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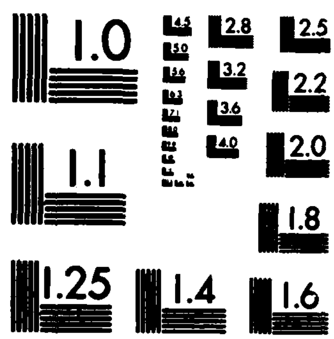
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FOREIGN TECHNOLOGY DIVISION

A NUMERICAL ANALYSIS OF THE EFFECT OF INHOMOGENEITY AND WIND SPEED SHEAR ON THE VERTICAL DISPERSION IN THE MESOSCALE RANGE

by

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FTD-ID(RS)T-1649-83

EDITED TRANSLATION

FTD-ID(RS)T-1649-83 23 December 1983

MICROFICHE NR: FTD-83-C-001555

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English pages: 10

Source: Huanjing Kexue Xuebao, Vol. 2, Nr. 1, March 1982, pp. 74-79

Country of origin: China
Translated by: SCITRAN
F33657-81-D-0263
Requester: DET 22
Approved for public release; distribution unlimited.

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A Numerical Analysis of the Effect of Inhomogeneity and Wind Speed Shear on the Vertical Dispersion in the Mesoscale Range /74

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Abstract

According to Expression (10) in Reference [1], the effect of inhomogeneity and wind speed shear on the vertical dispersion in the mesoscale range (10-100km) was analyzed numerically. Some beneficial results were obtained.

In this paper, starting from the correlation between the vertical dispersion parameter σ_z and $\bar{x}$ derived in [1] (the meanings and parametric values of all the symbols used in this paper are identical to those in [1], and in general will not be explained again), the effect of the variation of the effective roughness length z_0 with distance (i.e., inhomogeneity) and various wind profiles on σ_z was analyzed numerically. It provided a method to further resolve practical problems (such as the evaluation of the atmospheric quality in the Beijing-Tianjin-Bohai area).

I. Effect of Wind Shear Speed on σ_z

From the equation (10) in [1] one can see that the effect of the variation of the wind speed with the altitude on σ_z is an important factor. In the following, besides using equation (18) (profile II) given in [1], we also chose two other types of wind profile to carry out a comparative numerical analysis.

In order to describe the upper half of the PBL better, a two layer model such as the one used in Reference [2] to analyze the Eikman laminar wind speed profile (i.e., considering a transition layer $\bar{z}_1$, u_* is a constant below $\bar{z}_1$, and K_0 is a constant above $\bar{z}_1$) was adopted. Above $\bar{z}_1$, all the way to an altitude h,

$$w=Ge^{-i\alpha_0}+\frac{u_*^2}{\sqrt{PK_0}}e^{\left(i\frac{3\pi}{4}-(1+i)\sqrt{P/2K_0}(\bar{z}-\bar{z}_1)\right)} \qquad (1)$$

where $w=u+iv$ (2)

Based on (1) and (2), a complex number calculation was conducted. Finally, we obtained

$$u = G\cos\alpha_0 + \frac{\sqrt{2}}{p} u_*^2 l e^{-l(\bar{z}-\bar{z}_1)} \cos\left[\frac{3\pi}{4} - (\bar{z}-\bar{z}_1) l\right] \qquad (3)$$

Above the constant stress layer, equation (3) (Profile III) was more adequate than II. Below $\bar{z}_1$, it was possible to apply the near ground layer law. When $\bar{z}_1$ is very low, equation (3) can approximately describe the wind speed distribution characteristics of the near ground layer.

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*Comrade Yaun Suzhen participated in part of the calculation and analysis work.

The power series wind profile has been widely used by various industrial departments. For comparison, the following wind profile[3] was also chosen (Profile I) in the analysis: /75

$$u = G(\bar{z}/h)^r \qquad (4)$$

During the computation, r was chosen to be 0.05 in unstable conditions,[4] r = 0.1 in neutral conditions, and r = 0.4 in stable conditions.

Which one of the wind profiles I, II, and III agrees more with the reality? The dimensionless wind profiles ($\bar{u}/u_{20}$) with various stabilities were plotted in Figure 1. For comparison purposes, some of the wind profiles observed on a 430m tower in the United States[4] and a 320m tower in Beijing [5] were also plotted in dots in the figure.

From Figure 1 one can see that the distribution of I is different from II and III. II and III have the same distribution shape. Among the three, II has the largest vertical wind shear. The wind shear of I is close to that of III. A comparison with the wind actually measured shows that III is more close to reality.

The expressions of I, II, and III were substituted into the relation between σ_z and $\bar{x}$. Numerical computations were carried out on a TQ-6 machine. The u_* values are given in Table 1. Finally, the magnitudes of σ_z were obtained under different wind profile conditions. In order to examine the difference among them, the ratios of σ_z obtained under the three conditions are given in Table 2.

稳定度类	A	B	C	D	E	F
u_* (m/S)	0.365	0.355	0.32	0.26	0.244	0.16

Table 1. Values of u_* at various stabilities[6-9]

1. type of stability

距离 (km)		10	15	20	30	40	50	60	70	80	90	100	平均
B类	$\sigma_z(I)/\sigma_z(II)$	0.98	0.98	0.95	0.95	0.95	0.94	0.92	0.91	0.91	0.91	0.91	0.94±0.023
	$\sigma_z(III)/\sigma_z(II)$	1.02	1.00	1.00	1.00	1.00	1.00	0.99	0.98	0.98	0.98	0.98	0.99±0.012
	$\sigma_z(I)/\sigma_z(III)$	0.96	0.98	0.95	0.95	0.96	0.94	0.93	0.93	0.93	0.93	0.92	0.94±0.013
D类	$\sigma_z(I)/\sigma_z(II)$	1.11	1.23	1.29	1.35	1.38	1.38	1.40	1.40	1.43	1.43	1.45	1.35±0.099
	$\sigma_z(III)/\sigma_z(II)$	1.11	1.25	1.31	1.36	1.39	1.39	1.39	1.38	1.38	1.36	1.36	1.34±0.062
	$\sigma_z(I)/\sigma_z(III)$	1.00	0.98	0.98	0.98	0.99	0.99	1.01	1.01	1.04	1.05	1.07	1.01±0.03
E类	$\sigma_z(I)/\sigma_z(II)$	1.01	1.03	1.05	1.07	1.08	1.10	1.11	1.12	1.13	1.14	1.14	1.09±0.043
	$\sigma_z(III)/\sigma_z(II)$	1.01	1.03	1.02	1.02	1.04	1.04	1.07	1.08	1.09	1.09	1.09	1.06±0.03
	$\sigma_z(I)/\sigma_z(III)$	1.00	1.00	1.03	1.06	1.04	1.06	1.04	1.04	1.04	1.05	1.06	1.04±0.02

注 * 其中σ_z(I)、σ_z(II)和σ_z(III)分别表示用I、II和III廓线计算出的结果.

Table 2. Ratios of σ_z derived with various wind profiles *

1. type B
2. type D
3. type E
4. *in which σ_z(I), σ_z(II), and σ_z(III) represent the results obtained using Profiles I, II, and III in the computation, respectively.

The ratio of σ_z and the profile comparative analysis in Figure 1 showed that:

1. In a neutral condition, the wind shears of II and III can differ by as large as nearly 20 times. The σ_z ratio thus produced has a maximum of 1.39 (in the 10-100 km range). Its average is 1.34 ± 0.082. The shapes of Profiles II and I are not the same. The wind shear difference of the two differs by as much as 19 times.

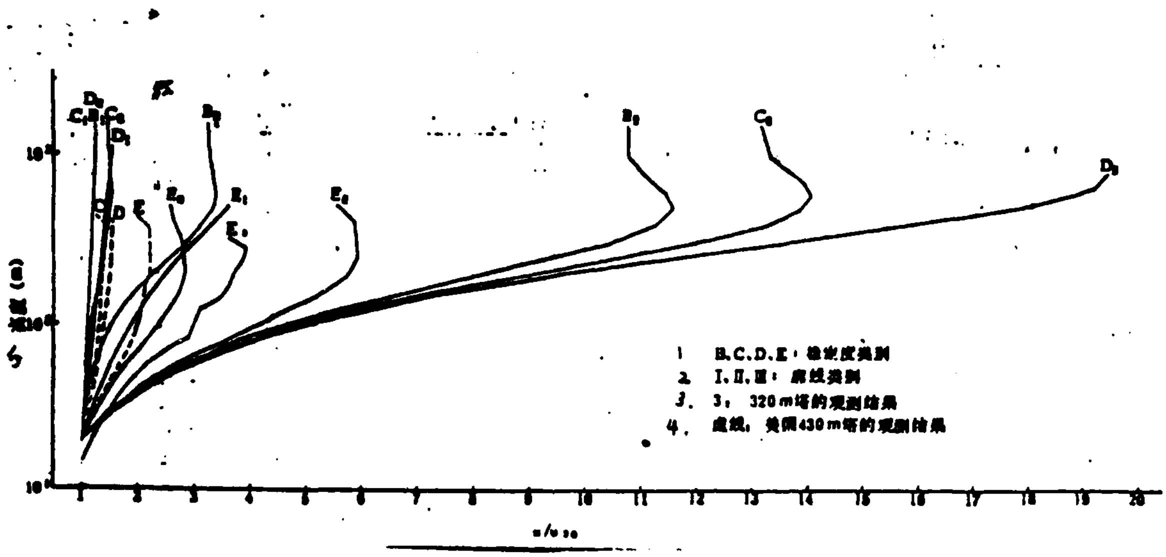

Figure 1. The Average Wind Speed Shear Profile

1. B.C.D.E: stability type
2. I, II, III: profile type
3. observation results obtained at a 320m tower
4. dotted line: observation results obtained at a 430m tower in the United States
5. altitude

The maximum σ_z ratio is 1.45. Its average is 1.35 ± 0.099. /77
Comparing III to I, despite the fact that the profiles type are not the same, the wind speed shear difference is very small. The difference in σ_z is also small. The maximum ration is only 1.07.

2. From the variation of σ_z derived from both II and III with stability, the difference of σ_z becomes greater and greater as the type changes from A to D. This is primarily because the wind shear of II is increased gradually from type A to D. Therefore, σ_z gradually becomes smaller. The wind shear of III, however, does not vary significantly with stability. The same trend of variation also exists from type F to D. However, it is not as obvious as under an unstable situation. The pattern of variation of the effect of both II and I on σ_z with stability is the same as that of II and III. Comparing III to I, due to the fact that the variation of the wind shear with stability is not very obvious for both cases, the wind shear is very close. Although the distribution shapes are different, the difference of the effect of the two on σ_z is always within 10%.

II. Effect of Inhomogeneity on σ_z

Due to the effect of roughness on dispersion, the discussion in Reference [1] used an effective roughness length to express the average value of a homogeneous geomorphology and an inhomogeneous geomorphology after an abrupt change takes place. This is feasible in the estimation of the average condition. However, in reality the roughness factor is frequently inhomogeneous. It is a problem of our great concern to know how large the effect of inhomogeneity is. For simplicity, but not losing its generality, z_0 is expressed as

$$z_0(\bar{x}) = \cos\left(\frac{2\pi}{x_0}\bar{x}\right) + 1.0006 \qquad (5)$$

For convenience, $\frac{2\pi}{x_0}$ was chosen to be 1. The value of z_0 given by equation (5) in fact is varying periodically with $\bar{x}$ between 0.0005-2.0005m. With regard to such a roughness distribution, the effective roughness length is approximately 1m.

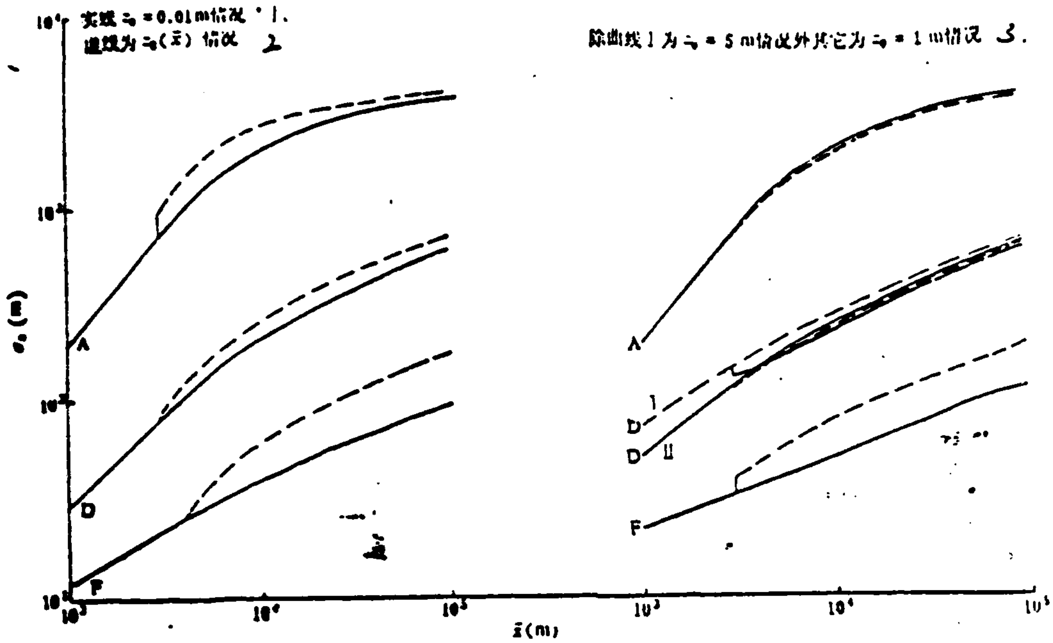

Figure 2. Effect of z_0 ($\bar{x}$) on σ_z

1. the solid line is for z_0=0.01 m
2. the dotted line is for $z_0=(\bar{x})$
3. Except for curve 1, which is for z_0=5m, other curves are for the situation z_0=1.

In order to compare the calculated results to the value of σ_z when z_0 is a constant, it is assumed that the inhomogeneity in the form of equation (5) begins at 3km away from the source in the calculation. Equation (5) is substituted into the correlation between σ_z and $\bar{x}$ to carry out the numerical calculation. The results, together with the values obtained when z_0 is a constant, are given in Figure 2. In the meantime, the mean, maximum, and minimum values of $\sigma_{z_0}(\bar{x})/\sigma_{z_0}$ (in the range of 5-100km) in various types of stability are tabulated in Table 3.

		4 最大值	5 平均值	6 最小值
1 A类	$\sigma_{z_g}(\bar{x})/\sigma_{0.01}$	2.29	1.68±0.361	1.25
	$\sigma_{z_g}(\bar{x})/\sigma_1$	0.98	0.95±0.023	0.89
	$\sigma_{z_g}(\bar{x})/\sigma_5$	0.69	0.56±0.107	0.39
2 D类	$\sigma_{z_g}(\bar{x})/\sigma_{0.01}$	1.25	1.21±0.023	1.18
	$\sigma_{z_g}(\bar{x})/\sigma_1$	0.99	0.98±0.008	0.96
	$\sigma_{z_g}(\bar{x})/\sigma_5$	0.89	0.86±0.028	0.81
3 F类	$\sigma_{z_g}(\bar{x})/\sigma_{0.01}$	1.81	1.69±0.168	1.20
	$\sigma_{z_g}(\bar{x})/\sigma_1$	1.66	1.59±0.073	1.38

7 * 其中σ的下标表示粗糙度长(m)，$z_{g(x)}$表示非均匀，z_0表示均匀情况.

Table 3. The Values of $\sigma_{z_0}(\bar{x})/\sigma_{z_0}$* /78

1. Type A
2. Type D
3. Type F
4. maximum
5. mean
6. minimum
7. *The subscript of σ represents the roughness length (m). $z_{g(x)}$ represents inhomogeneous situations and z_0 represents homogeneous situations.

From Table 3 and Figure 2 one can see that:

1. When the pollutant abruptly enters an inhomogeneous terain in the form of equation (5) after traveling originally in a flat and homogeneous terrain, the σ_z versus $\bar{x}$ curve shows an apparent change in the corresponding region to form a turning point. Due to the fact that the average roughness of the inhomogeneous geomorphology is greater than 0.01m, the value of σ_z is larger than that corresponding to a flat homogeneous terrain. The mean value of $\sigma_{z_g}(\bar{x})/\sigma_{0.01}$ becomes larger as it varies from D to F. From Type D to A, the variation trend is not obvious. The average ratio of Type D is the smallest.

2. When the pollutant abruptly enters an inhomogeneous region in the form of equation (5) from a homogeneous terrain whose roughness is 1m, the results indicate that $\sigma_{z_g}(\bar{x})/\sigma_1 \approx 1$ from Type D to A in neutral situations. It is basically very close to the homogeneous situation in which z_0 = 1m. However,

the stable situation is not quite the same. $\sigma_{z_g(\bar{x})}$ is apparently larger than when z_0=1m. This phenomenon tells us that, with regard to unstable and neutral conditions, it is as effective to use a homogeneous terrain with an effective roughness z_0 to represent an inhomogeneous rough terrain with average roughness z_0 to investigate the effect on σ_z. The stable situations are quite different. This inhomogeneity could also cause a turbulent disturbance, which caused σ_z to be larger than the average roughness length situation. This further explains the importance of the inhomogeneity of the terrain with respect to stability.

3. When the pollutant abruptly enters an inhomogeneous region in the form of equation (5) from a terrain whose roughness is greater than 1m, the results indicate that inhomogeneity would cause σ_z to produce a turning point under unstable and neutral conditions. But, the value of σ_z is smaller than that obtained when z_0 is 5m. This difference decreases with increasing distance. It is apparently different, however, under stable conditions. Regardless of the initial homogeneous topology, the value of σ_z is always larger than that obtained when z_0 does not vary due to inhomogeneity. This demonstrated the inhomogeneity of the roughness is purely mechanical in neutral and unstable situations. As for stable situations, in addition to a mechanical action, it indirectly intensifies the turbulence. This mechanism is yet to be further understood.

III. Conclusions

Through the above analysis, one can obtain that:

1. In the mesoscale range, the distribution of wind speed with altitude and the vertical wind speed shear have a greater effect on σ_z. The magnitude of the wind shear is more important than the profile type.

2. Inhomogeneity could cause σ_z to form a turning point /79
at the place where the terrain changes abruptly.

3. It is possible to use an effective roughness length to replace the inhomogeneity in neutral and unstable situations.

However, in stable situations, it would cause a large error.

Received on January 15, 1981.

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