On the Structure of the Atmospheric Turbulence Near the Ground[1]

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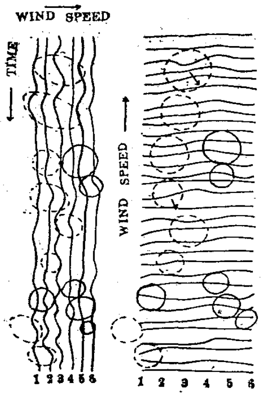
Introduction. There are many authors who investigated the structure of the wind[1)], but they generally treated the fluctuation of wind direction or wind speed as statistical quantities. However, when we recorded the wind velocity-fluctuation near the ground by using several hot-wire anemometers, the distance of which was 1,5~10 cm. each other, the correlation between each record was too much to treat the fluctuation as statistical quantity immediately and it seemed to be more natural that we interpreted them as the results of the deterministrical cause and that the cause occurred statistically. The time during which the process proceeds deterministically is not so short to be treated as a negligiblly small quantity, so when we investigate the atmospheric turbulence, it is very important to examine the order of sensitivity, for time and space, of measuring instruments and the deterministical structure of the turbulence. So we considered that the cause was the passage of small eddies, and observed the quantities concerned with them. From this standpoint of view we used at first hot-wire anemometers and then small wind vanes situated in a small area, and observed scale, sign, strength etc. of each eddy, following the procedure of the formation and disappearance of it.

I. Hot-wire method. We used a Pt-wire, 2 cm. in length and 0.04 mm. in diameter, as an arm of a bridge circuit for each of 6 anemometers and recorded unbalanced currents by a 6 element-oscillograph. The hot-wires were placed equidistantly on a horizontal line perpendicular to the wind, 1 m. high from the ground, and errected vertically. So we treated the fluctuation in a horizontal-plane. The distance varied from 1,5 to 10 cm. One record is as Fig. 1. Fig. 1 a) shows the record of wind speed vers time for each position of hot-wire, and Fig. 1 b) shows the spatial variations of speed at each instant of 0.1 sec. interval.

To explain these results, we assumed that 1) eddies (with vertical axis) were wandering through in a main stream (velocity: U, direction: ξ), as we often see on a river surface, and 2) each eddy had circular cross section (diameter: D) and inside of this circle, vorticity (ζ) is

[1] Contributions from Department of Physics, Faculty of Science, Ochanomizu University No. 2.

constant, but outside of it, circulation (Γ) is constant. Fig. 2 shows several calculated results of total speed for some cases of several



(a) (b)

Fig. 1.

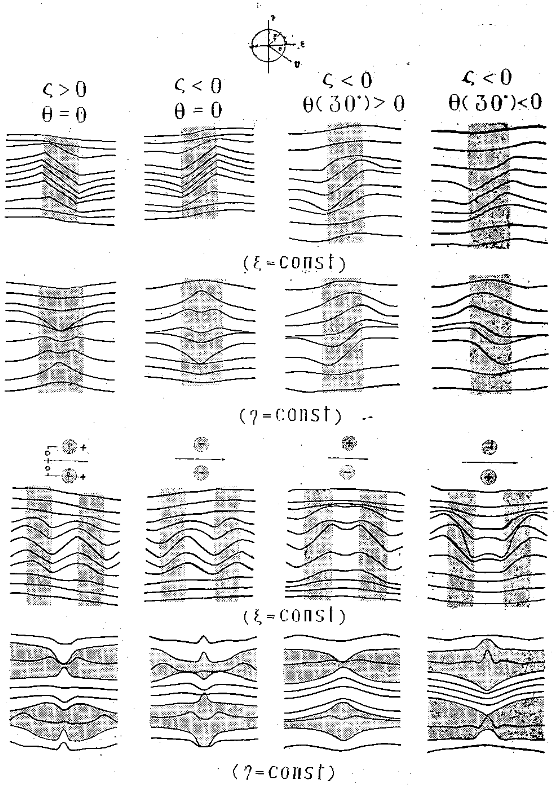


Fig. 2.

orientations of eddies, and Fig. 1 a) corresponds to "$\eta =$ constant" of Fig. 2, and b) to "$\xi =$ constant." Considering the characteristics of these figures, we could decide the existence and position of eddies in Fig. 1, and measure sign and D of each eddy. The observations were made at a sea-side near Chiba, and in an unoccupied area in Tokyo-to.

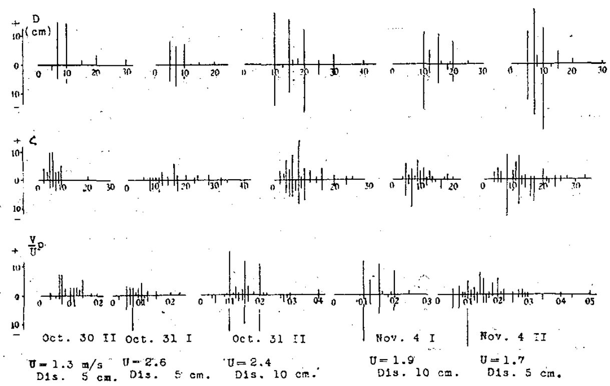


Fig. 3.

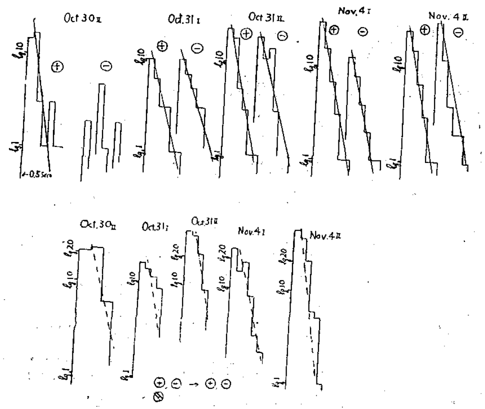


Fig. 4.

Result. The results are shown in Fig. 3[2]. In this Figure Vp is the peripheri-velocity of the eddy. Fig. 4 shows the hystograms of logarithmic numbers of occurance vers "returning time t (die Wiederkehrzeit)" and $\log(Ae^{-\frac{t}{\Theta}})$ for positive → positive, negative → negative

[2] The ordinates in Fig. 3 and Fig. 10 show the numbers of occurance of positive or negative eddies.

and $+ \to -$ or $- \to +$, where Ⓗ is a mean value of $t^{2)}$. These results indicate that positive eddies or negative eddies flow through quite accidentally, however, concerning to the case of $+ \to -$ or $- \to +$, it is difficult to recognize the accidence in the case, though the data were not sufficient in number.

II. Small wind-vane method. (A) In the forgoing method the observational space in each unit and the number of the setting are confined. To avoid the defect we set small wind vanes in 10 rows with the distance of 5 cm. each other, and in a row 12 vanes were set every 3 cm. We photographed them from upside by a cinecamera in every 0.05 sec. ca. Fig. 5 shows a wind vane:—A is made of paper, B is a pin and C a small glass pipe. We set up a nail (E) on a plate,

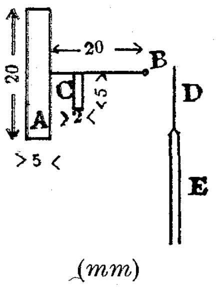


Fig. 5.

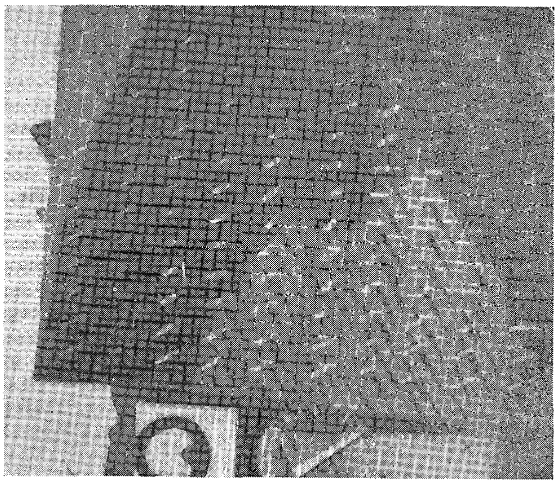


Fig. 6.

soldering a pin (D) to its top, then we put C on E. As it was very small and light, we could not measure its dynamical quantities, but judging from its vibrations in a turbulent domain behind of an obstacle in a wind tunnel, it could be considered for a vane to follow vibration of 100 cycles at least. In the same picture, the meter-face of a hot-wire anemometer and a clock (1 revolution in 10 sec.) were also photographed. The observation was made in a sea bleeze, 0.9 m. high from the ground, at a seaside near Odawara. (Fig. 6. This is the original figure of the picture No. 174 in Fig. 8.) We made equi-deflection maps by measuring the deflection angle at every vane. On the other hand we made some equi-deflection maps by calculation in various orientations of eddies (Fig. 7), and refering to the characteristics of these maps, we could find out the position of eddies in the observed maps. (Fig. 8, Table I). Then we made the spatial variation curves of deflection angles along lines parallel to the main flow direction ($\eta =$ const.) about the center of every eddy (Fig. 9), so we determined the value of Vp/U for every eddy.

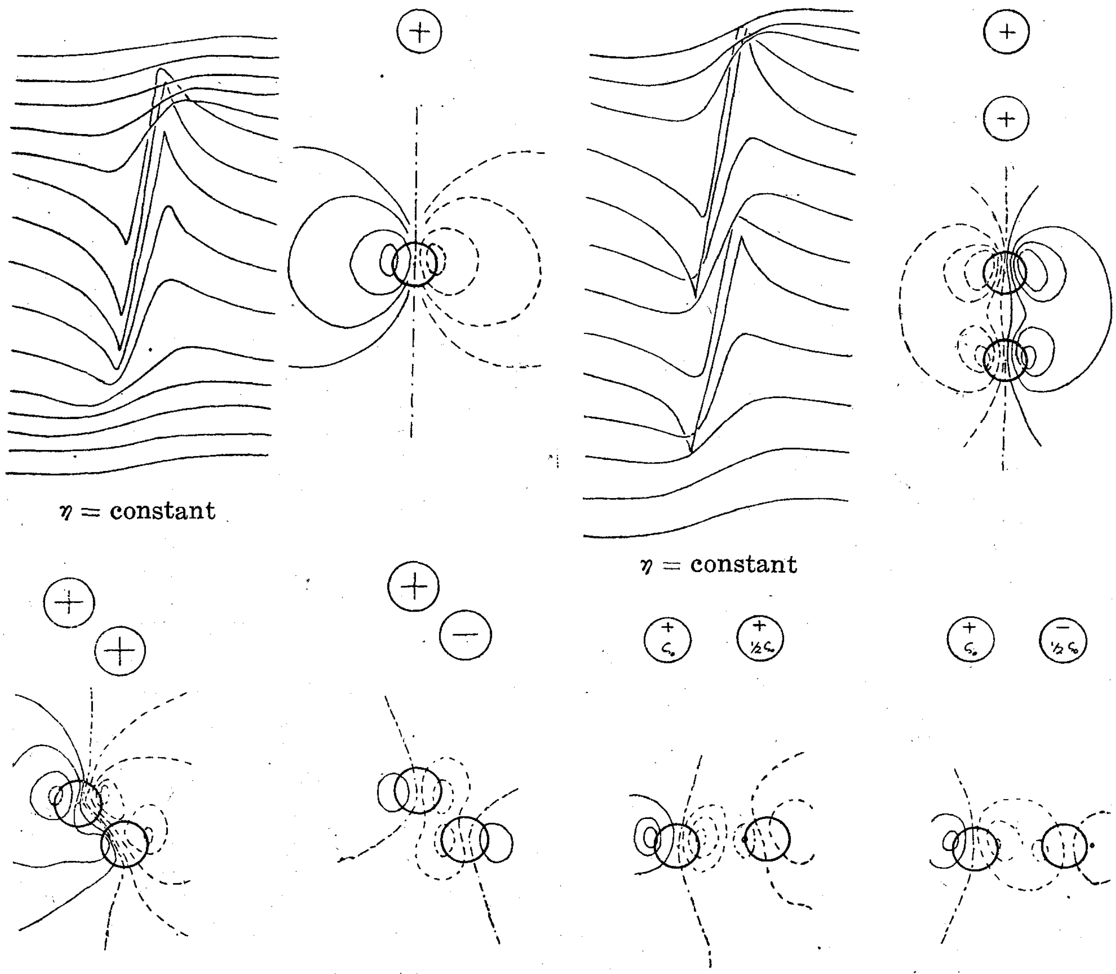


Fig. 7.

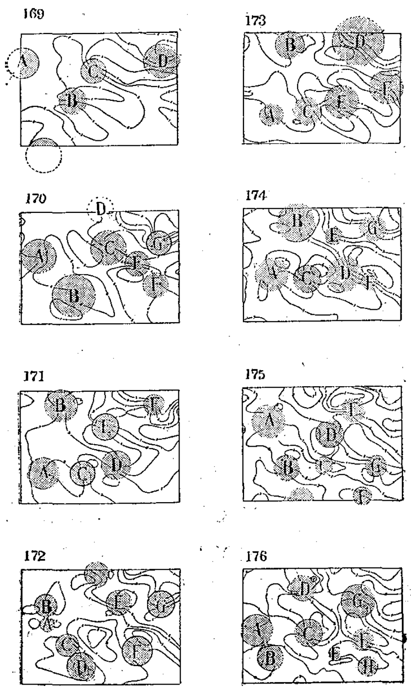


Fig. 8.

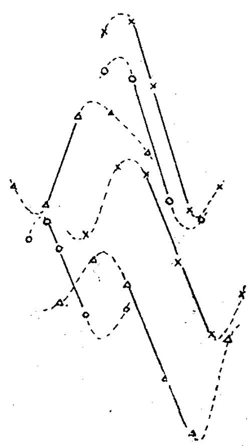


Fig. 9.

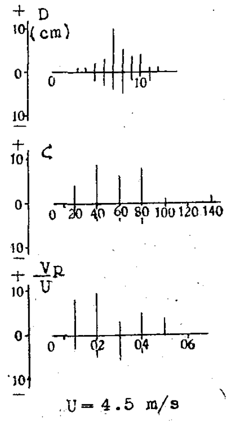


Fig. 10.

Table I.

(D (cm), ζ (rad/sec), Vp/U (%))

169	$U = 4.5$ m/s	$\theta_m = 36.5$	
A	9.5	0.03	6
B	7.0	0.09	32
C	7.5	0.32	76
D	10.0	0.46	82
		$\Delta t = 0.05$ sec.	
170	$U = 5.3$ m/s	$\theta_m = 35.2$	
A	10.0	0.15	14
B	11.5	0.23	42
C	9.5	0.38	84
D	7.0	0.10	30
E	7.0	0.43	130
F	7.5	0.17	48
G	7.0	0.34	102
		$\Delta t = 1.10$ sec.	
171	$U = 5.0$ m/s	$\theta_m = 34.0$	
A	8.5	0.15	34
B	9.0	0.22	48
C	7.5	0,27	72
D	9.0	0.35	78
E	8.0	0.35	88
F	6.0	0.46	154
		$\Delta t = 0.03$ sec.	
172	$U = 4.9$ m/s	$\theta_m = 29.1$	
A	6.0	0.08	26
B	6.5	0.11	32
C	7.0	0.28	78
D	8.0	0.33	80
E	7.5	0.30	78
F	9.5	0.19	40
G	8.0	0.31	76
		$\Delta t = 0.06$ sec.	
173	$U = 4.6$ m/s	$\theta_m = 26.3$	
A	5.5	0.06	20
B	7.0	0.18	36
C	8.5	0.30	64
D	15.0	0.48	58
E	10.0	0.40	94
F	10.5	0.19	34
		$\Delta t = 0.03$ sec.	
174	$U = 4.5$ m/s	$\theta_m = 24.4$	
A	8.5	0.22	46
B	11.0	0.37	60
C	8.5	0.24	54
D	11.0	0.63	114
E	5.0	0.21	76
F	5.5	0.35	124
G	5.5	0.37	124
		$\Delta t = 0.07$ sec.	
175	$U = 4.1$ m/s	$\theta_m = 32.7$	
A	10.0	0.17	28
B	7.0	0.24	56
C	5.0	0.23	64
D	7.0	0.24	56
E	7.0	0.14	32
F	4.5	0.18	64
G	6.5	0.37	94
		$\Delta t = 0.03$ sec.	
176	$U = 3.8$ m/s	$\theta_m = 26.7$	
A	9.0	0.13	22
B	7.5	0.12	24
C	8.0	0.37	70
D	8.0	0.37	70
E	3.5	0.13	56
F	7.0	0.30	64
G	10.0	0.24	36
H	5.5	0.10	28

Result. 1) The results for numbers of occurrence of D, ζ etc. were nearly equal to those obtained by hot-wire method. (Fig. 10). 2) Plotting the positions of max. and min. deflection along $\eta =$ const. around the eddies, we found that these points respectively formed a part of a circle, as in Fig. 11. The result corresponds to the assumption that the eddy has a circular cross section, as is easily verified by calculation. 3) In the graphs of spatial variation of the deflection angles for $\eta =$ const., some observed points which correspond to the inner position of an eddy are arranged on a straight line. (Fig. 9). This result justifies the assumption of $\zeta =$ const. inside of the eddy. 4) From these graphs it is difficult to make sure of the assumption of $\Gamma =$ const. outside of the eddy, because the influence of other eddies

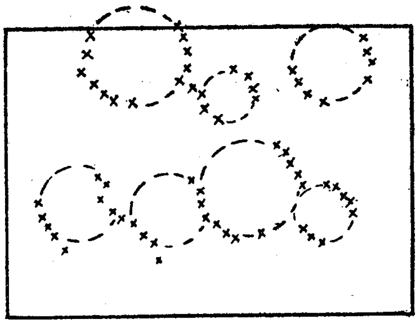


Fig. 11.

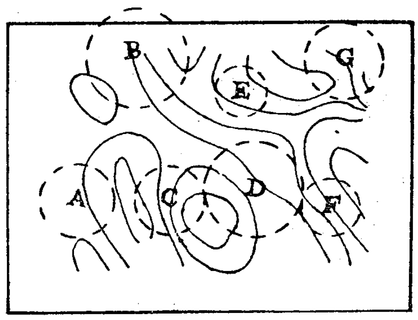


Fig. 12.

are so powerful there. So we made an equi-deflection map by calculation with those assumptions and the data of orientation, sign, D and strength determined by the above method. (Fig. 12). In the comparison of this calculated result to the observed result (Fig. 8 No. 174),

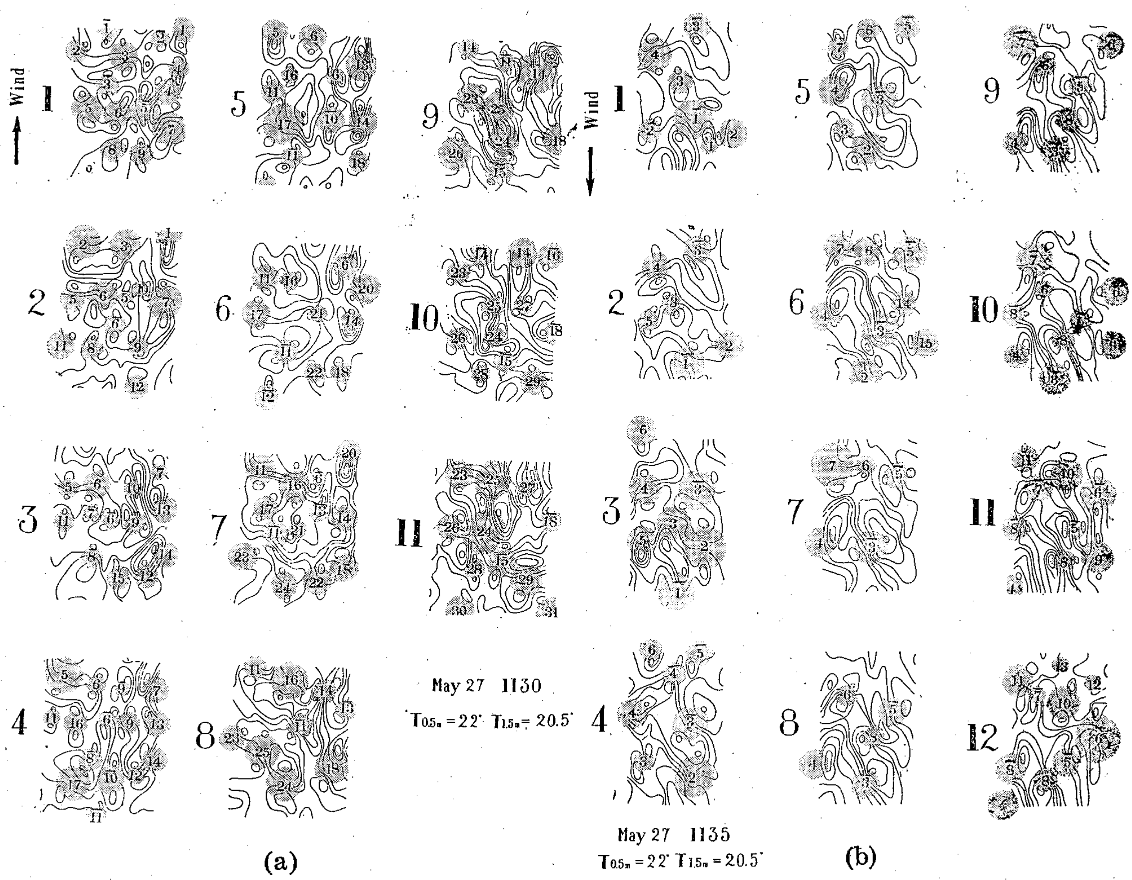


Fig. 13.

both may seem to be the same, though some discords appear in the figure which are presumably caused by the influence from outside of the setting. 5) So we can expect validity in the assumptions of the eddies and the method of determination of it.

III. Small wind-vane method. (B) This method was almost the same to (A) except 20 rows which enabled us to follow the motion of

Table

No. of Pictures		1	2	3	4	5
Wind Speed (m/s)		0.23	0.25	0.30	0.40	0.45
Time (sec.)		3.1	3.3	3.1	3.1	3.1
Sign	No. of Eddies				(*D* (cm)	ζ (rad/sec)
Positive	1			×		
	2	6 60 32 1.9		×		
	3	8.5 55 37 3.1		×		
	4	5 104 42 2.0	×			
	5	10 21 17 1.6	8 50 28 2.5	5.5 66 29 1.6	10 29 23 2.3	
	6	9 33 22 2.1	9 49 33 3.1	10 33 27 2.6	5 81 14 1.6	
	7	10 67 54 5.2	11.5 65 56 6.6	5 63 26 1.7		×
	8	6 25 12 0.6	6 13 4 0.4	*		
	9	6 65 31 1.8	6.5 62 30 2.0	6 107 52 3.0	7 29 16 1.1	*
	10	◎	3 137 31 1.0	45 141 51 2.2	*	
	11		◎	5.5 26 11 0.6	5.5 27 12 0.7	8 26 17 1.3
	12	○		6.5 105 55 3.5	6.5 93 45 2.6	×
	13		◎			8 72 47 3.7
	14		◎			9 111 81 7.1
	15		◎	6 51 25 1.4	*	
	16				8 30 20 1.6	6 10 5 0.3
	17				11 45 40 4.3	12.5 37 38 4.6
	18				○	5 50 20 1.0
	19				○	
	20					○
	21					◎
	22					○
	23					
	24					
	25					
	26					
	27					
	28					
	29					
	30					
	31					
Negative	1		×			
	2	5 18 14 0.7	×			
	3	5 12 28 4.2	*			
	4	9 41 33 1.6	*			
	5	10 32 53 5.1	7 21 23 1.6	*		
	6	◎	6 5 5 0.3	7 9 11 0.7	5.5 21 19 1.0	6 46 46 2.7
	7		◎	4 28 19 2.2	*	
	8		◎	6 33 38 2.2	8 24 31 2.4	9 16 19 2.1
	9			◎	4 39 25 1.0	*
	10			◎	10 15 25 2.5	*
	11				○	6 37 36 2.1
	12					○
	13					
	14					
	15					
	16					
	17					
	18					

[3] cf. Fig. 13 (a) and Fig. 14 (a).

II.[3]

6	7	8	9	10	11
0.50	0.53	0.60	0.70	0.73	0.76
3.0	2.7	2.4	2.5	2.5	2.8

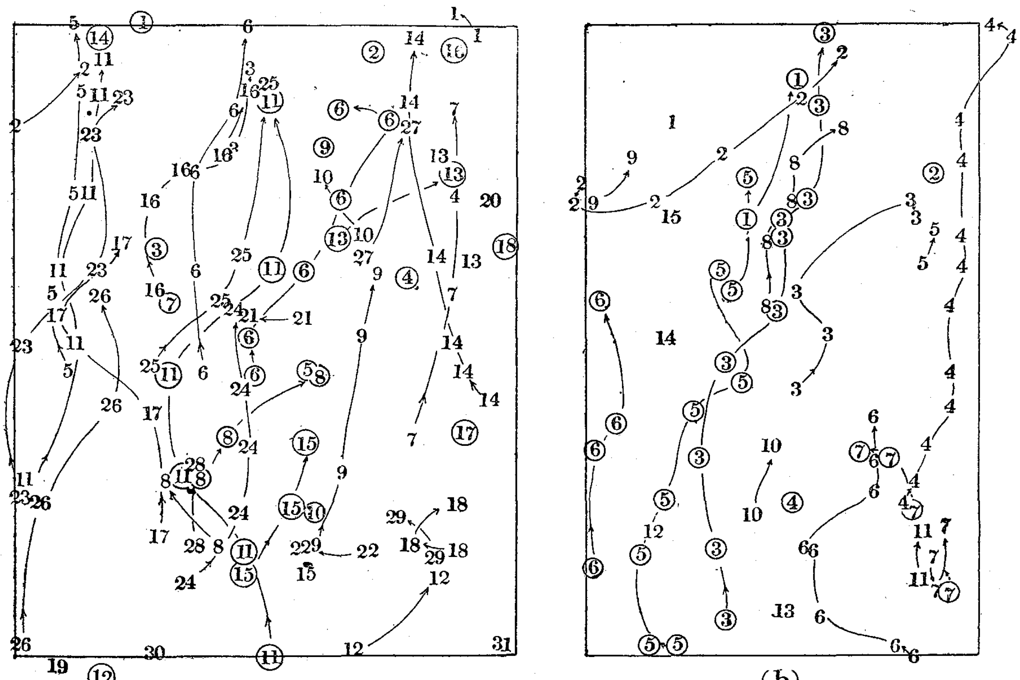
Vp/U (%) $\pi D^2\zeta/4\times10^{-3}$)

×					
×					
8.5 34 24 1.9	10 52 48 4.1				
×			?		
6 110 53 3.0	9.5 37 32 2.8	8 80 67 4.0	14 73 103 11.2		×
6 56 28 1.6	11.5 42 46 4.5	10 30 31 2.3	×		
8 37 25 1.9	6.5 20 11 0.6	*			
6 16 27 1.5	8 48 36 2.4	10 66 69 5.2		×	
*					
	×				
3 17 14 0.4	6 14 8 0.4	*			
5 6 10 0.5	6 48 26 1.3				
○			9 31 28 1.9	6 46 28 1.3	8.5 57 43 2.8
○	10 20 11 1.5	10 50 52 3.9	9 75 69 4.8	8 58 46 2.9	16 39 56 7.9
	◎	10 29 30 2.3	11 46 52 4.4	9 63 56 4.0	10.5 50 47 4.2
	○			6.5 57 32 1.6	9 45 36 2.9
			◎	4.5 46 16 0.6	6.5 50 29 1.7
			○	5.5 40 22 1.0	6.5 20 11 0.7
			○	7.5 42 32 2.0	9.5 72 60 5.0
				○	
				○	

7 35 41 2.7	5 22 21 0.9	×			
*					
6.5 43 47 2.9	10 26 41 4.0	6.5 51 70 3.4	6 17 21 1.0	×	
	*				
◎	6.5 4 5 0.3	6 20 25 1.1	×		
		◎	5.5 50 55 2.3		×
		○	8.8 29 47 2.9	7.5 27 34 2.0	10 35 58 5.1
			○		×
			○		×
			○		×

Table

No. of Pictures		1	2	3	4	5
Time (sec.)		0.13	0.20	0.25	0.35	0.38
Wind Speed (m/s)		1.20	1.24	1.24	1.16	1.16
Sign	No. of Eddies				(*D* (cm)	ζ (rad/sec)
Positive	1	5 10 11 0.2	×			
	2			14 19 37 2.0	11 22 52 2.1	10 22 49 1.8
	3	9 7 15 0.5	5.5 23 27 0.6	12 11 26 1.2	5 27 30 0.5	5.5 18 22 0.4
	4	10 13 36 1.0	7.5 23 34 1.0	10 20 40 1.6		
	5	◎	5.5 14 15 0.3	9 29 53 1.9	×	
	6		○			
	7				○	5 18 21 0.4
	8					
	9					
	10					
	11					
	12					
	13					
	14					◎
	15					○
Negative	1	14 13 31 1.7			×	
	2	6 19 24 0.5	×			
	3		9 16 29 1.0	13 15 38 2.0	10 22 48 1.8	10 25 57 2.0
	4			○	8 10 34 1.0	*
	5			○		
	6					
	7					
	8					



(a) (b)

Fig. 14.

4 cf. Fig. 13 (b) and Fig. 14 (b).

III.[4]

6	7	8	9	10	11	12
0.45	0.49	0.52	0.58	0.62	0.74	0.76
1.11	1.11	1.16	1.31	1.43	1.43	1.49
Vp/U (%) $\pi D^2\zeta/4 \times 10^{-3}$)						
8 25 44 1.5	×					
×						
9 15 30 0.9	5 18 21 0.4	6 45 58 1.0	6.5 30 43 1.1	5 10 9 0.2	*	
10 16 36 1.3	13 11 31 1.4	×				
	◎	5 51 58 1.2	7 44 56 1.6	7 46 62 1.8	7 47 57 1.8	6.5 57 28 1.7
			○		11 10 19 1.0	*
				◎	10 22 39 1.8	10 27 47 2.2
				○	8 16 23 0.8	6 14 14 0.4
					○	4.5 12 9 2.0
					○	3 22 11 0.1
7 24 25 0.6	*					
	*					
—	**—**	**—**	**—**	**—**	**—**	**—**
12 17 46 2.0	11 20 51 2.0	9 36 69 2.3	10 34 65 2.6		×	
11 11 26 1.0	8 17 31 0.9	8 19 33 1.0	7 33 44 1.3	7 27 33 1.0	4.5 5 47 0.9	8 24 43 1.2
		○			10 18 32 1.4	14 18 41 2.7
		○		12 19 39 2.1	9.5 30 49 2.1	6 52 52 1.5
				○		

eddies to some extent. This observation was made at Odawara coast. Analysed map is as Fig. 13.[5]

Result. 1) In most cases the eddies flowed in the direction of the main stream and when they came so near each other that they affected each other to the considerable extent, they moved in special manners respectively. (Fig. 14.)[6] 2) At the instant of formation and extinction of an eddy, the variation of its radius was not remarkable, and during the motion, the value of $\pi D^2\zeta/4$ suggested the tendency that it increased gradually at first then showed some fluctuation and finally diminished gradually. (Table II, III)[7] 3) The life of the eddy was observed to be 0.1～0.6 sec. or more, but considering the observational area was limited, we imagine that it will be generally 1 sec. ca.

Future planning. 1) By using the setting with more vanes, we want to investigate the mechanism of formation and extinction of eddies.

[5] In this figure, the numeral without a bar descriminates every positive eddy, but with a bar negative one.

[6] In this figure, the numeral without a circle descriminates every positive eddy, but with a circle negative one.

[7] In these tables, ○ or × indicates that the eddy flowed into or went out the area, and ◎ or * indicates that it was suddenly formed or became extinct.

2) The eddy with vertical axis is commoner in the space as 1 m. high from the ground than that with horizontal axis, but we intend to investigate the latter also.

Cordially I want to express here my deepest thanks to Messrs. K. Hoshi, H. Tokuue and K. Okunushi for their sincere cooperations.

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