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Diffusion Experiments Using Balloons

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Abstract

Rubber balloons with cards, 48,900 in total, were released 16 times from 13 places in August 1960. The collected cards which informed the conditions of being captured and the states of balloons were 11,152. The data of 7 experiments which are suitable for detailed investigations were analysed. In these experiments, the diffusion phenomena up to 450 km leeward were observed.

Lateral standard deviations were calculated and parameters for lateral diffusion were determined. Examining these results together with those of other experiments, it is noticed remarkably that the parameters vary considerably in each experiment. This fact can be explained by the considerations that the diffusion phenomena depend upon the heights of layers where the phenomena take place.

The detailed examinations show that the curves of standard deviations versus leeward distance have some peaks and valleys. It can be explained by the considerations made in the analyses of data of the Tokai experiments.

Introduction

There have been only a few experiments of atmospheric diffusion, because they are very laborious and expensive. The experiments carried out hitherto were those on a scale of few km leeward, so there has been scarcely any datum of the diffusion experiment on a scale of the order of 10^1 or 10^2 km, except the pioneering work of Saito and Yoshitake who investigated the diffusion by using small balloons up to 100 km leeward.[1)] However, for the problems of casualties caused by industrial wastes, especially by the radioactive ones, it is necessary to consider the diffusion at least 10 km leeward from the source.

A series of diffusion experiments using rubber balloons was carried out in August 1960 by the Meteorological Association under the sponsorship of the Asahi Beer Co. The releasing of the balloons was done chiefly by the members of the Aerological Department, Japan Meteorological Agency, and the members of the Research Group of the Atmospheric Turbulence cooperated with them. The author took part in for planning and analysis of the experiments. As some of the experiments have been analysed, those results are reported in this paper.

Balloon

Two kinds of balloons were used, one of them was pilot balloon for aerological observation and the another one was rubber balloon for advertisement. The pilot balloons were chiefly 20 g in weight, and only those which were used at the summit of Mt. Fuji were 30 g; and the balloons for advertisement were 10 g.

In order to prevent the balloons to ascend too high, a plastic 'leak tube' whose weight was 10 g (Fig. 1) was inserted to the inlet portion of each ballon to promote the out flow of hydrogen. Any such a tool did not used to the balloon for advertisement and the decrease of the lift was caused only by the leakage of hydrogen through the rubber film of the balloon.

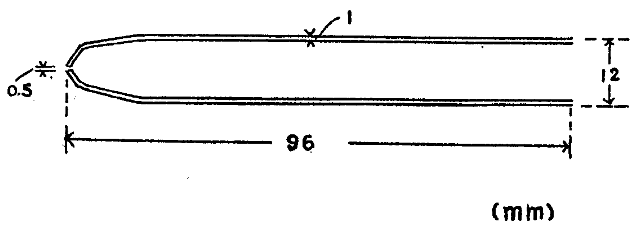


Fig. 1. Leak tube.

Two cards in a thin polyethylene bag (6 g in total) were attached to each balloon, and one of the cards was used for the explanation of the purpose and the significance of the experiments, and the another one was asked to be sent back after filling required informations as follows:—(Fig. 2) 1) Name, age, occupation and address of the captor. 2) Date and time of the capture. 3) Location. 4) Capturing conditions; whether the balloon was floating or already landed (or hanged on trees etc.) 5) The state of the balloon; whether it was complete or already broken.

The cards were grouped in every 100 sheets and on each of them group number was printed.

Releasing

The general schemes of the experiments are summarized in Table 1. The releasing locations were selected in 13 places including the summit of Mt. Fuji* and the number of the experiments was 16. Total number of the balloon was 48,900. The rate of release of the pilot balloons was about 300 balloons per hour and that of the balloons for advertisement was about 1,000 balloons per hour.

In order to release so many balloons in a rather short time (one hour or so), it was difficult to measure the buoyancy of each balloon by buoyancy balance, so the diameter of the balloon was determined by special gauge. On the other hand, as many balloons were used,

* The height is 37,878 m above sea level.

気流調査カード

________組

㋑風船をひろった場所 (なるべくくわしく書いてください)	(例: ○県郡△村番地先の路上)	
㋺その日時	昭和35年　月　日　時　分ごろ	
㋩落下の状態 (○印をつけてください)	① ちょうどその時空から落ちてきた	② すでに地上などに落ちていた
㋥風船の状態 (○印をつけてください)	① 破れていた	② 破れていなかった

㋭あなたのおところ			
㋬あなたのお名前		㋣おとし	才
㋠ご職業 (学生さんの場合は学校名と学年)			

Group No.

Location		
Date and Time		
Capturing Condition	① Floating	② Landed
State of Balloon	① Broken	② Complete

Adress of Captor			
Name		Age	
Occupation			

Fig. 2. Card.

the diffusion of these balloons corresponded to that from a continuous point source.

The number of cards which were sent back after filling the necessary informations was 11,152, so the recovery percentage was 22.8.

Though the scientific interests may be directed to the diffusion phenomena in every height, the practical interests are chiefly directed to those in lower heights, for example, the diffusion from a stack is usually considered within several hundred meters high utmost.

The vertical trajectory of the balloon has generally its maximum height of about several km or more than 10 km, but from the practical points of view, these heights are not suitable for the diffusion experiments. We used the leak tubes in some experiments, but even such a treatment anticipated us the unsatisfactory results. However, we had no time to prepare to adopt more adequate method, and any attempts to measure the ascending heights of the balloons were unable to carry out.

Table 1. General scheme.

Location	Date	Weight (g)	Diameter (cm)	Number of balloons				Number of collected cards		
					Sum (20 or 30 g)	Sum (10 g)	Total		Sum for each run	Total
Fuji	Aug. 7 AM 0630~0920	30 (L) 30 (L) 30 (L) 10	47 50 52 41	200 200 100 400	500	400	900	34 33 19 25	86 25	111
Omori I	Aug. 14 AM 0800~0900	10	37	2,000		2,000	2,000	855	855	855
Daita	Aug. 14 AM 0740~1040	10 10 10	40 32 37	1,000 600 900		2,500	2,500	124 340 601	1,065	1,065
Omori II	Aug. 15 PM 1350~1530 1200~1400	10 10 20 (L) 20 (L)	37 37 41 42	500 2,500 1,200 1,200	2,400	3,000	5,400	63 520 538 344	583 882	1,465
Ochanomizu Univ. I	Aug. 16 AM 0945~1125	10 10 10	37 30 40	700 900 900		2,500	2,500	230 341 351	922	922
Futago	Aug. 17 PM 1330~1415	10	37	1,000		1,000	1,000	215	215	215
Komatsugawa	Aug. 17 PM 1555~1645	10 10	37 30	1,200 300		1,500	1,500	137 43	180	180
Tokyo Tower	Aug. 23 AM 0910~1015 1045~1115	10 10	31 31	700 300		1,000	1,000	445 114	559	559
Ochanomizu Univ. II	Aug. 27 PM 1340~1620	10 (L) 10 20	37 37 60	1,200 300 100	100	1,500	1,600	451 62 4	513 4	517
Sendai	Aug. 14 AM 0825~0925 PM 1500~1544 AM 0925~1050 PM 1240~1344	20 (L) 20 (L) 10 10	41 42 — 37	900 600 1,200 1,300	1,500	2,500	4,000	223 254 180 187	477 367	844

Nagoya (Met. Obs.)	Aug. 14 AM 0830~0915	20 (L) 20 (L) 20 (L)	39 41 42	400 200 200	800			129 59 44	232	
	PM 1515~1600	20 (L) 20 (L) 20 (L)	39 41 42	300 200 200	700		1,500	96 50 46	192	424
Nagoya (Race-course)	Aug. 14 (AM~ PM)	10	37	5,000		5,000	5,000	1,247	1,247	1,247
Nishinomiya I	Aug. 14 AM 0800~0906	20 (L) 20 (L) 20 (L)	41 42 43	300 300 300	900		900	87 78 79	244	244
	PM 1600~1640 1000~1425	20 (L) 20 (L) 20 (L) 10	43 42 41 37	200 200 200 2,500	600	2,500	3,100	85 68 65 385	218 385	603
Nishinsmiya II	Aug. 18 0900~1530	10 10	37 37	3,500 1,500		5,000	5,000	306 151	457	457
Kobe	Aug. 19 AM 1030~1130 1130~1220 1220~1240	10 10 10	37 37 37	1,500 500 500		2,500	2,500	231 85 73	389	389
Hakata	Aug. 21 AM 0830~0930 (AM)	20 (L) 20 (L) 20 (L) 10	41 42 43 37	300 300 300 2,500	900	2,500	3,400	142 62 55 325	259 325	584
	PM 1345~1430 (PM)	20 (L) 20 (L) 20 (L) 10	43 42 41 37	200 200 200 2,500	600	2,500	3,100	105 47 34 278	186 278	464
					9,000	37,900	48,900			11,145

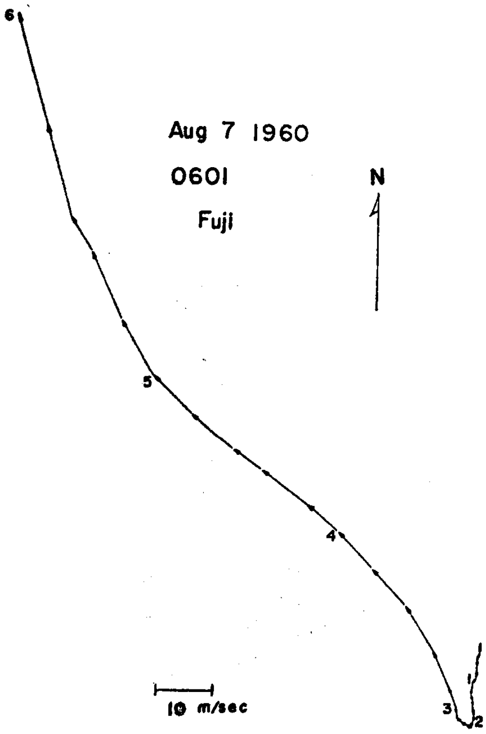


Fig. 3-1a.

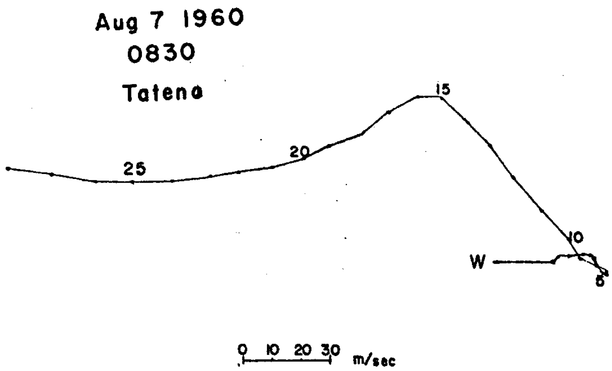


Fig. 3-1b.

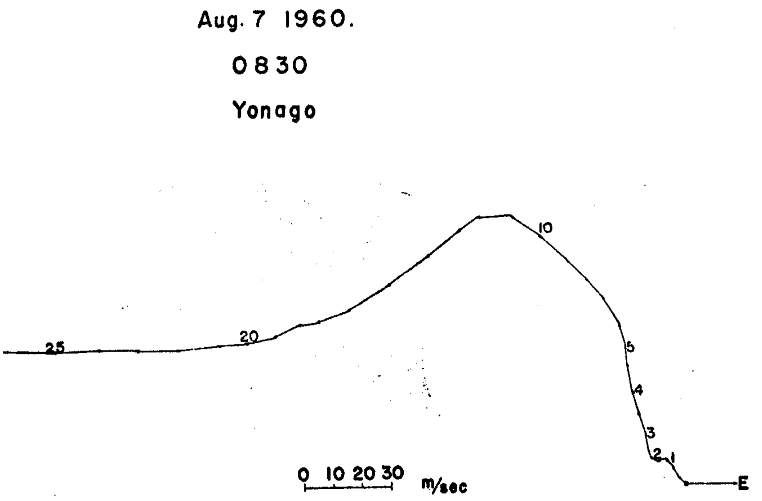


Fig. 3-1c.

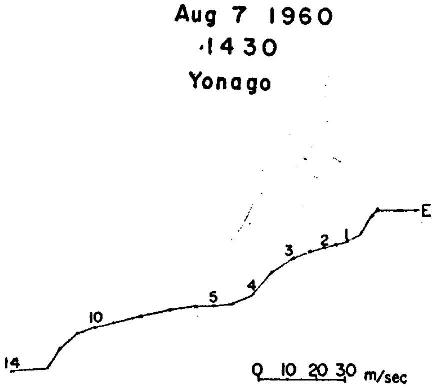


Fig. 3-1d.

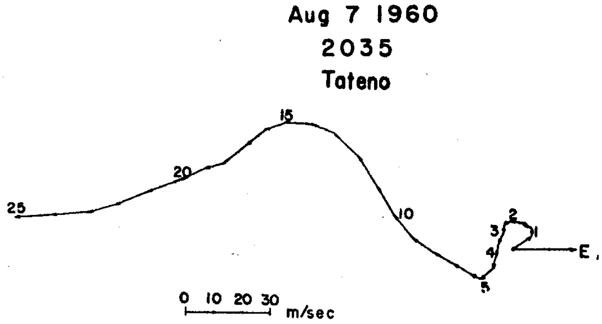
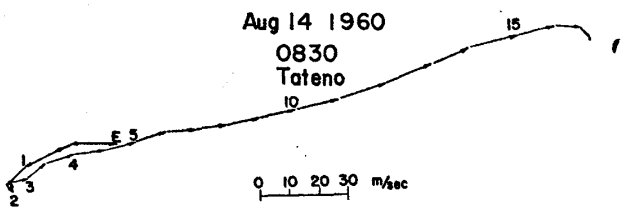


Fig. 3-1e.



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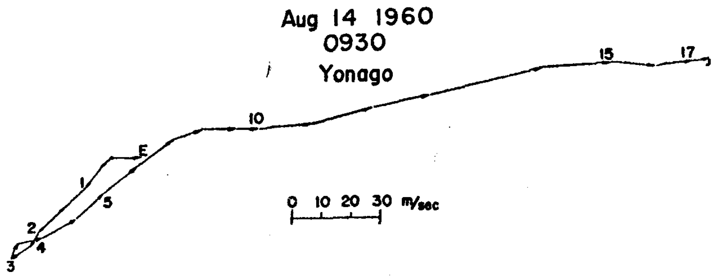


Fig. 3-2b.

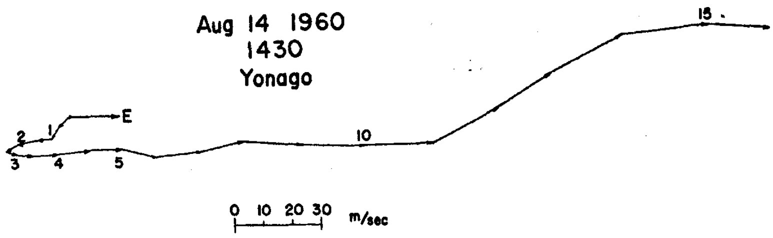


Fig. 3-2c.

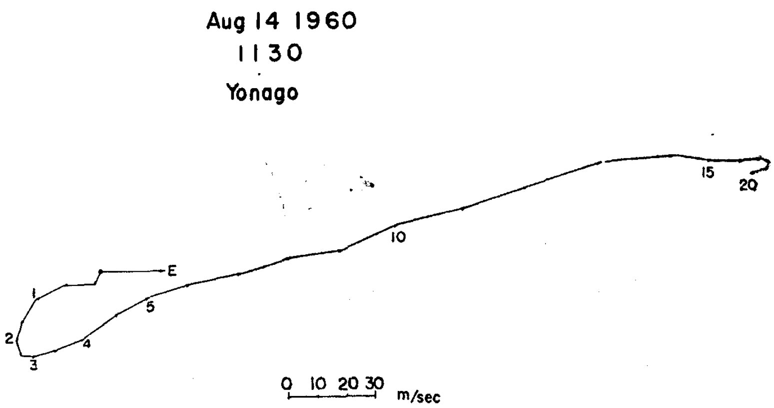


Fig. 3-2d.

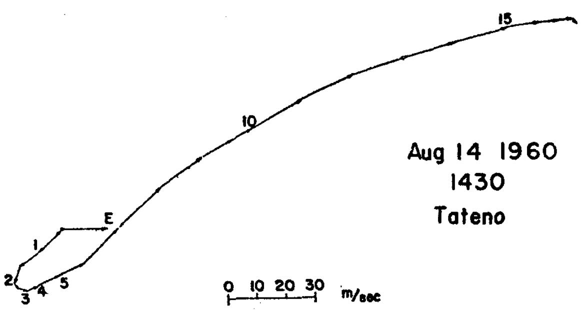
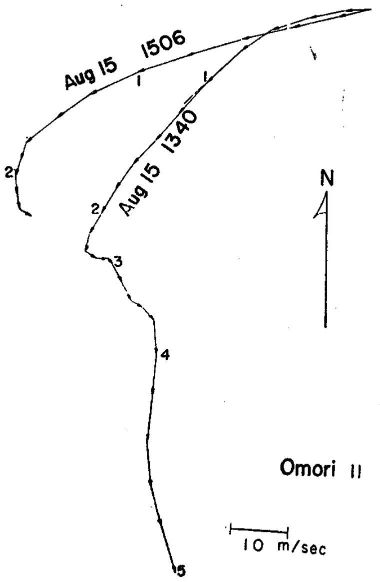


Fig. 3-2e.



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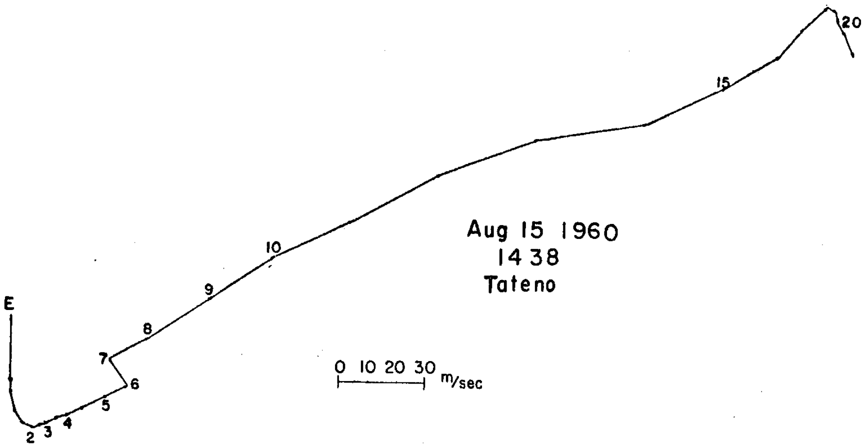


Fig. 3-3b.

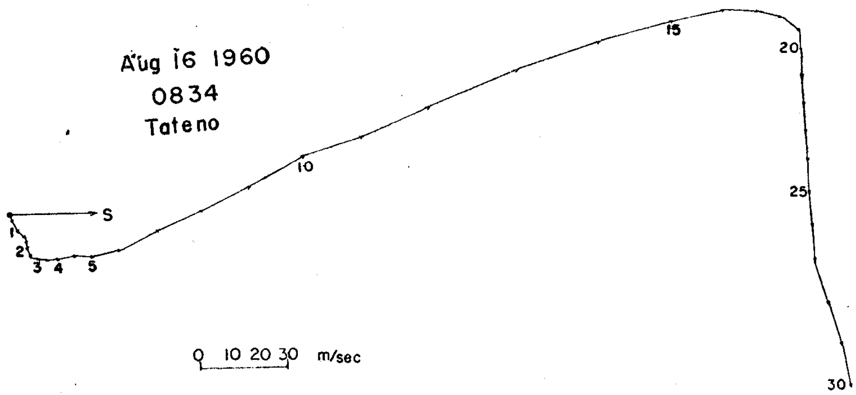
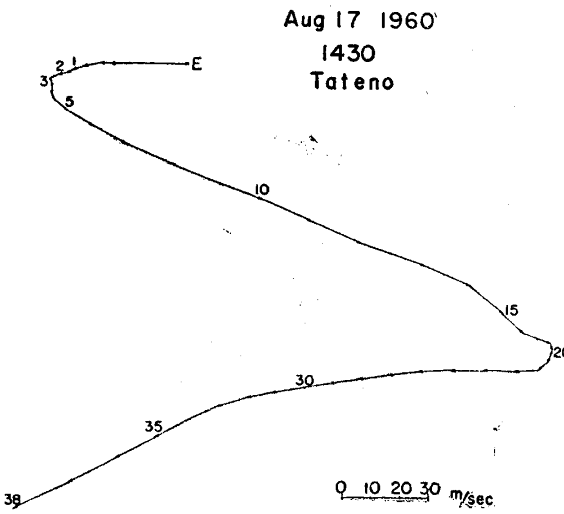


Fig. 3-4.



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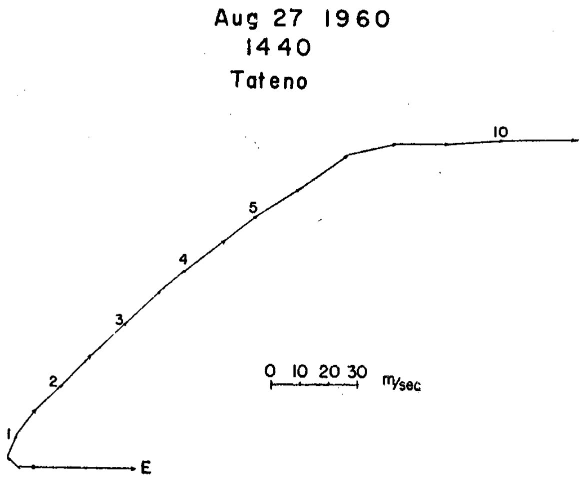


Fig. 3-6.

Fig. 3. Trajectories of pilot balloons or rawinsondes.

When we compared the maps of the capturing locations with the trajectory diagrams obtained by aerological observations, we could conclude that the balloons might ascend more than few km, even about 20 km, above the ground.

We have investigated thoroughly properties of the rubber balloon with and without the leak tube which was used in these experiments, and calculated the maximum ascending height for various initial states of balloons, and also looked for the most reasonable method for these experiments. The results will be reported in another paper.

Trajectories of the rawinsondes

The trajectories of rawinsondes and pilot balloons which are necessary to the analyses of the experiments considered in this paper are shown in Fig. 3. Some of these figures are reproduced from the 'Aerological Data of Japan' and others are the copies of the figures which were kindly given by the members of Yonago Observatory.

Scatter maps

At first we plotted on maps the capturing locations from the cards which were sent back, and we may call them as 'scatter maps'. In some of these maps, the states of the balloons are classified, namely, whether the balloon was floating (State F) or already landed (or hanged

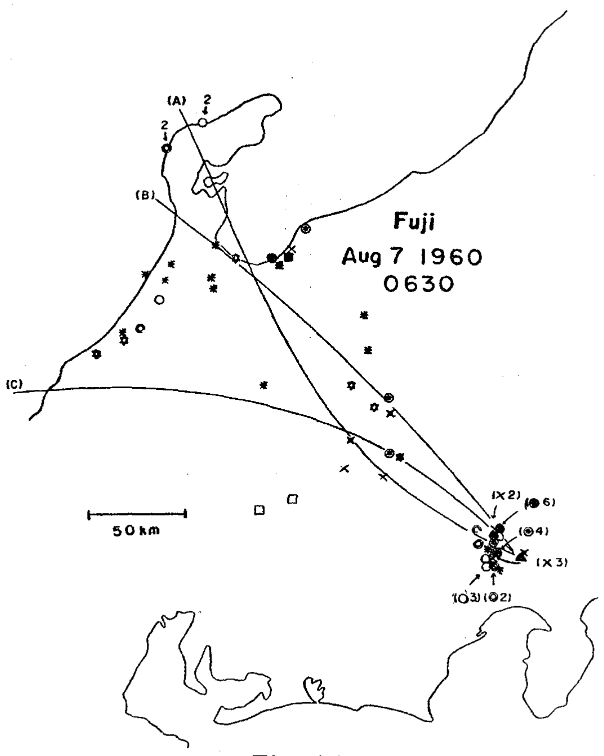


Fig. 4-1.

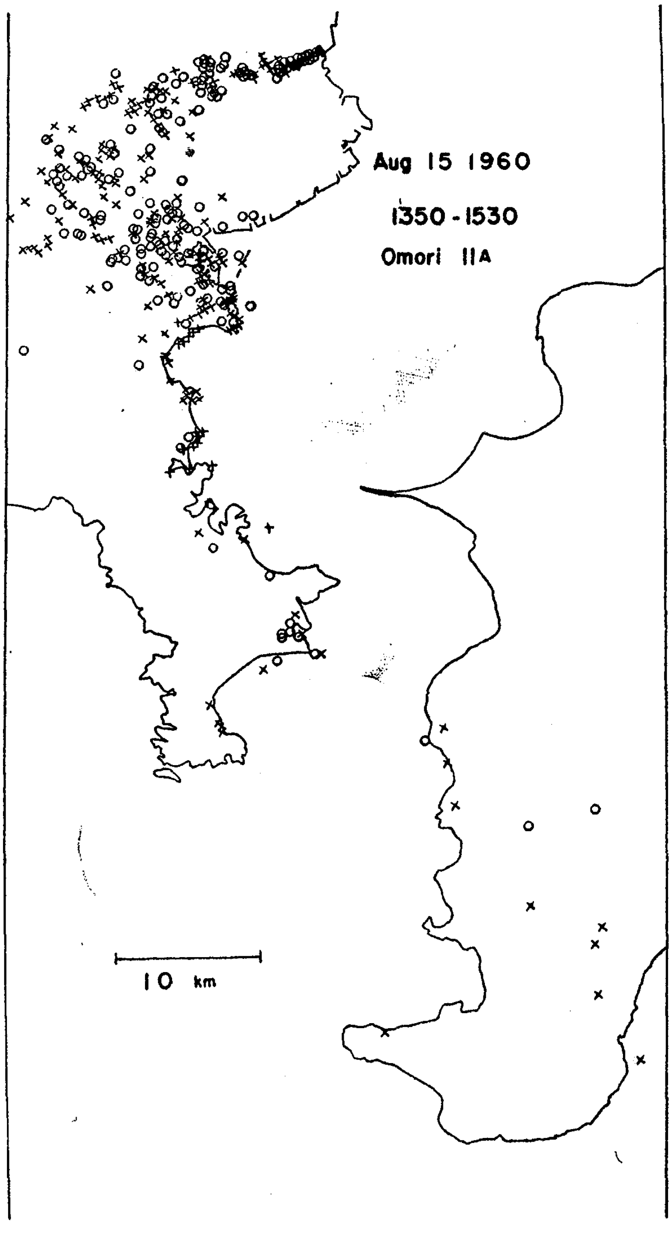


Fig. 4-2a

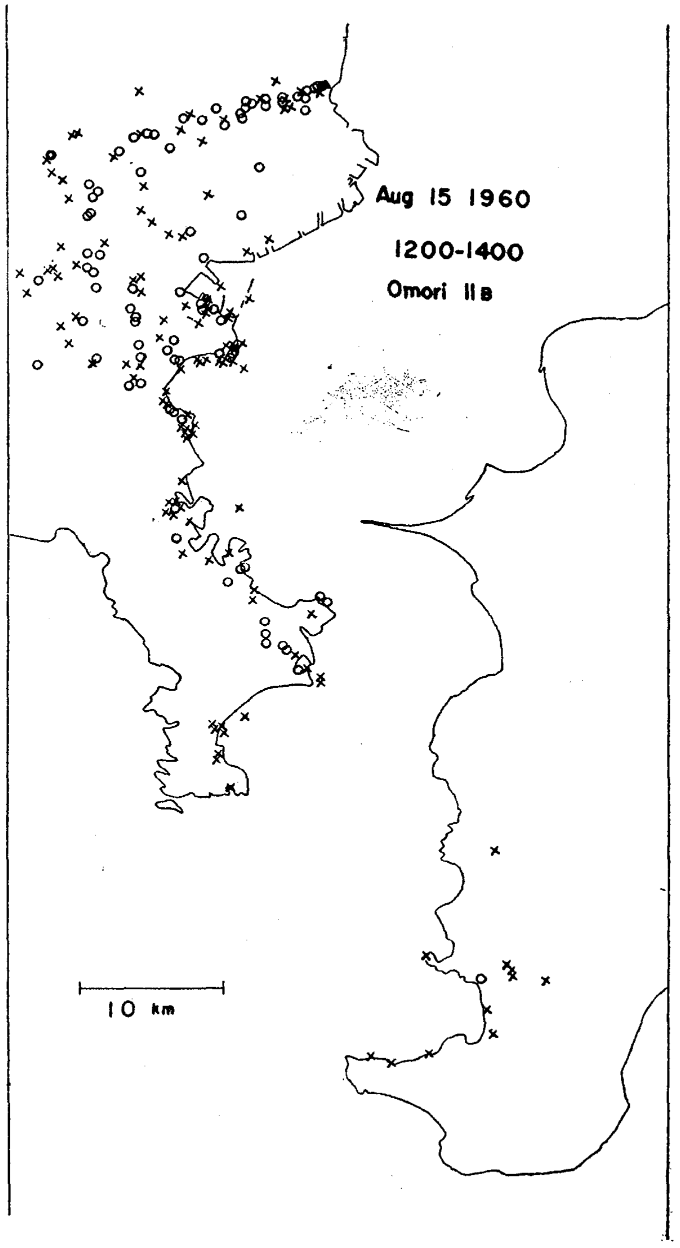


Fig. 4-2b.

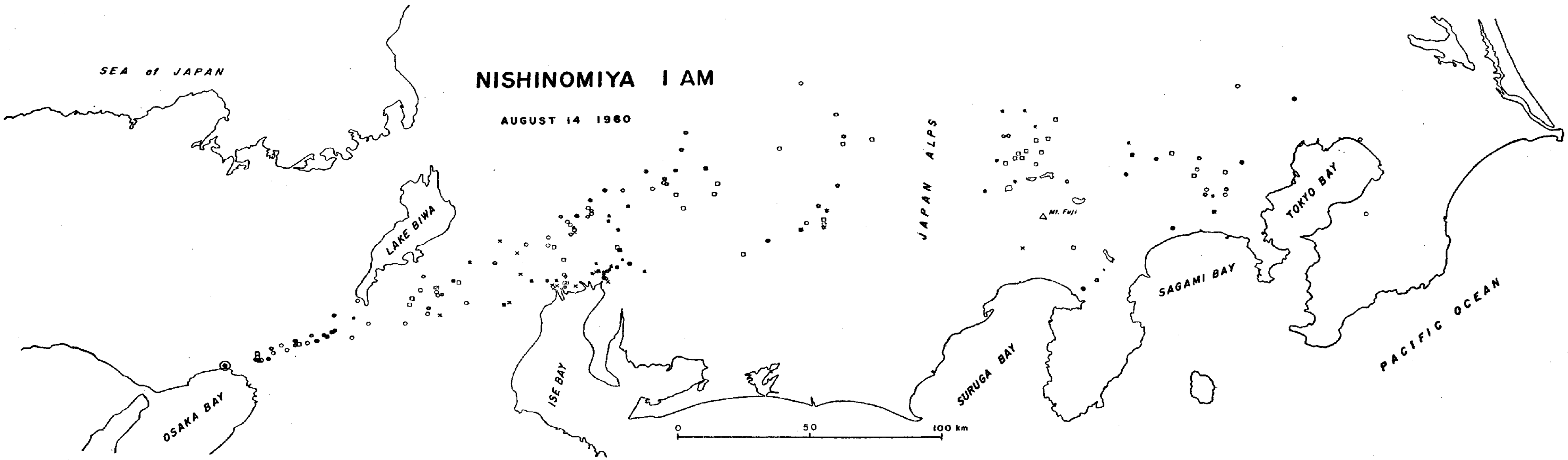
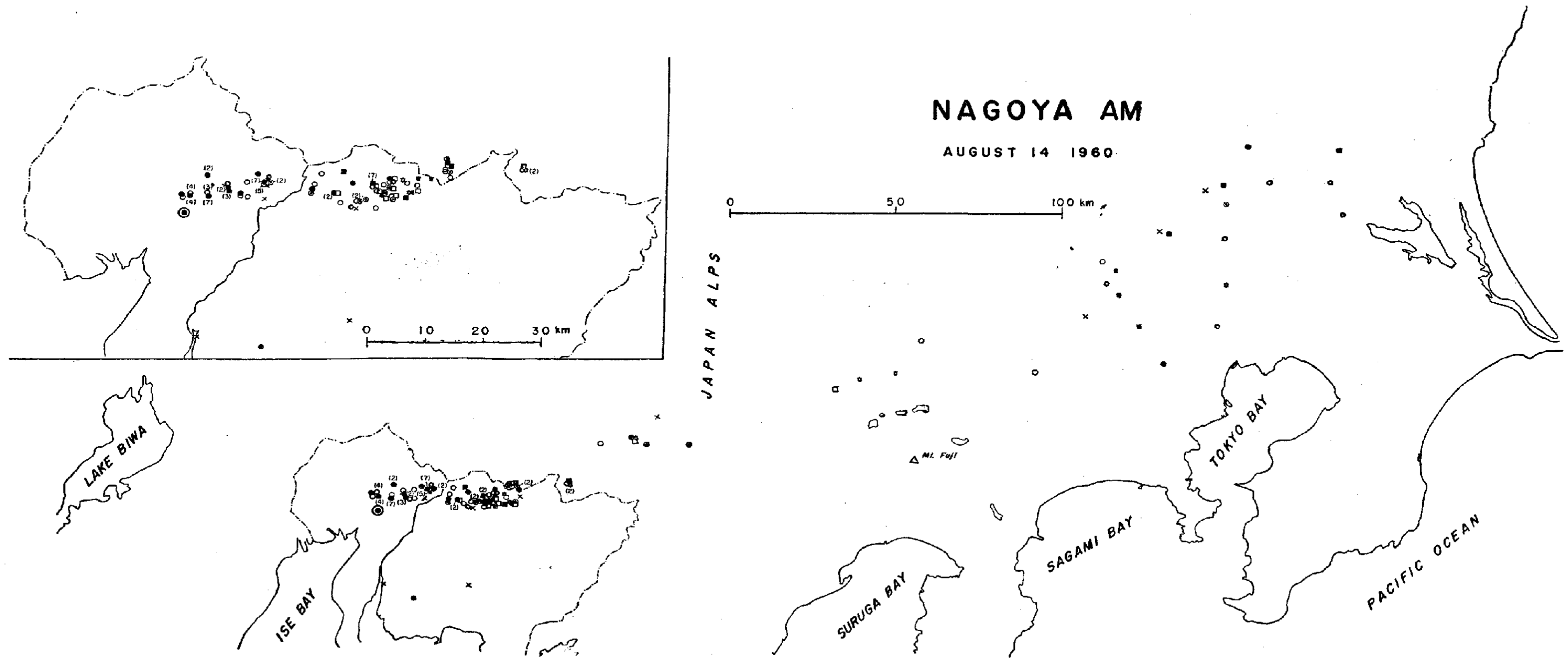

NISHINOMIYA I AM
AUGUST 14 1960
SEA of JAPAN
LAKE BIWA
OSAKA BAY
ISE BAY
JAPAN ALPS
Mt. Fuji
SURUGA BAY
SAGAMI BAY
TOKYO BAY
PACIFIC OCEAN
0
50
100 km

Fig. 4-3.



NAGOYA AM
AUGUST 14 1960
0
50
100 km
0
10
20
30 km
JAPAN ALPS
LAKE BIWA
ISE BAY
Mt. Fuji
SURUGA BAY
SAGAMI BAY
TOKYO BAY
PACIFIC OCEAN

Fig. 4-4.

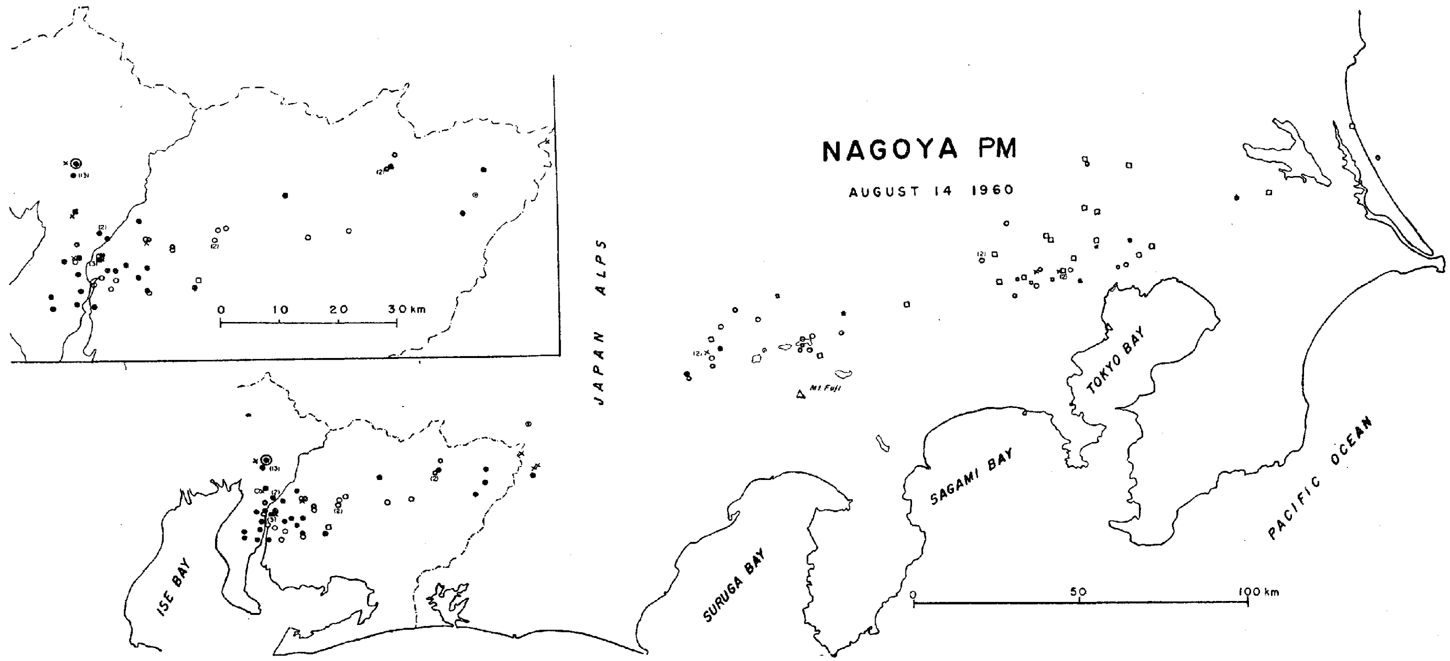

NAGOYA PM
AUGUST 14 1960
JAPAN ALPS
Mt Fuji
TOKYO BAY
SAGAMI BAY
SURUGA BAY
ISE BAY
PACIFIC OCEAN
0 50 100 km
0 10 20 30 km

Fig. 4-5.

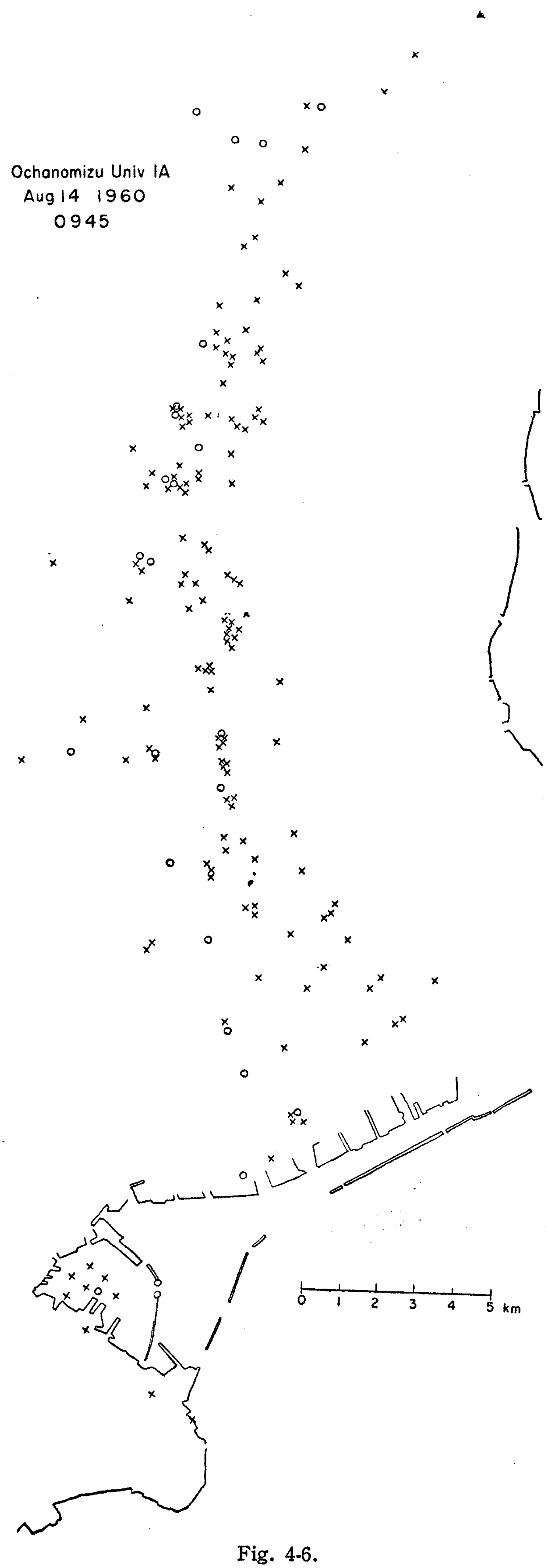


Fig. 4-6.

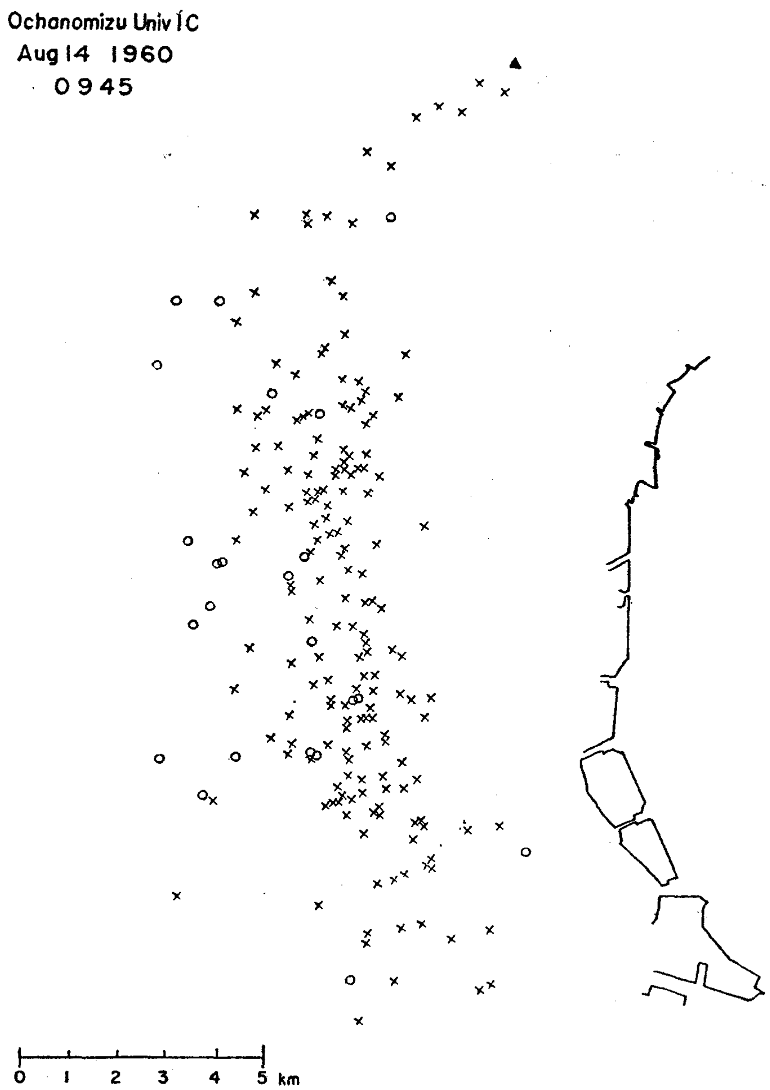


Fig. 4-7.

on trees etc.) (State L), and whether it was perfect (State P) or already broken (State B).

The scatter maps are shown in Fig. 4. Fundamental informations are listed in Table 2.

Lateral standard deviations

Though the capturing locations are comparatively many, they are distributed over wider ranges leeward, so the density of the marks on the scatter maps is not so high. Moreover, the scatter maps did not show any significant differences for various capturing conditions or states of balloons, so in the case of the calculation of the standard deviations, we used all the marks without distinction. Besides, in the first stage, in the experiments Nishinomiya I AM and Nagoya AM, PM, all marks regardless of the run A, B and C were used altogether.

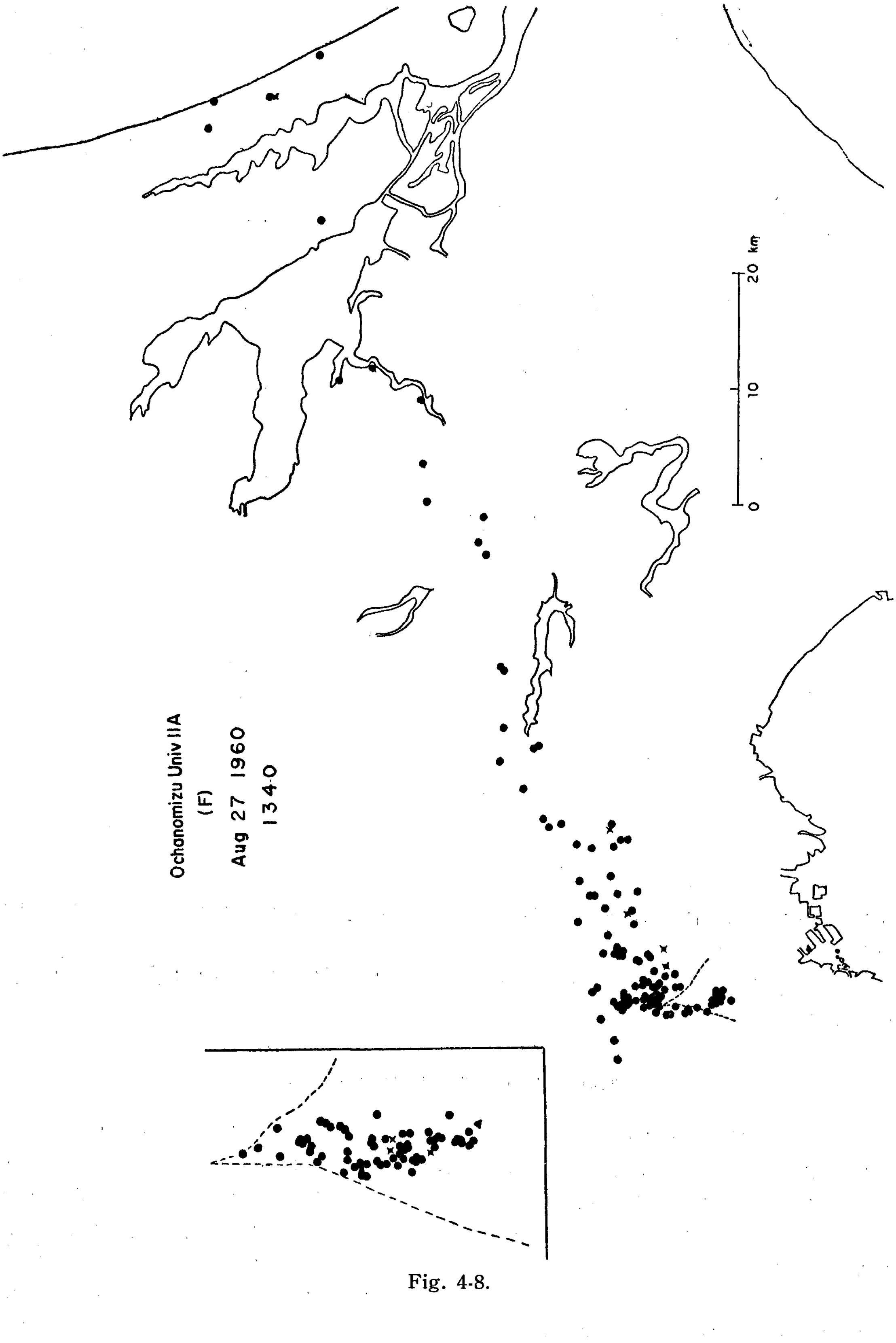


Fig. 4-8.

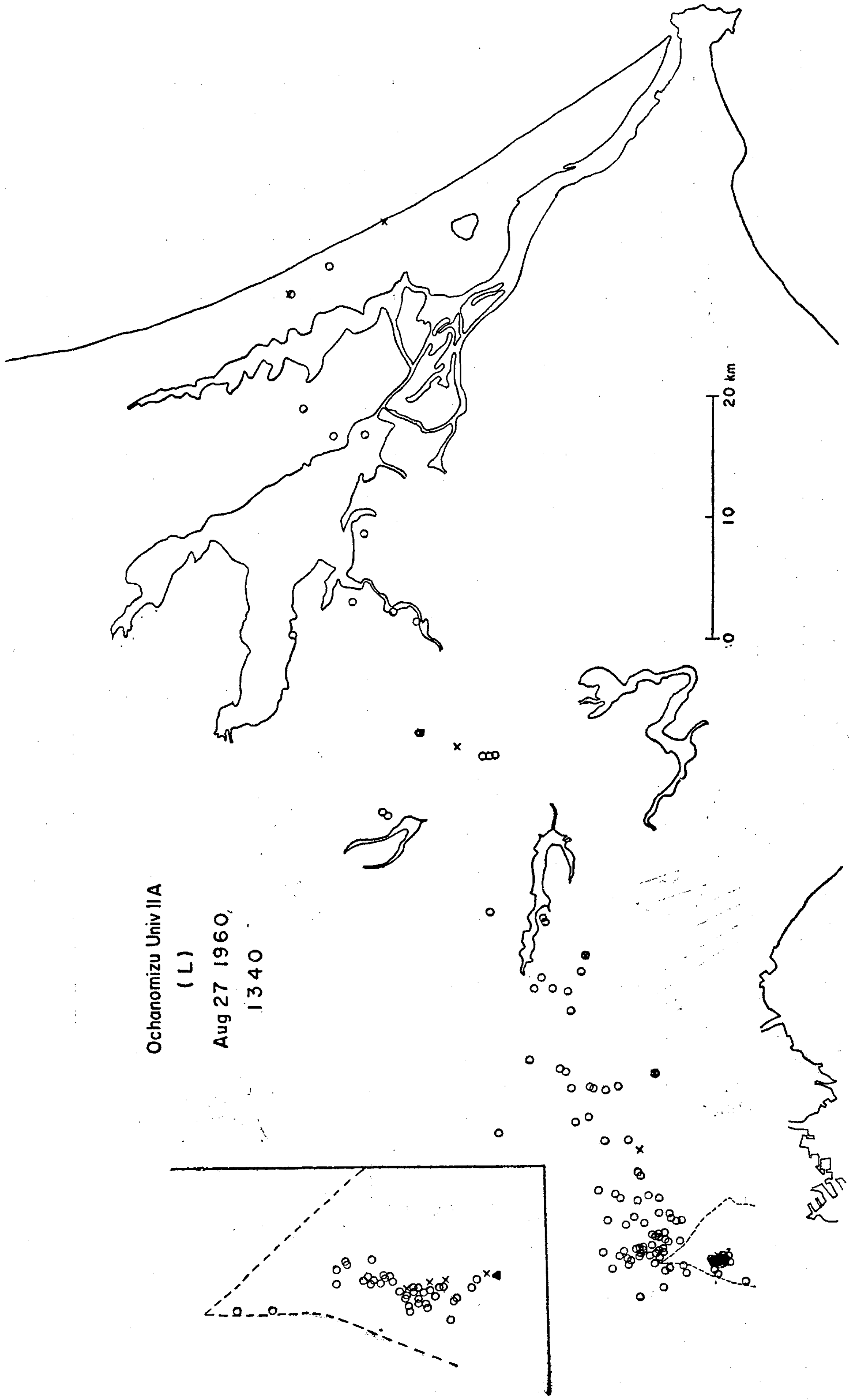


Fig. 4-9.

Fig. 4. Scatter maps.

Table 2. Fundamental informations of the analysed experiments.

No. of Fig.	Location	No. of run	Date	Weight (g)	Diameter (cm)	Mark of state			
						F		L	
						P	B	P	B
Fig. 4-1	Fuji	A	Aug. 7 0630~0920	30 (L)	47	●	✖	○	×
		B		30 (L)	50	⊙	✹	◎	✳
		C		30 (L)	52	■	✱	□	✡
Fig. 4-2a	Omori II	A	Aug. 15 1340~1400	20 (L)	41	○	×	○	×
4-2b		B	1500~1600	20 (L)	42	○	×	○	×
Fig. 4-3	Nishinomiya I AM	A	Aug. 14 0800~0906	20 (L)	41	●	✖	○	×
		B		20 (L)	42	⊙	✹	◎	✳
		C		20 (L)	43	■	✱	□	✡
Fig. 4-4	Nagoya AM	A	Aug. 14 0830~0915	20 (L)	39	●	✖	○	×
		B		20 (L)	41	⊙	✹	◎	✳
		C		20 (L)	42	■	✱	□	✡
Fig. 4-5	Nagoya PM	A	Aug. 14 1515~1600	20 (L)	39	●	✖	○	×
		B		20 (L)	41	⊙	✹	◎	✳
		C		20 (L)	42	■	✱	□	✡
Fig. 4-6	Ochanomizu Univ. I	A	Aug. 16 0945~1125	10	37			○	×
4-7		C		10	30			○	×
Fig. 4-8	Ochanomizu Univ. II	A	Aug. 27 1340~1620	10 (L)	37	●	+		
4-9				10 (L)	37			○	×

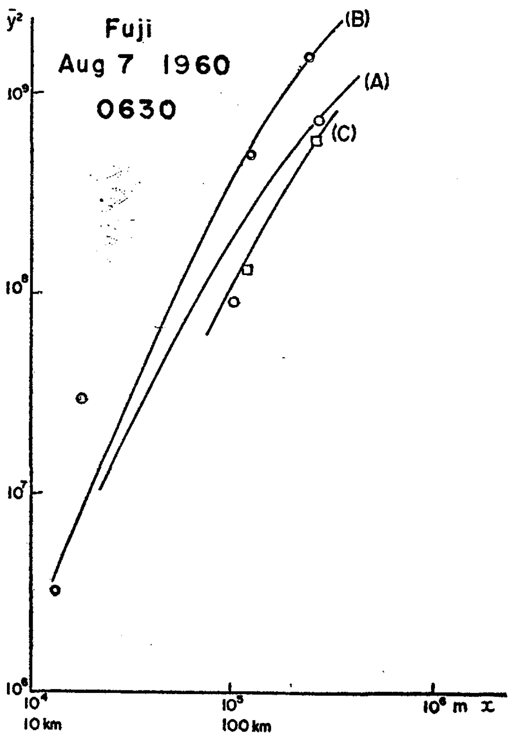


Fig. 5-1.

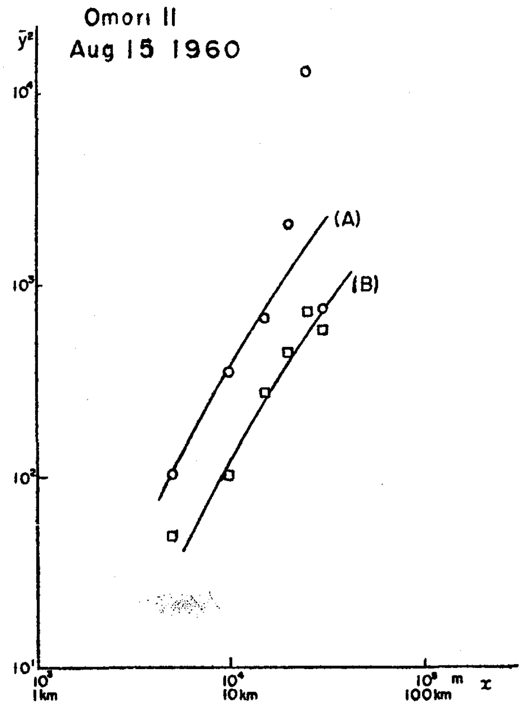


Fig. 5-2.

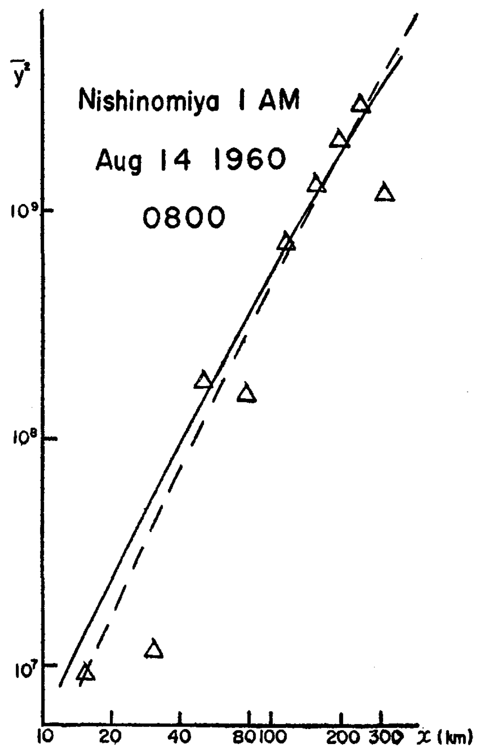


Fig. 5-3.

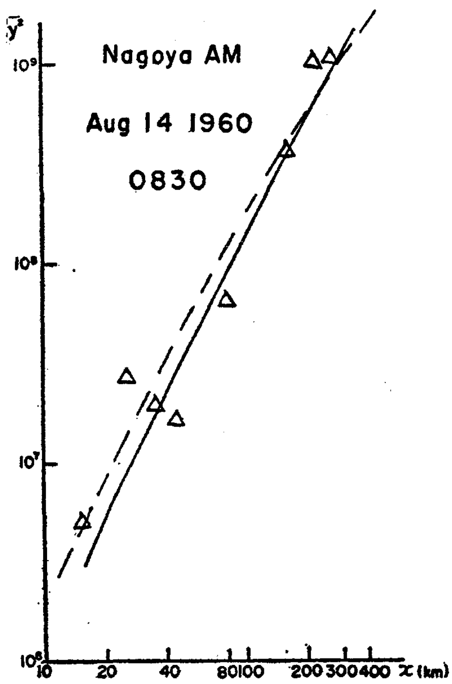


Fig. 5-4.

We divided the marks on the maps into several groups and we calculated the mean position of the marks in each group, and joinning these mean positions, we assumed the mean trajectory of balloons, then we calculated lateral standard deviations $\overline{y^2}$ for each group. In some cases, some mean positions deviate considerably from the probable trajectory joinning them, owing to the small number of the marks in those groups. In those cases, we assumed smoothed curves for the probable trajectories.

The divided distances of the groups were as follows :—

Experiment	*Leeward distance of divided positions* (km)
Fuji (A) (B) (C)	50, 180
Omori (A) (B)	7.5, 12.5, 17.5, 22.5, 27.5, 32.5
Nishinomiya I AM	20, 40, 60, 100, 140, 180, 220, 260, 280, 340, 380, 440
Nagoya AM	10, 20, 30, 40, 50, 60, 100, 140, 180, 200, 250, 280, 320
Nagoya PM	40, 80, 100, 120, 160, 200, 240, 280, 320, 340
Ochanomizu Univ. I	2.5, 5, 7.5, 10, 12.5, 15, 17.5, 20, 22.5
Ochanomizu Univ. II	10 15, 20, 25, 30, 40, 50, 70

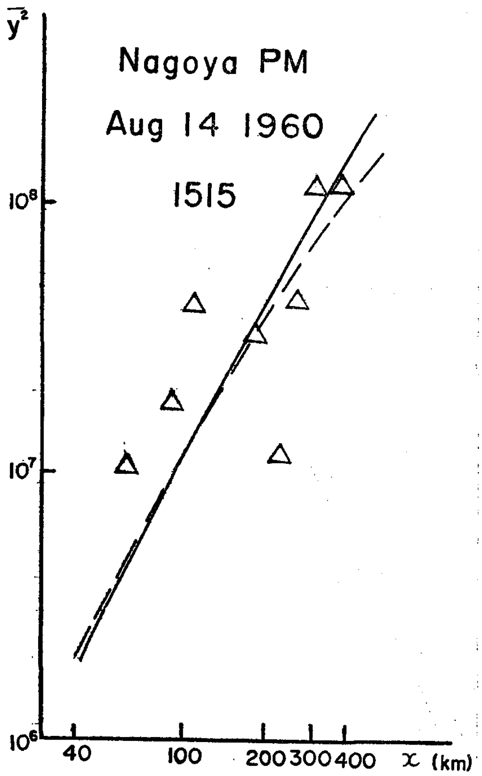


Fig. 5-5.

Fig. 5. Curves of standard deviations versus leeward distances.

The calculated standard deviations $\overline{y^2}$ are plotted against leeward distances x in Fig. 5.

If we assume that the Lagrangian correlation has the form

$$R(\xi)=\exp(-\alpha\xi)\,, \qquad (1)$$

we get from the Taylor's equation the standard deviation of the form

$$\overline{y^2}=q_A'(\exp(-\varphi_A x)+\varphi_A x-1)\,. \quad (2)$$

This functional form was varified as the adequate one when it was adopted for the analyses of the data of the 'Prairie Grass Project'[2] and those of the Tokai experiments.[3] Applying this equation to the curves of the standard deviations, we obtained a set of values of parameters φ_A and q_A' or the probable upper limit and lower limit of these values for each experiment. Using these estimated values, the curves are calculated from Eq. (2), and they are shown in Fig. 5 by solid

Table 3. Values φ_A and $\sqrt{q_A}$.*

Experiment		x_m (km)	H (m)	φ_A	$\sqrt{q_A}$
Prairie Grass	(ζ=0)	0.8	0.5	1.2^{-2}	6.0^{1}
〃	(ζ=−0.15)	0.8	0.5	2.5^{-3}	4.3^{2}
Tokai	(ζ=−0.15)	3	65	6.5^{-4}	2.1^{3}
Asama		60	(15^{3})	3.5^{-5}	3.3^{4}
Fuji	A		(10^{3}～15^{3})	1.4^{-5}	5.5^{4}
	B		(15^{3}～20^{3})	5.0^{-6}	1.8^{5}
	C		(25^{3}<)		
Omori II	A		(6^{3})	1.25^{-5} 3.3^{-5}	4.5^{4} 1.7^{4}
	B		(6^{3})	4.5^{-5} 1.33^{-4}	2.0^{4} 8.0^{3}
Nishinomiya I	AM		(10^{3}～15^{3})	1.6^{-6} 5.0^{-6}	2.1^{5} 7.6^{4}
Nagoya	AM		(8^{3}～14^{3})	2.5^{-6} 6.6^{-6}	8.0^{4} 3.5^{4}
	PM		(15^{3}～20^{3})	2.2^{-6} 5.0^{-6}	8.3^{4} 3.5^{4}
Ochanomizu Univ. I	A		(1^{3}～3^{3})	1.0^{-4} 4.4^{-4}	4.6^{3} 1.4^{3}
I	C		(1^{3}～3^{3})	3.1^{-4} 8.3^{-4}	2.3^{3} 1.1^{3}
Ochanomizu Univ. II	A		(2^{3}～5^{3})	1.45^{-4} 7.14^{-4}	1.0^{4} 2.4^{3}

or broken lines. The values of φ_A and $\sqrt{q_A}$ are shown in Table 3.

Comparison with other experiments

Lateral distributions of the marks do not take the Gaussian form,

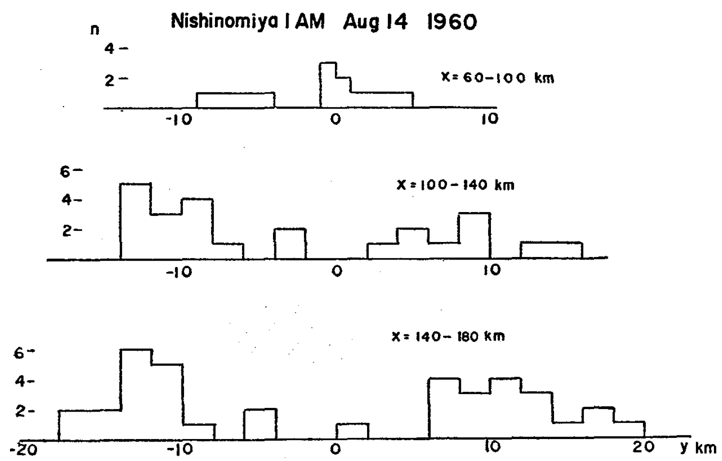


Fig. 6. Lateral distributions of marks.

* In this table, $a\times10^{b}$ is expressed by a^{b}.

but rather plateau type. Some examples are shown in Fig. 6. In the former papers[2,3], similar results were reported, and it has been shown that the suitable quantity for describing the lateral dispersion is the length L which is defined by the distance between the positions where the concentration is 1/10 of the maximum (plateau) concentration. This quantity L has a relation with the standard deviation $\overline{y^2}$:

$$L=3.46\overline{y^2}, \tag{3}$$

when the distribution is rectangular (plateau) type, just as in the cases of these experiments.*

So in order to compare the results of these experiments with those of other ones, the curves of L^2 versus x in these experiments, together with other several experiments, are shown in Fig. 7.

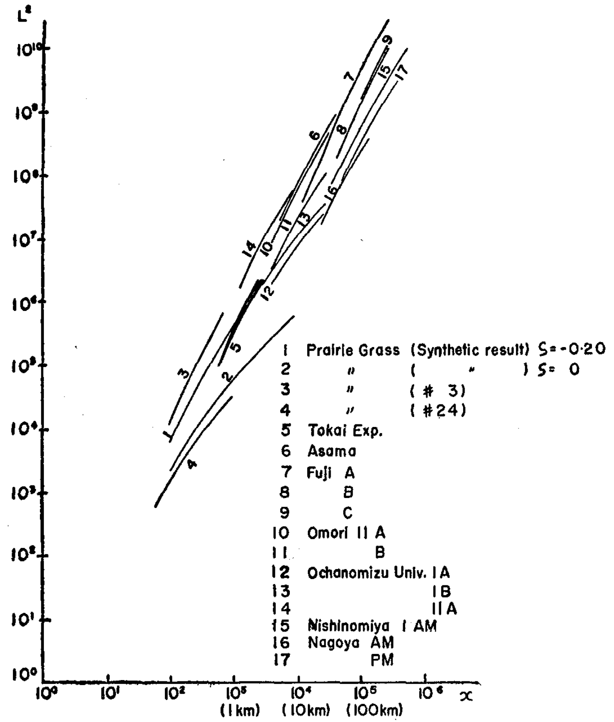


Fig. 7. Curves of L^2 versus leeward distances in various experiments.

Each curve in this figure similarly has the characteristics that it increases as x^2 as the value of x increases in the first stage, and decreasing gradually its inclination, it becomes increase as x. However, even at the distance where the curves already increase as x in the experiments on smaller scales, e.g. at 1 km in the Project Prairie Grass, the curves increase still more as x^2 in the experiments on larger scales, e.g. in the Tokai experiments and these balloon experiments.

If the time interval of sampling (or observation) for each experiment differs considerably, it is natural that the standard deviation differs each other, because the meandering period of the effective eddies increases as the time interval increases. While the time intervals of sampling were the same in the 'Project Prairie Grass' and in the Tokai experiments, but the lateral dispersions at the same leeward distances differ remarkably.

This fact means that the values of φ_A in Eq. (2) are larger in the experiments on smaller scale and smaller in those on larger scale. The values of $1/\varphi_A$ correspond to the sizes of of the eddies which are effec-

* If the distribution is Gaussian, $\exp(-y/A)^2$, there is a relation: $L=3.035\sqrt{A}$.

tive to the diffusion. Furthermore, the curves for larger scales generally locate in large $\overline{y^2}$ regions, so the values of q_A also become larger in those cases.

Therefore, the fact above mentioned means the sizes of the effective eddies become larger in the experiments on larger scales. This fact may remind us the famous Richardson's results that the diffusion coefficients become larger by $l^{4/3}$, where l is the scale of the phenomena.

However, it is not so evident, what quantity should be adopted as the measure of scale. If the farthest distance of the observation in an experiment x_m is regarded as the measure of scale, this value x_m is quite artificial, and the diffusion phenomena within this range take place indifferently, whether there are any farther observation posts or not. On the other hand, the diffusion parameters q_A and φ_A are determined not only by the observed data of the farthest observed distance, but also by all the observed data within that distance. So the farthest distance of the observation is not adequate to be the scale of the diffusion.

The only quantity which relates to the diffusion phenomena and differs its value in respective case is the source height. When we plot the values of $\sqrt{q_A}$ versus the respective source height H, Fig. 8 is obtained, and a relationship may be noticed. This relation may be a natural result that the size of eddies in the lower layer is smaller than that in the higher layer.

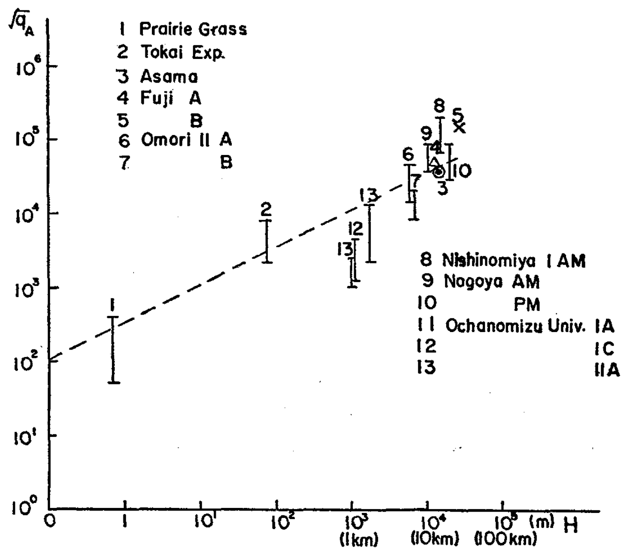


Fig. 8. Curves of $\sqrt{q_A}$ versus source height.

Wavy shape of the curves of standard deviations

The curves of the standard deviations have generally wavy shapes, remarkably in the regions farther than 10 km. The curves for each run of the experiments Nishinomiya I AM, Nagoya AM, PM, Ochanomizu Univ. I and II are shown in Fig. 9.

The number of data by which the standard deviations are calculated is not the same for each divided group, so the influence of the sample number may be considered. The qualitative correlations between the excess or shortage of the sample number in each group compared with its mean value and those of $\overline{y^2}$ compared with its mean tendency curve are almost zero. So the effects of the sample number should be considered as not significant (Fig. 10).

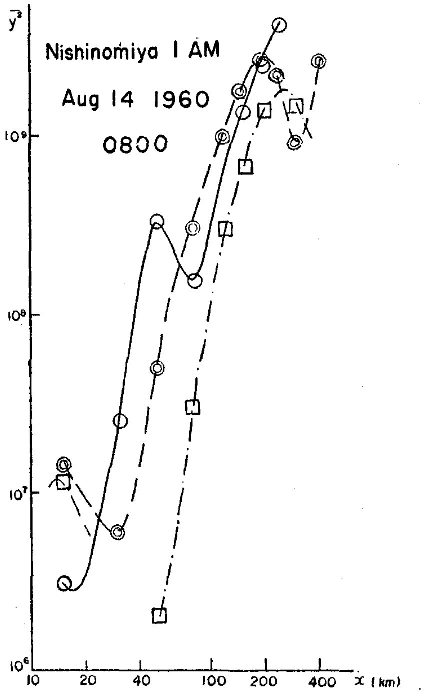


Fig. 9-1.

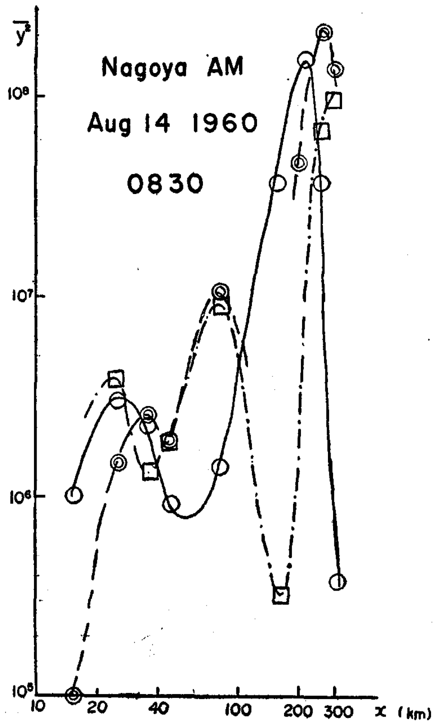


Fig. 9-2.

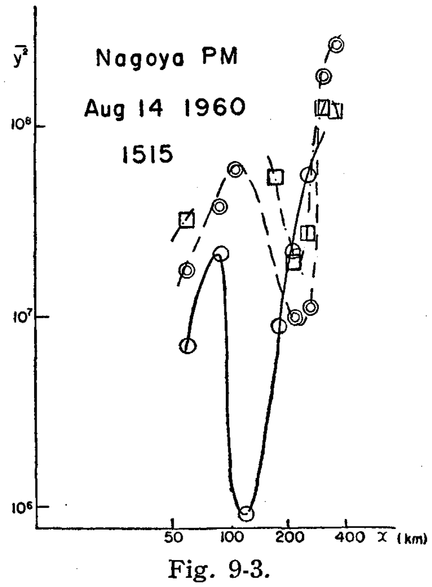


Fig. 9-3.

Fig. 9. Curves of standard deviations versus leeward distances for each run.

In the former paper,[2] peculiar forms of the lateral concentration distribution for 0.5, 0.9 and 3 km leeward were explained by the assumption that the concentration distributions are chiefly governed by the changes of wind directions which occur simultaneously over the whole field of experiment. According to this assumption, the concentration at time ξ is proportional to $\varphi(\xi)$:

$$\varphi(\xi)=\int_{t_1-(x/\bar{u})+\xi}^{t_1+\xi}\theta(t)dt\Big/ x/\bar{u}\,, \qquad (4)$$

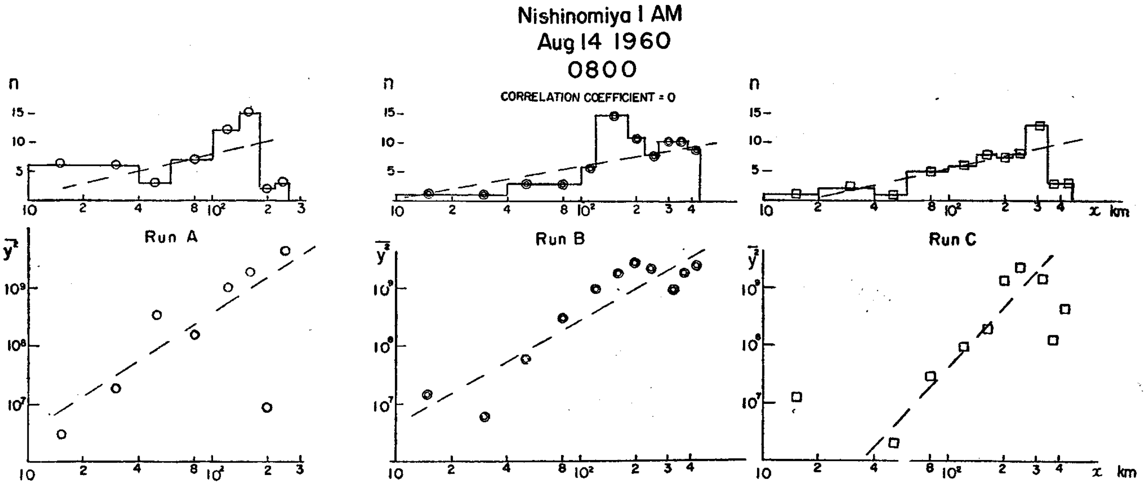


Fig. 10-1.

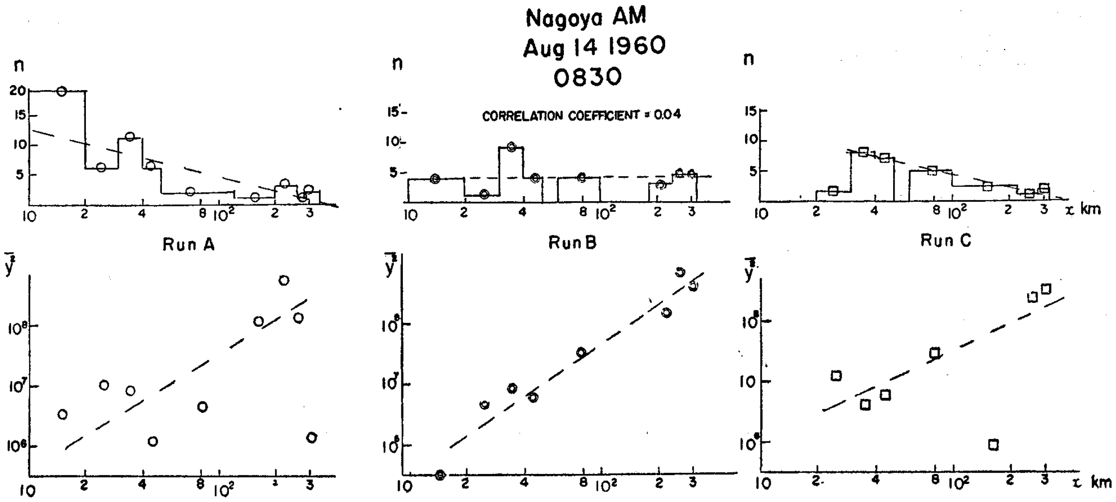


Fig. 10-2.

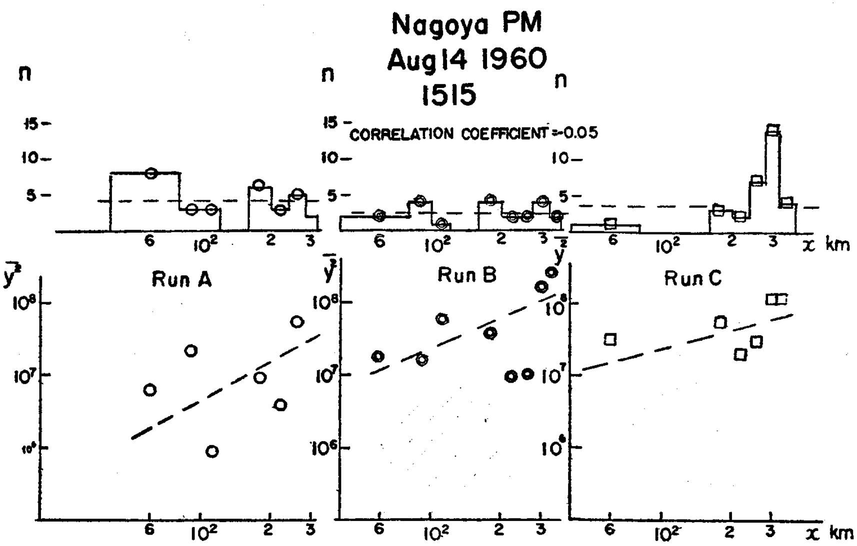


Fig. 10-3.

Fig. 10. Correlations between the fluctuation of sample numbers and that of standard deviations.

where t_1 is the instant when the sampling begins, $\theta(t)$ is the wind direction at the source and $\bar{u}$ is the mean wind velocity. The concentration distribution observed during the sampling period is proportional to the occurrence frequencies of φ during that period. As a result of that, it was remarked that, as the wind direction $\theta(t)$ can be expressed by a Fourier series in t:

$$\theta(t)=\frac{a_0}{2}+\sum(a_n \cos nt+b_n \sin nt)\,, \qquad (5)$$

so Eq. (4) becomes

$$\varphi(\xi)=\frac{a_0}{2}+\frac{1}{\tau}\sum\frac{2}{n}\sin\left(\frac{n\tau}{2}\right)\left[a_n \cos n\left(\xi-\frac{\tau}{2}\right)+b_n \sin n\left(\xi-\frac{\tau}{2}\right)\right], \qquad (6)$$

where we put $t_1=0$ and $\tau=x/\bar{u}$. If $\tau=x/\bar{u}$ is given, some components in the series vanish, when

$$n=2m\pi/\tau \qquad m: \text{integer}. \qquad (7)$$

Therefore, if τ_0 satisfies the condition that the term with large Fourier coefficient may vanish, the standard deviation becomes minimum. The distance $\Lambda=\bar{u}\tau_0$ may be called as 'wave length of the mean flow'. The positions of valleys in the figures of the experiments Nishinomiya I AM, Nagoya AM and PM are as follows:

Nishinomiya I AM:	(A)	20, 80, 350
	(B)	30, 300
	(C)	40, 400
Nagoya AM:	(A)	(10), 45, (120), 300
	(B)	(15), 45, (120), 350
	(C)	(10), 35, 150, 400
Nagoya PM:	(A)	(40), 120, 220
	(B)	(40), 200
	(C)	(40), 250

These positions for each run are nearly the same.

In each of these experiments, intervals of the divided groups are not the same over the whole range, so the relation between the fundamental wave length and the higher harmonics is not so clear.

We analysed the results of Ochanomizu Univ. I and II as more suitable data, because they include many data in nearer regions. The results are shown in Fig. 11, and we can notice that there is a wave length of 8 km for I A, 11 km for I C and 12∼13 km for II A (F and L).

From these results the wavy shapes may be explained by the changes of the general wind directions.

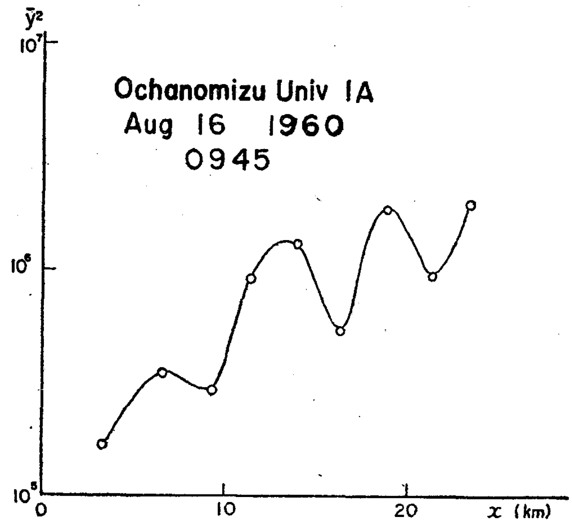


Fig. 11-1.

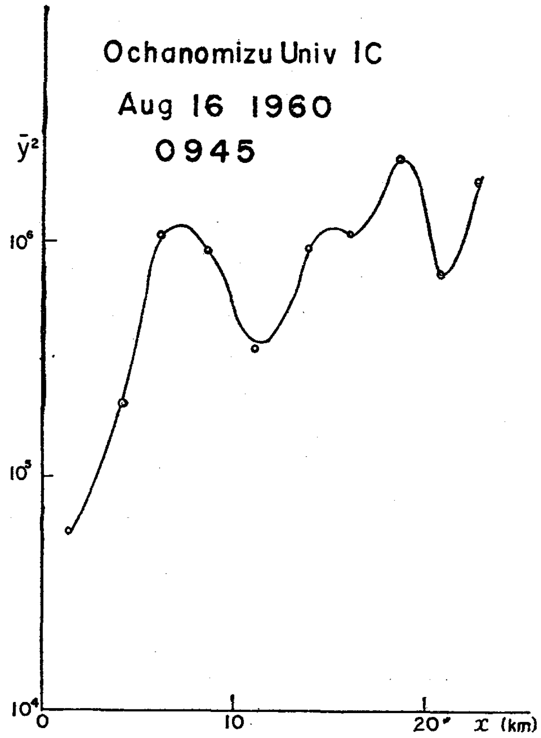


Fig. 11-2.

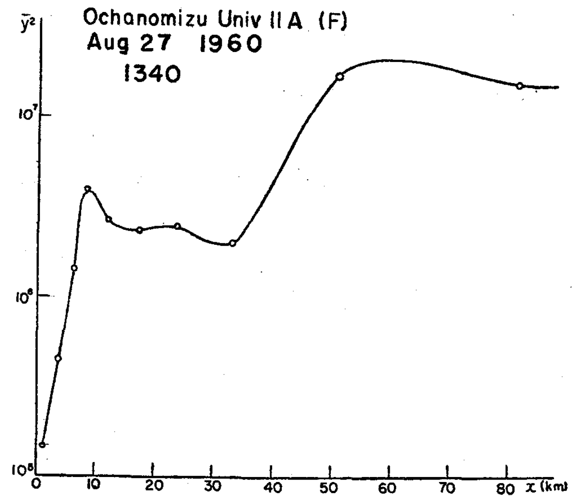


Fig. 11-3.

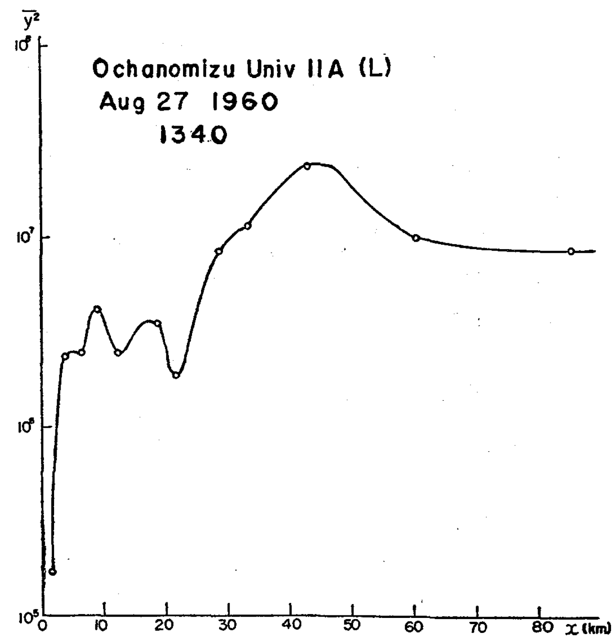


Fig. 11-4.

Fig. 11. Curves of standard deviations versus leeward distances.

Changes of general wind directions and diffusion phenomena

If the changes of the mean wind directions are considered as another kind of dispersion phenomena, rather than usually called 'pure' diffusion ones, and if the parameters for 'pure' diffusion are the quantities to be calculated, a curve joinning the valleys in Fig. 9 should be adopted for the calculation, because the valleys correspond to the values of the standard deviations for which the effects of the changes of the mean wind directions favorably disappear.

However, the period of the changes of the wind direction may not always be constant when the diffusion in a farther range is considered, so the curves through the valleys are not adequate for the estimation of the 'pure' diffusion. Furthermore, apart from the pure theoretical interests, the over-all results observed or should be observed are the objects important for the experimentalists and for practical interests. So we calculated φ_A and q_A from the curves without any special considerations for the wavy shapes of the curves.

Though the standard deviations by the 'pure' diffusion increase as x^1, in farther regions, those by the changes of the mean wind directions still increase as x^2, so it may regard that the diffusion phenomena on larger scale depend chiefly on the changes of wind direction over the whole field.

Conclusion

The lateral diffusions up to 450 km leeward were able to be analysed. Though in these experiments informations of vertical diffusion could not be obtained and the heights of layers in which the diffusion occurred were too high for the practical purposes, but the obtained results may be regarded valuable, because they include wide observation ranges and have many regularities.

The diffusion parameters depend on the 'scale' of the phenomena, and it is concluded that the source heights should be adopted as the 'scale', and the relation between the parameter $\sqrt{q_A}$ and the source height H may support this conclusion.

The curves of standard deviations versus x have wavy nature, and this fact has been remarked already in former report. From these results, it may be regarded that the diffusion phenomena on larger scale depend chiefly on the changes of wind directions over the whole field.

As these experiments have made a success in a certain degree, we wish to try to make another chance to carry out the experiments by much more improved methods in near future.

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