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On the Structure of the Atmospheric Turbulence Near the Ground IV.

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Introduction According to the recent development of the theories of the turbulent flow, the models which serve as the basis for the formulation of the theories become concretely more and more, so the knowledge concerning to the details of the eddies which act as immediate elements of the turbulence becomes more important. Therefore, in order to investigate the shape and the structure of the three dimensional eddies, we made preliminary observations to obtain the fundamental data for the designing of the appropriate observing apparatus[1], and from the crude results, we might infer that: 1) the eddies were rather long comparing to their diameters, 2) they had the tendency that they move inclining forwardly on the whole, 3) for each eddy the strengths were constant at every cross section along its length, and 4) at the ending part, each eddy became obscure in a very short distance.

As the arrangement of the puppus wind-vanes was adopted on trial at that time, these inferences were not so sure, so we carried on the observations in which we distributed the wind-vanes more reasonably following the experience of these preliminary observations.

Method The method of the present observations was the same to the method of the previous observations, except for the adoption of a newly designed frame for the puppus wind-vanes. As the eddies are long comparing to their diameters and are inclining to the vertical line, 8 vanes were set in every 3 cm. in every column (cross wind direction), these 15 columns were set at intervals of 5 cm. from 40 cm.[1] to 110 cm. high from the ground (vertical direction) and 6 these sheets were placed in every 5 cm. (leeward). Therefore, 720 wind-vanes were distributed in a space of a dimension of 21 cm. × 70 cm. × 30 cm. (Fig. 1) These wind-vanes were photographed with a standard cine-camera equipped with a stereo-attachment. When we measured the deflecting angles of the vanes, we set the film to the camera which was in the same state to the photographing one and

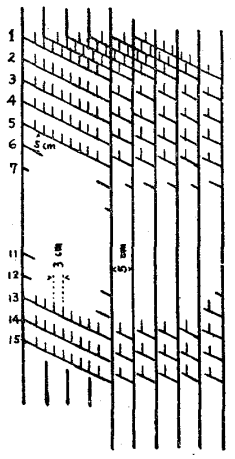

Fig. 1.

1) The variations of the wind-directions in the vertical plane become very small at the places where the height are more than 40 cm. and become almost zero, above 60cm. high[2].

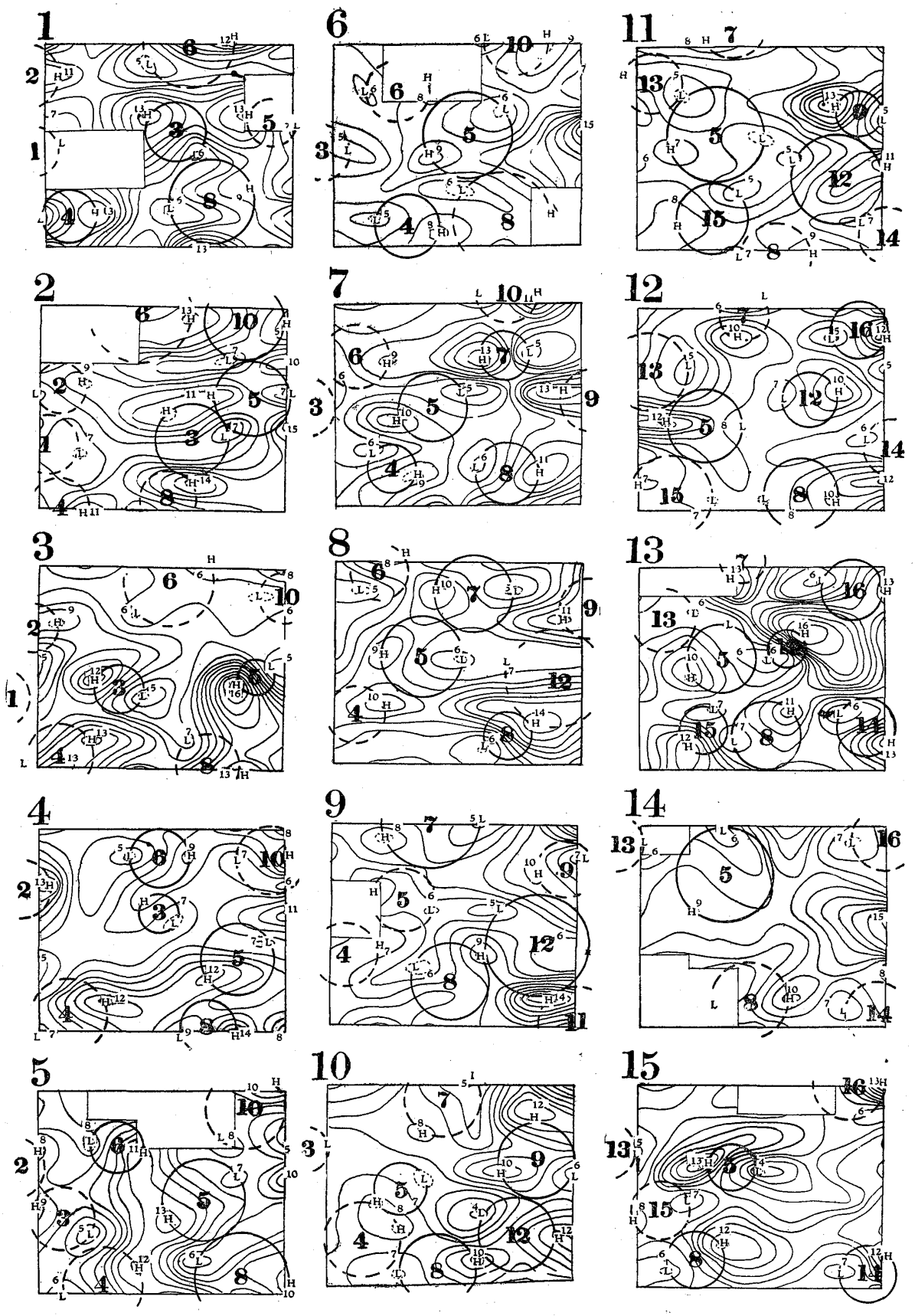

Fig. 2.

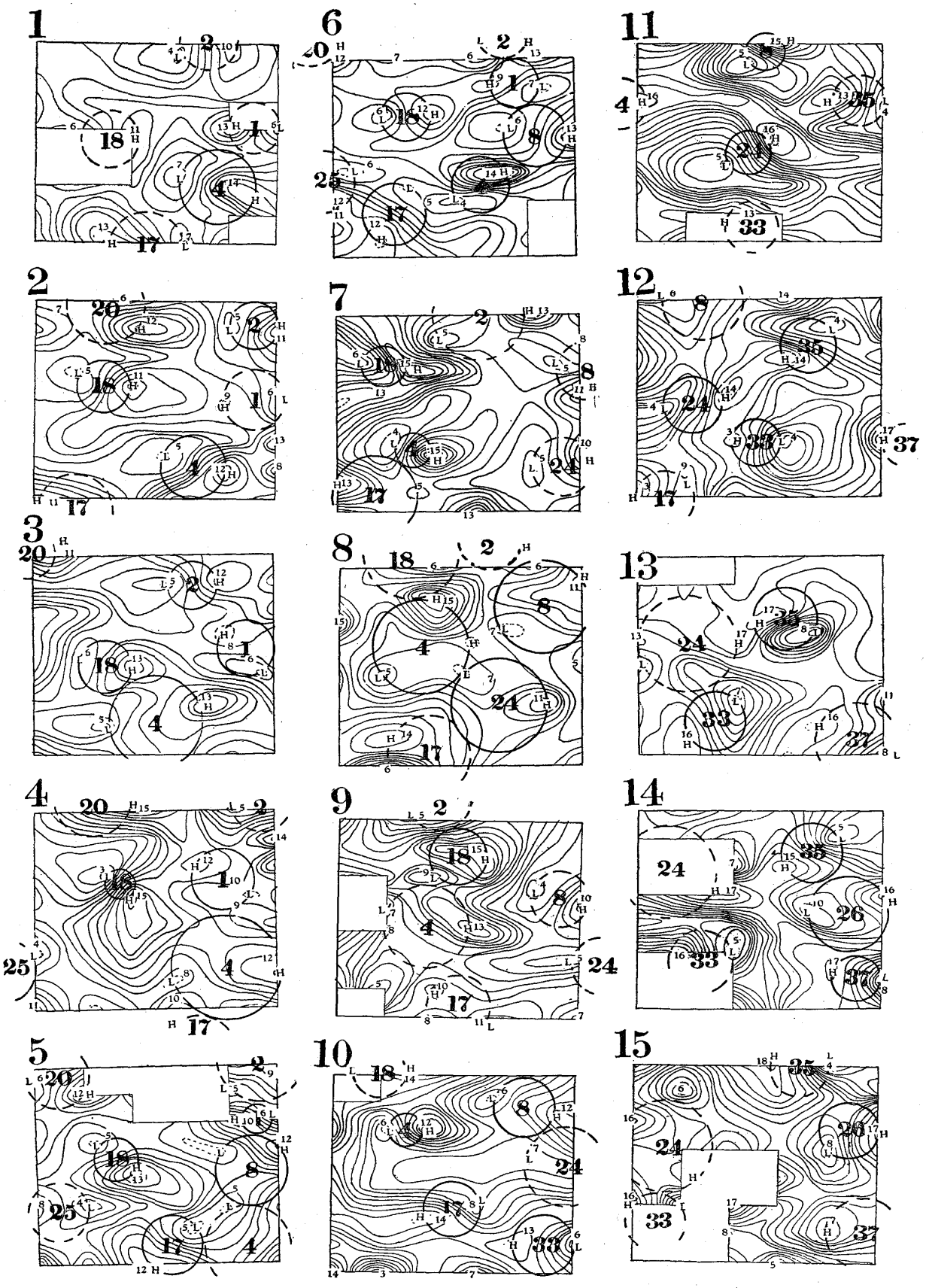

Fig. 3.

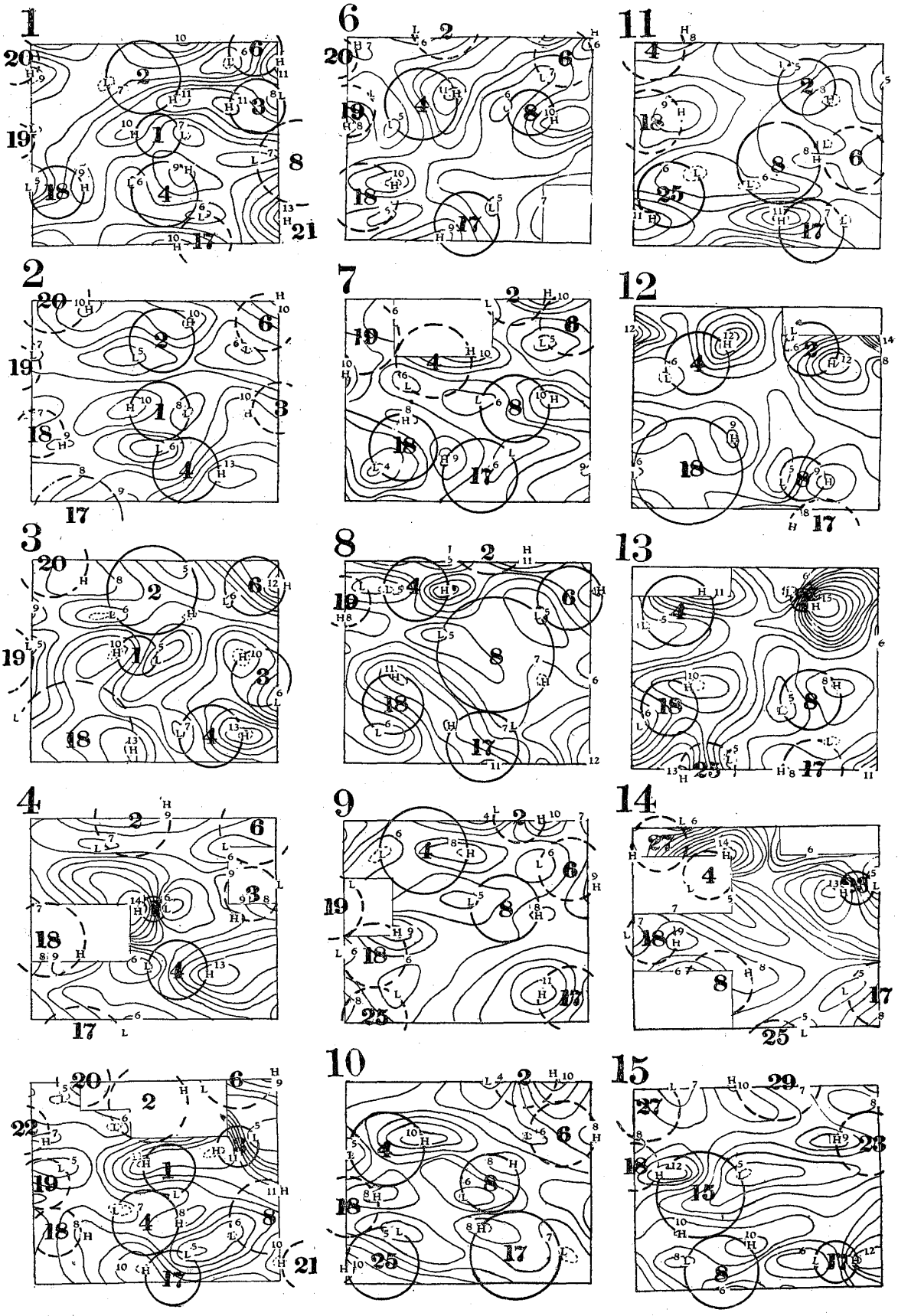

Fig. 4.

then the film was illuminated from the back and we determined the positions where two rays comming from the right and the left half portions of the film coincide each other. With these procedures, we determined the positions of the axes and those of the puppi and measured the wind-directions at each wind-vane. So 1440 points were determined for each film and measured the wind-directions at 720 places. Then we draw the contours of equi-deflecting angles for each horizontal plane and found out the eddies by means of the previous report[3].

The observations were made in a sea breeze at the beach near Katase in the beginning of May, 1954.

Results As the analyses needed much time and labour, only 3 pictures of one observation were examined. (Table 1).

Table 1 May 10 0943, 1954 (Clear)

Picture No.	Wind Velocity (U) (m/sec)	Time (sec)	Time Interval (Δt) (sec)	$U\Delta t$ (cm)
101	1.3	0.528	0.091	11.9
102	1.3	0.619		
103	1.3	0.705	0.086	11.2

Heigt (cm)	50	100	150
Air Temp. (°C)	23.0	22.0	20.0

The results are shown in Fig. 2, 3 and 4[2]. The deflecting angle is measured unticlockwise from the left edge of the observing area. Full lines in these contours are drawn in every 10° ; and for example, 8 indicates that the contour is that for 80°. The mean deflecting angle

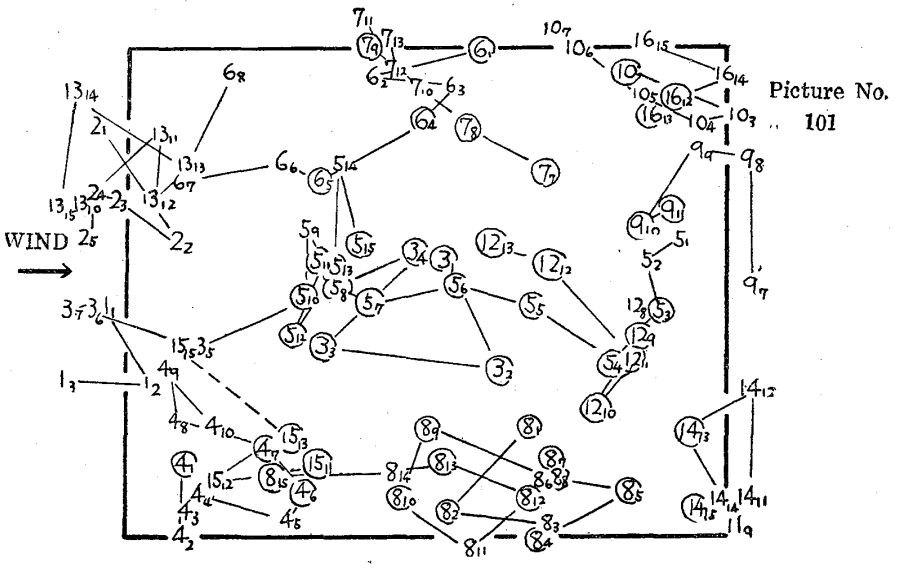

Fig. 5.

2) In these figures odd numbers for the eddies indicate positive eddies and even numbers indicate negative ones. The same numbers in the different figures show the same eddy.

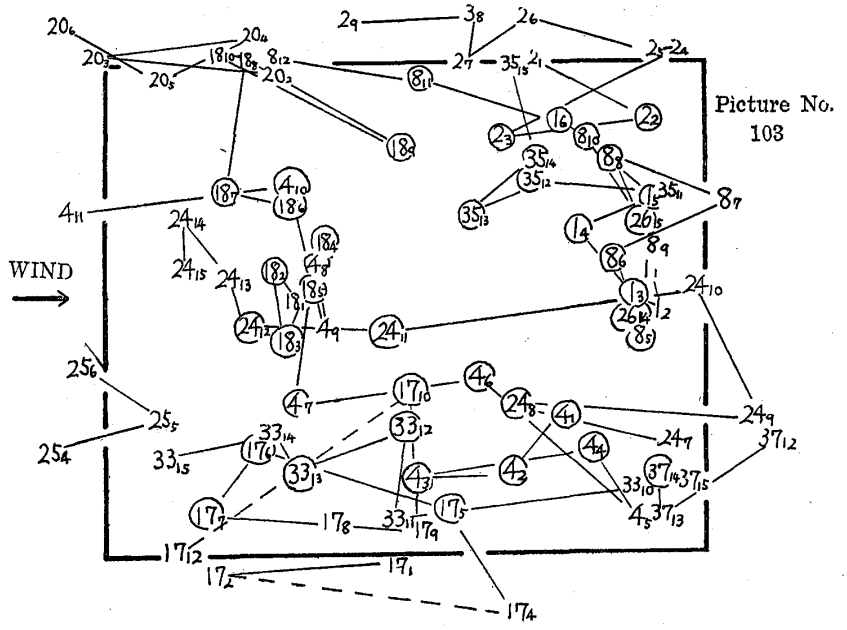

Fig. 6.

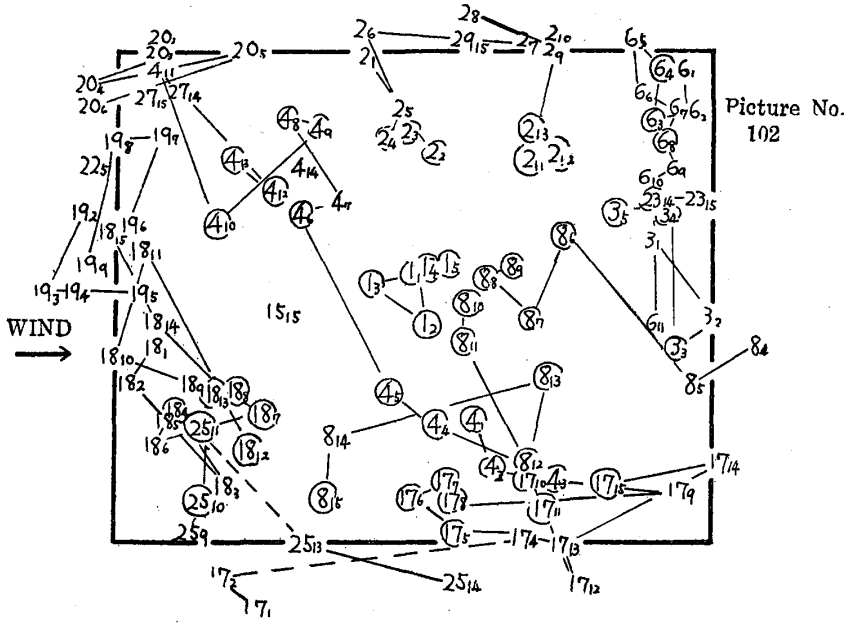

Fig. 7.

was about 90°. Marks H and L show the positions of the miximum and the minimum deflections respectively. When we project the positions of the eddies on different levels onto one plane, we get Fig. 5, 6 and 7[3]. In these figures the mark ○ indicates that the position of the eddy is more reliable than that without the mark, because the positions of both maximum and minimum deflections of it are in the observing area. As the levels become lower, the eddies have the tendency to appear leftward, this means that the eddies generally incline forwardly. When we calculate the angles of the inclination between every adjacent

3) For example, 8_3 means the position of the eddy No. 8 on the 3rd level.

Table 2 a

	No.of Level / No.of Eddy	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	Appeared Length (cm)
101	1	−22.3	35.7														10
	2	−33.4	27.5	10.2	4.6												20
	3	(−25.6)	(56.0)	(−37.2)	61.6	37.9	9.1										30
	4	0	−3.4	−4.6	−36.5	−9.1	(12.9)	36.9	5.8	−20.8							45
	5	14.6	−4.6	(20.8)	(33.0)	(33.0)	(35.0)	(15.6)	11.3	0	(−6.3)	(11.8)	(−16.7)		0	−10.2	70
	6	40.7	−30.9	11.3	(40.0)	15.6	40.7	−23.3									35
	7							(35.0)	(37.9)	−18.8	20.8	−12.4	0				30
	8	(35.7)	−38.7	2.3	(−37.9)	35.7	−4.6	(−0.6)	(45.6)	(11.3)	−30.9	−24.1	(35.0)		19.8	45.0	70
	9							2.3	20.8	26.6	(−13.5)						20
	10		−41.3	19.8	22.8	26.6	10.2										25
	11																
	12								−1.1	(20.8)	(−14.6)	(33.4)	(24.1)				25
	13										−34.2	4.6	−15.6		41.3	5.8	25
	14											−3.4	26.6		−12.9	9.6	20
	15											42.6	−35.8		/	/	20
	16												6.8		−31.8	34.2	15

Table 2 b

	No.of Level / No.of Eddy	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	Appeared Length (mc)
102	1	(−5.8)	(24.7)	(−24.7)	(−11.3)												20
	2	(−30.1)	(12.4)	(7.4)	−6.8	15.6	−53.7	28.4	−36.1	−1.1	7.4	(−7.4)	(10.2)				60
	3	−25.6	16.7	(2.3)	(20.8)												20
	4	(−10.2)	(−26.6)	(43.8)	(18.3)	(34.6)	−18.3	20.8	(−14.0)	(40.3)	24.2	−39.7	(15.6)	30.1			65
	6	−4.6	14.6	(−3.4)	16.7	−5.8	−14.6	6.8	−4.6	11.3	−2.9						50
	8				28.8	45.0	(15.6)	(18.3)	(−10.2)	(20.8)	(0)	(−25.6)	(−10.2)	(61.0)	(2.9)		55
	15																
	17	14.6	/	/	27.9	(19.8)	(−15.6)	(−3.4)	−62.0	50.9	−9.1	−11.8	8.5	−51.6	43.8		70
	18	11.3	−37.9	19.3	4.0	5.8	−40.7	(11.3)	17.7	33.0	−10.2	−40.0	(16.7)	23.7	20.3		70
	19		15.6	−10.2	−30.9	6.8	−19.3	20.8	11.3								35
	20		1.7	32.6	−53.5	52.0											20
	21				4.6												5
	22																
	23														−15.6		5
	25									−8.5	(0)			−52.0			25
	27													12.9			5
	29																

Table 2 c

	No.of Level / No.of Eddy	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	Appeared Length (cm)
103	1	−4.6	12.4	(23.3)	(30.9)	(37.9)											25
	2	-43.2	(50.7)	−56.0	10.2	47.2	27.9	−4.6	46.1								40
	4	(23.3)	(37.9)	(−56.0)	−20.3	52.4	(56.9)	(−9.1)	−3.4	12.4	61.4						50
	8					(12.9)	−42.9	42.9	−18.3	30.1	(53.1)	49.7					35
	17	56.3	/	/	28.8	(56.8)	(23.2)	−45.0	−35.0	2.9							45
	18	9.1	(−4.6)	−18.3	(7.4)	(6.8)	(26.6)	−7.4	−51.1	56.0							45
	20		56.3	−52.0	36.9	40.7											20
	24							52.4	−63.5	25.6	68.8	(47.7)	7.4	19.3			40
	25				42.6	33.0											10
	26															(5.8)	5
	33										63.3	−4.6	(40.7)	11.3		40.7	25
	35											48.5	(25.6)	(29.3)		10.2	20
	37												42.9	2.3		−12.9	15

level, we get Table 2a, 2b and 2c, in which the angles are measured from the upward vertical line and are positive when the eddies incline leeward. These tables show that the eddies have meandering shapes which we also have observed in the experiments of vortices[4]. The total mean for all eddies is $+6.9°$. In these tables mark ( ) shows that the value is more reliable than that without the mark, because the positions of both ends are sure. The mean of these values is $+7.9°$. So we can conclude that the eddies generally move inclining forwardly about 10°. This result is consistent with that reported in the preliminary observations[5], though the value differs to some extent.

In the Fig. 5, 6 and 7, there are many eddies with the same numbers, this means that the eddies are long. Because that the eddies inclined or bended and the dimension of the observing space was not sufficiently wide, there were only few cases in which both ends of an eddy were in the observing space, so it was difficult to measure the accurate length of the eddies. However, almost all eddies appeared on 3 or 4 levels, namely appeared for 10 or 15 cm. at least, and we measured even the eddies more than 70 cm. in length (Table 2 and 3[4]). As the diameters were generally 5~10 cm., the lengths were several times or more than ten times as large as the diameters.

When an eddy was being noticed until one level but vanished from the next level, the mode of the disappearance was very rapid. (Picture No. 101: $4_{10\text{-}11}$, $7_{6\text{-}7}$, $9_{11\text{-}12}$, $12_{13\text{-}14}$, $15_{10\text{-}11}$, $16_{11\text{-}12}$; Picture No. 102: $1_{5\text{-}6}$, $3_{5\text{-}6}$, $4_{14\text{-}15}$, $6_{11\text{-}12}$, $15_{14\text{-}15}$; Picture No. 103: $1_{6\text{-}7}$). So we can consider that the eddies have lumpy shapes.

We noticed in some cases that an eddy appeared in the position of a level where an eddy with the opposite sign vanished. These cases were experienced in the former observations[6]. (Picture No. 101: 4_{10}–15_{11}, 9_{11}–16_{12}; No. 102: 4_{14}–15_{15}, 6_{12}–23_{14}). However, the number of these cases are not many, we want to consider these mechanisms in future.

For each eddy we calculated the diameter, the vorticity and the strength and we get Table 3. For an eddy in one picture, namely at the same instant, the diameter and the vorticity on each level often varied considerably, but the strengths were nearly constant. However, some eddies showed the deviations on some levels (Picture No. 101: 3_4, 4_1, 5_{10}, 5_{11}, 12_{12}; No. 102: 3_4, 4_4, 4_5, 4_9; No. 103: 4_8, 24_8), these results were interpreted that the angles of deflections of the eddy were

4) In this table the mark ◎ indicates that the eddy comes in the observing area and ⊀ indicates that the eddy goes out the area; A means the appearance and V means the vanishment of the eddy; / means that the existence of the eddy is noticed, but these values cannot be calculated, because the positions or values of the extremum deflections are undetermied.

Table 3 a

Picture No. 101

D (cm)

ζ ($\times 10$ rad/sec)

S (rad/sec cm^2)

No. of Eddy \ Level	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
1				✳											
2						✳									
3	6 6.9 19.5	7.5 3.6 15.8	5 8.3 16.2	4 2.1 2.7				✳							
4	5.5 5.8 13.7					6.5 3.0 9.9	5 4.0 7.7				V (cf. 15)				
5		8 3.0 15.2	3.5 25.2 24.5	7.5 3.5 15.0	8.5 3.4 19.3	9 2.1 13.2	7 4.6 17.6	8.5 2.6 12.5		5.5 1.7 4.2	1.0 7.8 6.5	7.5 3.8 16.6	7 3.4 13.1	1.0 2.1 16.1	4.5 11.6 18.3
6				6 3.9 11.0	5.5 5.4 12.9				✳						
7						A	5 9.2 18.1	8 3.5 17.4	1.0 1.8 14.4				✳		
8	9 2.3 14.2			6 4.4 12.7	9.5 2.6 18.5		6.5 4.8 16.0	5 9.2 18.0	8 2.6 13.3	8 3.3 16.8		7.5 2.8 12.4	7 3.3 12.6		6 6.0 17.0
9						◎				8 3.3 16.3	5 10.5 20.6	V (cf. 16)			
10	◎	8 4.8 12.2						✳							
11								◎		✳					
12							◎		11 2.5 23.6	8 5.6 28.3	9.5 3.9 27.9	5.5 4.0 9.5	3.5 21.2 20.6	V	
13									◎						
14										◎			6 7.9 22.1		6 5.4 15.2
15									(cf. 4) A		7.5 2.8 12.3		5 5.5 10.7		
16										(cf. 9) A		6 6.7 19.0	6.5 5.8 19.3		

Table 3 b

Picture No. 102

D (cm)

ζ ($\times 10$ rad/sec)

S (rad/sec cm^2)

No. of Level / No. of Eddy	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
1	2.5 19.7 9.7	6 2.6 7.7	4 7.4 9.2	5 3.7 7.2	5 3.7 7.3	V									
2		6.5 3.8 12.5	9.5 1.5 10.9	8 3.1 15.6							6 3.6 10.2	5.5 6.6 15.6	2.5 25.8 12.6	⊛	
3			6 3.7 10.5	5.5 4.1 9.8	4 10.4 13.0	V									
4	6 7.9 22.1	6.5 6.8 24.5	6.5 5.6 18.9	7 2.6 10.2	7 2.0 7.7	7.5 4.5 20.2		6.5 6.3 20.9	9 2.6 11.5	8 4.3 21.4		6.5 6.0 20.0	7.5 4.7 19.5		V (cf. 15)
6			6 6.2 17.5	5.5 5.6 13.2				6.5 3.9 13.0				V (cf. 23?)			
8			◎			4.5 5.7 8.9	7 2.8 10.7	12 0.8 8.7	7 2.5 9.3	6 2.8 7.7	8.5 1.7 9.5	4.5 5.7 9.1	6.5 3.0 9.9		7.5 2.0 8.9
15													(cf. 4) A		9 3.2 20.3
17					5.5 5.6 13.3	7 3.4 12.8	8 2.4 11.9	7.5 3.0 13.2		9.5 1.4 10.3	6.5 3.8 12.7				4.5 8.5 13.5
18				5.5 5.4 12.7			7 3.1 11.9	6 5.0 14.0				11 1.4 13.1	6 5.0 14.3		
19	◎														
20	◎						⊛								
21			◎			⊛									
22				◎		⊛									
23													A? (cf.6)	3.5 13.5 13.0	
25								◎		8 3.6 17.9	7 4.5 17.2	◎⊛			⊛
27													◎		
29														◎	

Table 3 c
Picture No. 103
D (cm)
ζ ($\times 10$ rad/sec)
S (rad/sec cm^2)

No.of Level / No. of Eddy	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
1			6 2.4 6.8	6.5 2.4 7.9	3 10.8 7.7	5 4.3 8.5	V								
2		5 7.6 14.9	5 8.3 16.4							✳					
4	8 5.9 29.7	6 9.0 34.7	10 4.6 36.2	12 2.7 30.2		6 11.6 32.8	3.5 36.3 34.9	12.5 1.1 13.7		3.5 38.1 36.8		✳			
8				◎	7.5 4.9 21.7	6.5 7.3 24.1		10 2.2 17.4		6.5 6.5 21.5	4 26.7 25.3		✳		
17					6.5 6.1 20.2	6.5 5.9 19.7	8.5 3.8 21.6			6 6.5 18.4			✳		
18		5.5 7.0 16.7	5.5 6.7 16.0	3 7.5 17.9	4.5 10.4 16.5	5 7.0 13.7	4.5 14.5 22.8		6 6.4 18.3		✳				
20	◎						✳								
24						◎		10 2.4 19.0			4.5 20.3 32.1	6 13.0 37.0			
25			◎				✳								
26													◎	8 4.7 24.0	6 8.9 25.2
33									◎	6.5 7.3 24.3		5 13.5 26.6	6.5 8.5 28.3		
35										◎		6 12.8 36.3	6.5 8.9 29.0	6.5 11.0 36.7	
37											◎			5 12.7 25.0	

affected with the other eddies which were near to the former one.

Owing to the restriction caused by the measuring technique, the observing space was not so wide, we could not notice any particularity concerning to the time variations.

Conclusion With the present observation, we confirmed the results inferred from the former observation and we could make clear the three dimensional shape of the eddy in the atmospheric turbulence in the main.

To measure the wind-directions very densely, in three dimensional space and in time, is very difficult and, using the apparatus which we can use now, the present arrangement is considered as nearly the limit, but we are intending to improve the arrangement as possible as we

can, and to measure the diameter, the vorticity and the strength more accurately, and to make clear the time variations of these quantities.

To carry out these observations, many assistances were offered by scholars of Ochanomizu University. Miss. M. Matsuda exerted herself from the beginning to these observations and carried out very laborious measurements and analyses of the data. Here the author wants to express his deepest thanks to these persons.

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