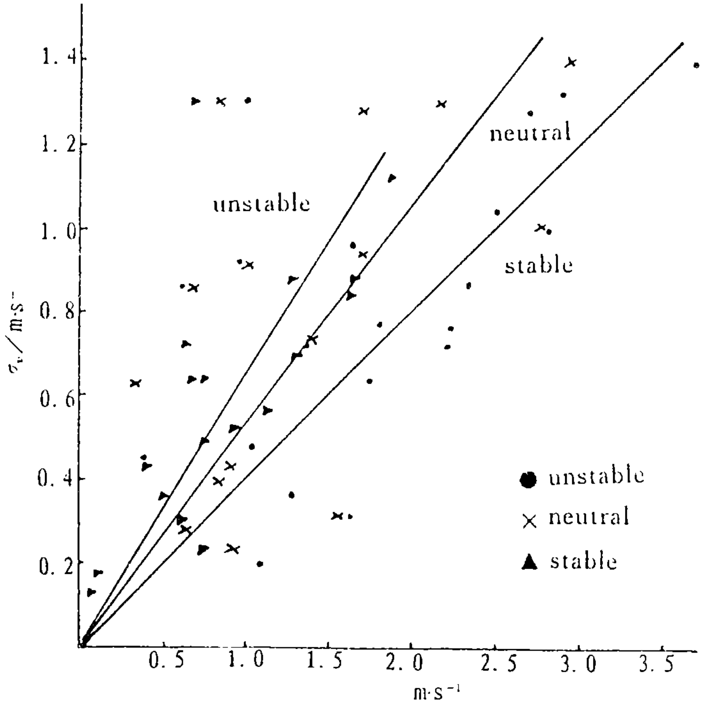

Fig. 2. Relationship between standard deviation of transverse winds and wind speed at 22 m above ground with conditions of different stratification. (28 July-7 August, 1995)

3. *Turbulence intensity*

Two separate atmospheric measurement were made in each of the representative seasons of summer and winter. Comprehensive analytic and statistic work has been done for the large amount of UVW anemographic samples of mean wind velocity and turbulence intensity and the results are shown in Table 2.

Table 2. Intensity characteristics of turbulence with conditions of different stratification.

		Unstable		Neutral		Stable	
		Range	Mean	Range	Mean	Range	Mean
Mean wind velocity	(m/s)	1.2—2.3	1.8	0.9—2.1	1.6	0.6—1.8	1.2
σ_i/u	I_u	0.29—0.77	0.48	0.30—0.65	0.46	0.27—0.48	0.38
	I_v	0.28—0.97	0.51	0.36—0.62	0.45	0.34—0.39	0.36
	I_w	0.09—0.22	0.15	0.07—0.18	0.12	0.08—0.17	0.10
σ_i/u^*	σ_u/u^*	1.53—4.06	3.56	2.55—4.31	3.25	1.53—3.52	2.64
	σ_v/u^*	1.60—6.31	4.80	2.32—4.40	3.70	2.05—6.50	3.66
	σ_w/u^*	0.97—2.78	1.86	0.91—1.76	1.43	0.75—0.98	0.92

From the analyzed result we have the following conclusions.

(1) Given varied condition of stability, turbulence in the form of σ_i/u gives rise to longitudinal and transversal means by relatively small margins, the longitudinal values are slightly larger than the transversal ones with the condition of unstable stratification, and vertical mean values are sharply reduced with all degrees of stability. The turbulence intensity is averaged at 0.11～0.51, a range that is somewhat smaller than that of 0.26～0.55 observed at Guangzhou, but quite close to the observation (Xu et al., 1993) for Yizheng, Jiangsu Province (0.12～0.26) and slightly larger than those for American mid-plateau (0.18, 0.10, 0.06).

(2) Turbulence values in terms of σ_i/u^*, on the other hand, yield greater means transversally for all state of stability, though the one in the vertical remains as small as with σ_i/u. The values are averaged at 0.92～4.80, being in contrast to the observation for Guangzhou (1.47～3.25), or, greater than the latter both longitudinally and transversally, but much smaller vertically.

4. *Atmospheric diffusive parameter*

In Fig. 3 through Fig. 8, the variations of mean diffusive curves with distance are given in comparison with the $f(x)$ function computations of Pasquill-Gifford (PG value in short) and that of American Brookhaven National Laboratory (BNL values), for different conditions of stratification which are derived from the atmospheric turbulence intensity, which is computed on basis of the UVW anemographic and balloon-tracked dual-theodolite observational data. The figures indicate that the σ_y value, as observed in the manner stated above for the complex underlying surface at Meizhou, are apparently little larger than the PG or BNL values (Li et al., 1985). On the other hand, the observed σ_z by the UVW anemograph is significantly smaller than the experimental PG or BNL results while that for the balloons is a little larger than PG or BNL values within the range of 2000 m. It is caused by the fact that the observation at Meizhou are affected by lifting mechanic turbulent current produced by hills of 100 m or more in altitude around the measuring sites of the balanced balloons which are drifting 100～200 m above the ground. During the neutral period, the σ_y observed by the balloons are all larger than the values of BNL, PG, and those observed by the UVW anemograph, the latter being close to the PG value. With stable stratification, however, the σ_y value measured by both anemograph and balanced balloons are much greater than the BNL and PG values; the σ_y results recorded by the balloons are greater (smaller) than those by the anemograph within (outside) the range of 1000 m; observations are larger for the balloons; those byUVW anemograph and PG value are close to each other within the 1500-m range, but the former is much larger than PG value and the BNL experimental σ_z result is much smaller outside the 1500-m range.

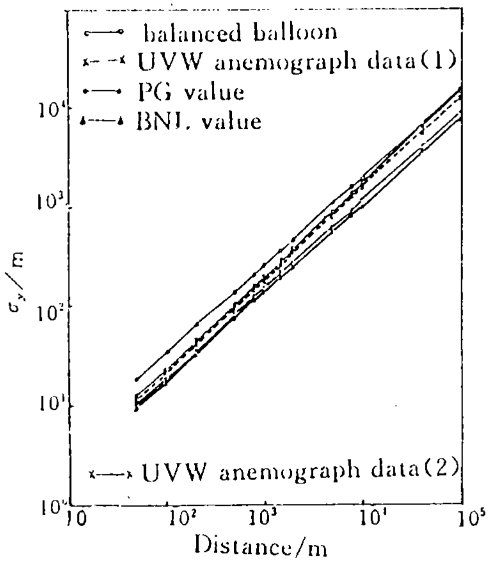

Fig. 3. Variation of observed horizontal diffusion parameter σ_y with distance and its comparison against PG and BNL values, with conditions of unstable stratification.

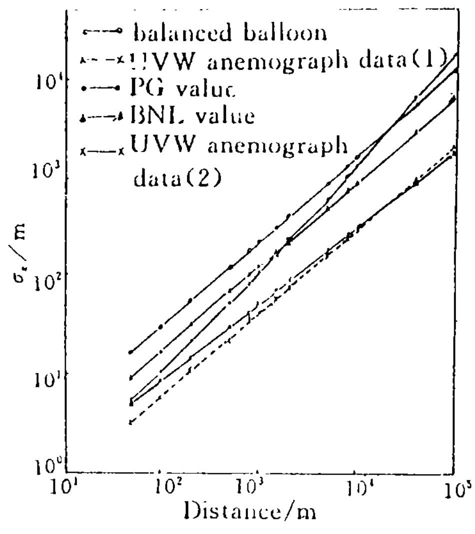

Fig. 4. Same as Fig. 3 except for σ_z.

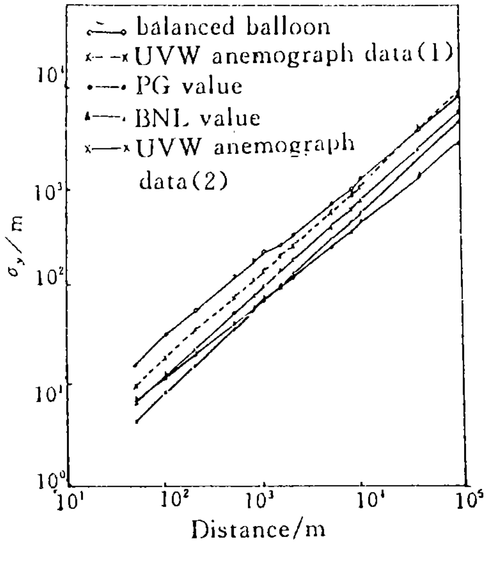

Fig. 5. Variation of observed σ_y with distance and its comparison against PG and BNL values, with conditions of neutral stratification.

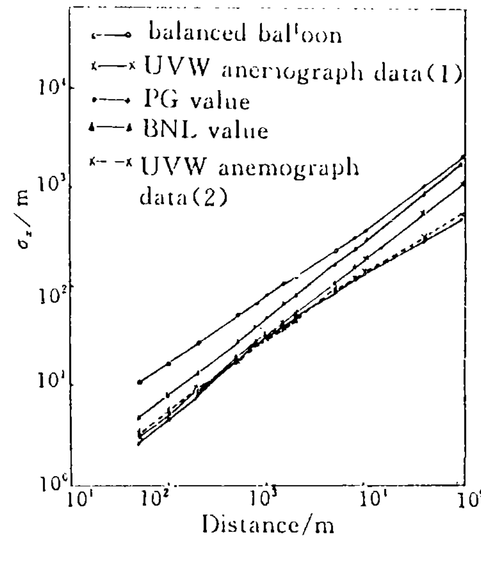

Fig. 6. Same as Fig. 5 except for σ_z.

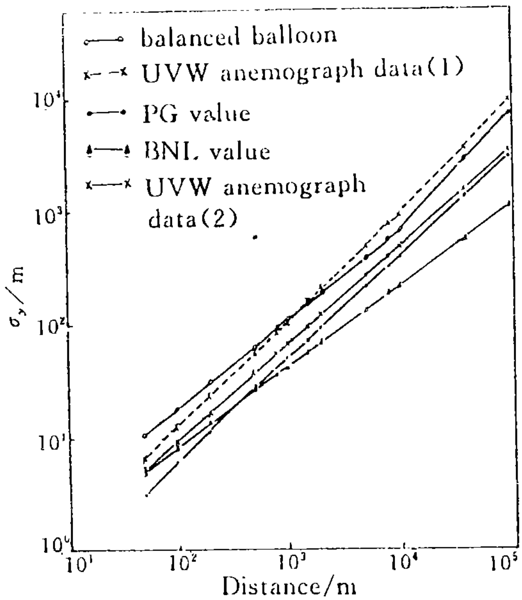

Fig. 7. Variation of observed σ_y with distance and its comparison against PG and BNL values, with conditions of stable stratification.

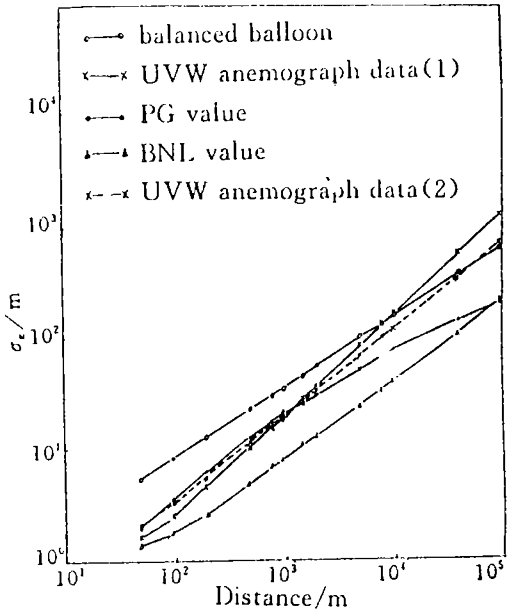

Fig. 8. Same as Fig. 7 except for σ_z.

Ⅳ. CONCLUSION

a. With Slade's variances of horizontal fluctuations, atmospheric stability is more reasonably categorized for complicated underlying surface.

b. For the particular complicated underlying surface at Meizhou, eastern Guangdong, there is good linearity between the transversal standard deviation and wind velocity and the more unstable the atmosphere, the more obvious the linearity will be.

c. In the area tested, the intensity of turbulence in the near-surface layer is larger than in the area of flat topography but a little smaller than urban Guangzhou.

d. The values of σ_y and σ_z observed by the balanced balloon with all conditions of stability are all larger than experimental PG and BNL results in all stratifications; the σ_z observations are close to the PG value in neutral condition, much smaller than both PG and BNL experimental results with unstable stratification.

e. The PG value and BNL atmospheric diffusive parameters are readily relied on for regions with flat topography, but they need some correction for areas of complicated topography.

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