NOTES AND CORRESPONDENCE

The Scale of Turbulence in the Atmospheric Surface Layer

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1. Introduction

The scale of turbulence of vertical component of the wind is one of good measures to express the structure of the wind. Accordingly, the scale has been investigated from observational point of view by many meteorologists [e.g., Panofsky and McCormick (1960), Takeuchi and Yokoyama (1963), Pasquill (1972)]. Their results suggest that the scale of turbulence increases with the height and decreases with the stability.

The present author has analyzed the scale of turbulence for a vertical component of wind in three ways. These scales are compared simultaneously in relation with the height from ground and the stability.

2. Analytical method, data and result

There are many different ways to estimate the scale of turbulence for a vertical component of wind. Three ways here applied are as follows:

- (1) Integral length scale subject to frozen turbulence:

$$l_E = U \int_0^\infty R(t) dt$$

where U is the mean wind velocity and $R(t)$ is the auto-correlation coefficient for velocities at one position at times separated by t .

- (2) Mixing length including the stability parameter:

$$l_m = kZ/\phi$$

where ϕ is the nondimensional wind shear ($\phi = \frac{kZ}{U_*} \frac{\partial U}{\partial Z}$), u_* is the friction velocity, Z is the height from the ground and R is Karman's constant.

- (3) Scale in spectral term:

$$l_p = U/2\pi n_p$$

Table 1. Summary of the data and the scale of turbulence (Kasumigaura, 1969)

RUN NO.	DATE	TIME (h:m)	height (m)	U (m/s)	n_p (Hz)	u_* (m/s)	Z/L'	l_E (m)	l_p (m)	l_m (m)
1	13 Dec.	21:37—22:40	6.65	3.6	—	0.32	−0.017	1.30	—	0.27
2	13 Dec.	21:37—22:40	2.17	4.4	—	0.32	−0.059	—	—	0.90
3	13 Dec.	21:37—22:40	16.35	4.7	0.12	0.32	−0.452	6.72	6.23	6.64
7	14 Dec.	7:45—8:18	0.65	3.1	—	0.18	−0.010	—	—	0.28
8	14 Dec.	7:45—8:18	2.17	3.4	0.20	0.18	−0.036	2.45	2.71	0.88
9	14 Dec.	7:45—8:18	16.35	3.8	0.15	0.18	−0.272	5.13	4.03	6.64
10	14 Dec.	8:30—9:00	0.65	4.15	0.15	0.15	−0.013	3.90	4.40	0.26
11	14 Dec.	8:30—9:00	2.17	4.5	—	0.15	−0.046	2.39	—	0.85
12	14 Dec.	8:30—9:00	16.35	4.9	0.04	0.15	−0.335	10.4	19.5	6.64
13	11 Dec.	21:06—21:36	7.78	4.54	0.08	0.22	−0.110	6.36	9.03	3.07
14	13 Dec.	12:35—13:10	2.17	7.3	—	0.42	0.003	1.10	—	0.68
15	13 Dec.	12:35—13:10	16.35	11.0	0.17	0.42	0.036	2.86	10.3	5.68
16	14 Dec.	10:05—11:08	0.65	2.13	—	0.13	−0.031	1.85	—	0.85
17	14 Dec.	10:05—11:08	2.17	2.45	0.18	0.13	−0.113	2.28	2.17	1.16

$$L' = \frac{u_* T(\partial U / \partial z)}{kg(\partial \theta / \partial z)}, \quad u_* \text{ from dröfile}$$

Table 2. Summary of the data and the scale of turbulence (Syowa Station, 1971).

RUN NO.	DATE	TIME (h: m)	height (m)	U (m/s)	n_p (Hz)	u_* (m/s)	Z/L	l_E (m)	l_p (m)	l_m (m)
1	4 Dec.	14:42	20.0	0.67	0.03	0.06	2.74	—	3.55	—
2	4 Dec.	14:42	20.0	0.67	0.24	0.24	2.74	0.46	0.44	—
3	11 Nov.	1:03	20.0	12.8	0.55	0.23	1.06	3.46	3.70	4.61
4	4 Dec.	14:30	20.0	0.48	—	0.07	4.20	0.46	—	—
5	4 Dec.	1:28	20.0	3.07	0.47	0.05	2.53	2.33	1.04	1.92
6	4 Dec.	13:54	20.0	0.85	0.15	0.04	3.04	0.92	0.90	—
7	13 Dec.	23:47	20.0	6.33	0.17	0.14	1.65	5.19	5.93	3.01
8	8 Nov.	23:59	20.0	7.5	0.49	0.10	2.06	2.10	2.44	1.49
9	8 Nov.	23:59	20.0	7.5	0.58	0.10	2.06	1.65	2.06	1.49
10	28 Nov.	15:31	20.0	10.4	0.34	0.41	-0.04	6.14	4.87	9.42

U, u_* , Z/L are obtained from Adachi (J. Met. Soc. Jap., 1974)

where n_p is the specific frequency at which the spectral curve $nS(n)$ has the maximum value and $S(n)$ is the power spectral density at frequency n . If we assume exponential form for auto-correlation coefficient, this scale l_p is equal to the integral scale mentioned above.

Two different series of data are analyzed. First, the vertical wind fluctuation in the slightly unstable condition: they were observed at the tower by the Lake Kasumigaura in Ibaragi Prefecture in 1969 by means of ultra sonic anemometers which were mounted at the four levels of the tower (0.65 m, 2.17 m, 7.78 m and 16.35 m). The other data in the stable condition: these were obtained at the 20 m level of a meteorological

tower at Syowa Station in Antarctica in 1971 (Adachi, 1974) by the same type anemometer. The analogue data were read out for 5 minutes from each run (30~60 min.) every 1 sec in the former series and every 0.2 sec in the latter.

Analyses have been done for spectrum and auto-correlation coefficient by digital method as described by Blackman and Tukey (1958). In processing the data, special attention was paid for calculating the auto-correlation coefficient and for estimating the specific frequency n_p . That is, the trend and the slowly varying component of the wind velocity are removed by eye. Determination of the specific frequency n_p was made in the frequency range from 0.01 Hz to 5 Hz, only in

Fig. 1 Each scale (l_E , l_p , l_m) versus the height from ground in the slightly unstable condition (at Kasumigaura).

such cases as a spectral peak is evident.

The details of analytical results are tabulated in Tables 1 and 2.

3. Consideration

It can be seen from Figs. 1 and 2 that each scale depends on the height from ground and the stability (Z/L' or Z/L) where L is Monin-Obukhov length and L' is related to L by the equation: $L=L'/P$ (P is the turbulent Prandtl number, the ratio of the momentum diffusivity to the thermal diffusivity).

The scales of turbulence in the surface layer, l_E and l_p are studied in relation to the height. However, l_m is not here taken into consideration because it can be regarded as being proportional to the height. The dimensionless scale l/RZ where l is the representative of l_E and l_p , is plotted against the stability (Z/L' or Z/L) in Fig. 3. In the stable condition, it seems that despite

Fig. 2 Each scale (l_E , l_p , l_m) versus the stability (Z/L') in the slightly unstable condition (at Kasumigaura) and the stability (Z/L) in the stable condition (at Syowa Station).

Fig. 3 Each nondimensional scale (except l_m) versus the stability (Z/L' or Z/L) from the slightly unstable condition to the stable condition. Dots without alphabet are from Syowa Station.

scattered data, the dimensionless scale decreases with increasing stability. To date, this qualitative tendency has been indicated by many workers. On the other hand, in the slightly unstable condition the dimensionless scales seem to be greater at lower level than at higher level, though the dots are in the limited range of the stability.

The fact that the dimensionless scale in the slightly unstable condition has a much larger value at a lower level implies that should l be proportional to Z^α , the index α would not equal to, but would be smaller than unity. In Fig. 4, l obtained during one same observation time are plotted against the height. This shows that $\alpha < 1$ is well supported.

The present analytical results are similar to those obtained by Taylor *et al.* (1970) and Warner (1972). Considering the fact that the scale of turbulence for a vertical wind velocity depends both on the height from ground and on the

stability, it is inferred that the scale l is proportional to $Z^\alpha F$ (Z/L' or Z/L) where F is a function of stability and $\alpha < 1$.

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Fig. 4 Each scale (l_E , l_p) versus the height from ground during same observation time in the slightly unstable condition (at Kasumigaura).

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