A Study of the Minor Fluctuation of the Atmospheric Pressure (II)

By

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Part II

Analysis of the Microbarograms[1]

Introduction

Prof. T. Shida constructed a new microbarograph in Oct. 1918, and ordered the microbarographic observation to be carried on as a part of the official work of our institute from Jan. 1919, at the Kamigamo Geophysical Observatory in Kyoto. Afterwards four of the same were constructed, of which two are working in the Kyoto Basin. It is a kind of U-tube manometer, with magnification power of about 40; i. e. the change of pressure of 1 mm. Hg corresponds to 40 mm. on the record. The speed of the recording drum is about 1 mm. per 1 min.. Practically, it is used as a leaking microbarograph.[2] This report shows the results of the observations by means of this microbarograph.

In ordinary weather, this microbarogram indicates a very simple curve, which we shall call "Normal Type of the Microbarogram"; in the warm season, the curve is extremely simple as in Fig. 1 and we shall call it "Normal Warm Season Type"; while in the cold

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[1] The outline of this part of the paper was read at the Annual Meeting of the Physico-Mathematical Society of Japan in Jul. (1929).

[2] Details of this instrument and the location of our observatories will be noted in the last part of this paper.

season a very small fluctuation is superposed on this simple curve and this time we shall call it "Normal Cold Season Type." Fig. 1 illustrates these types.[1] But sometimes we find on our microbarograms some interesting curves, which, we shall say, belong to "Abnormal Type." By the character of these curves, we can classify them into several types, and study them separately.

Fig. 1

Normal Type of Warm Season.
4. Aug. 1923.

Normal Type of Cold Season.
17. Feb. 1923.

Section I

Periodic Fluctuation of Atmospheric Pressure

1. Introduction

One of the most typical features of the microbarogram is regular periodic change of pressure with period of 3 min. to 15 min. and double amplitude of about 0.1 mm. Hg or so, which suggests that it is due to the wave motions of the atmosphere. At first, offering some typical examples of this kind, we enter into its statistical study.

2. Examination of the periodic fluctuation of atmospheric pressure

Typical examples are classified into following groups.

i) Examples of "Group D".

Oscillations of this kind with very regular periods and great amplitudes are often recorded when *discontinuous lines* appear near Kyoto. It is very natural that the vicinity of discontinuous surface, especially, a warm front or an occluded front should be the most suitable structure

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[1] All the reproductions of our microbarograms indicated in this part without any remarks are one half of the original size.

for making such barometric oscillations, if we suppose that these fluctuations are due to the internal gravitational wave of the atmosphere. In almost all cases, this type is accompanied by decreasing of pressure and rising of temperature which are the characteristics of a warm front or the vicinity of the trough line of an occluded front.

Ex. 1. 0 h.–5 h. 20th. March 1921.

Reproduction of the microbarogram: Fig. 2.

Mean period: ca. 5 min..

Weather chart: Fig. 3.

Remark: Oscillation occurred near the steering line of cyclone.

Fig. 2

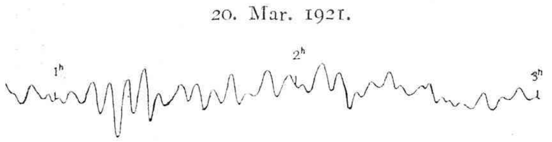
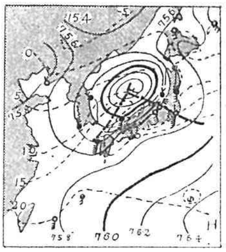


Fig. 3



1921. Mar. 20th 6h

Temperature and wind at Hikone and Mt. Ibuki (ca. 1300 m. height) are as follows:

	22 h. 19th.		6 h. 20th.	
	Temp.	Wind	Temp.	Wind
Hikone	6.2 C	−0.3 m/s	6.6 C	SSW 3.2 m/s
Ibuki	−1.4 C	S 24.3 „	5.4 C	S 37.5 „

The above observation shows the existence of warm southerly upper currents above the surface layer which is cooled by radiation during the night and dawn. Therefore there exists an inversion of temperature at the deck of the surface layer. Internal waves are formed at this discontinuous surface. This upper southerly current flows into the Kyoto Basin after the warming of the lower strata by solar radiation at about 8 o'clock, at which time a sudden rise of air temperature and disappearance of barometric wave occur. Such phenomenon had been investigated by W. Schmidt at Insburg[1] as an phenomenon associated with "Föhn." His view seems to be accept-

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[1] Sitz. Ber. d. Akad. d. Wiss. in Wien. Math.-Nat. Klasse. **122**, 835–911 (1913).

able; but the present writer believes that it may be a secondary cause which stimulates this phenomenon, and the primary cause of the barometric wave is the existence of warm and cold air at the warm front. If it is so, we must observe squalls afterwards. In this example, the condition is verified in reality by the meteorological observation of that day. i. e.

≡′6^h05^m—●′10^h25^m—●′10^h55^m, Minor squall, ●° 17^h58^m—18^h53^m●° 19^h20^m
. . . . . . 20^h00^m (20^{th} March 1921)

Ex. 2. 4 h.–9 h. 28th. April 1921.
Reproduction of the microbarogram: Fig. 4.
Mean period: ca. 6 min.

Fig. 4

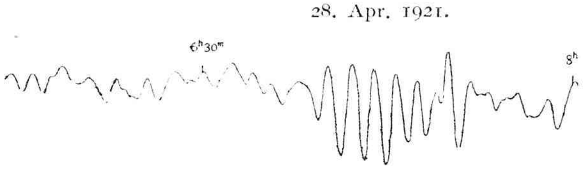
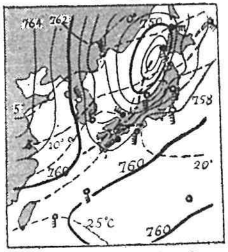


Fig. 5



1921 Apr. 28th. 6^h

Remark: The weather chart at 6 h. (Fig. 5) shows that the warm southerly wind flows over the thin cold surface air lying above the inland stations. The warm air, which once appeared in the suburbs of Kyoto, appears again on the coast of the Japan Sea, and forms the occluded front.

Following observations also show such condition:

	6 h. 28th. April 1921.	
	Temp.	Wind
Ibuki	10.8 C	S 19.8 m/s
Hikone	15.7 C	calm

Other examples of this group are listed as follows:

Duration	Mean period ca.
9 h. — 12 h. 30th. Jan. 1926.	6 min.
10 h. — 13 h. 10th. Feb. 1926.	6 min.
6 h. — 11 h. 6th. Feb. 1925.	4–7 min.
5 h. — 7 h. 5th. Jan. 1926.	7 min.

ii) Examples of "Group C".

The north-easterly quadrant of a *cyclone* or an intermediate portion of two cyclones is also a suitable structure for forming internal waves, because there the southerly warm current flows over the cold air. In such case, the oscillations are classified as Group C.

On this occasion, the weather will be calm with some rain, and variations of the temperature and pressure are not considerable. The waves in this class are not so regular as that of Group D.

Ex. 3. 0 h.–3 h. 2nd. April 1920.

Reproduction of the microbarogram: Fig. 6.

Mean period: 6.4 min.

Direction and velocity of propagation found by phase identification: Fig. 7.

Weather chart: Fig. 8.

Mean direction and velocity of propagation:

WSW→ENE 11 m. p. s.

Wave length:

$$\lambda = VT = 11^{(m)} \times 7.5 \times 60 \doteqdot 5^{(km)}$$

Fig. 6

Microbarograms.

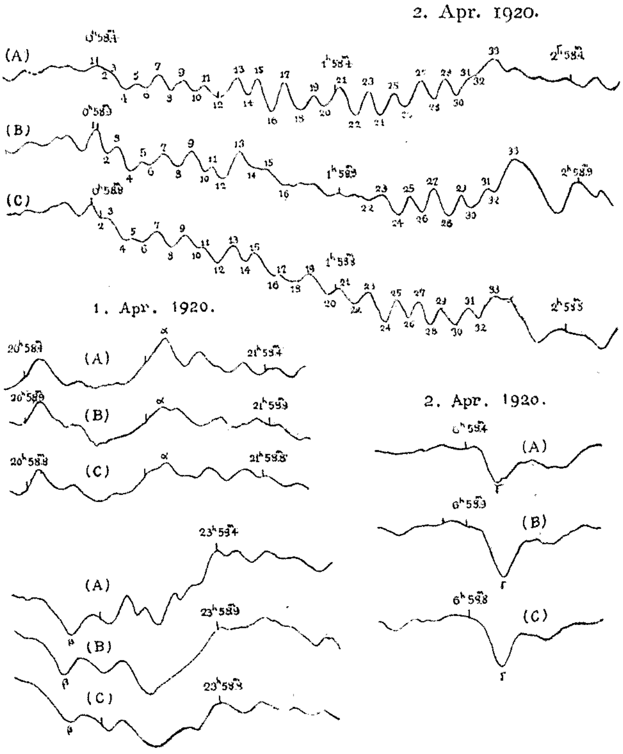


Fig. 7

Direction and Velocity of propagation.
1920. April 1—2.
Arrows indicate the direction of propagation and length of – indicates 10 m. p. s.

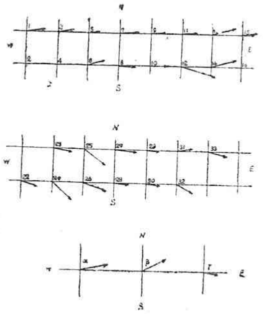
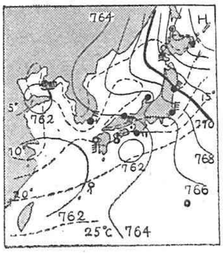


Fig. 8



1920 Apr. 2nd 6^h

Remark:
Estimation of upper air condition.

Height of surface of discontinuity:	1 km.
Temperature at ground:	10 C
Temperature at 1300 m. height:	7 C
Temperature lapse-rate of lower layer:	n=0.45
Temperature lapse-rate of upper layer:	n'=0.7

These assumption is backed up by the following data.

	22 h. 1st. April.		6 h. 2nd. April.	
	Temp.	Wind	Temp.	Wind
Kyoto	10.5 C	SW 1.8 m/s	10.2 C	−0.1 m/s
Hikone	9.0 C	calm	8.7 C	−0.4 ,,
Ibuki (1300 m)	7.8 C	NNW 5.3 m/s	6.8 C	SSE 8.4 ,,

Then the jumping temperature at the surface of discontinuity is $\Delta\theta=3.6$, or $\frac{\Delta\theta}{\theta}\doteqdot 1/75$. Velocity of propagation of the long wave is calculated as 11 m. p. s. and its period is 7.5 min. This coincidence means that these assumptions are roughly correct. The double amplitude of pressure wave is 0.15 mm. Hg, which roughly corresponds to that of the internal wave of 100 m.. Of the many questions in detail which remain on the simultaneous records of the three different stations, the disappearances of wave crests of 17, 19, 21, in B, and weakness of the corresponding crests in C are the most noticeable ones. It seems to the present writer that these phenomena are affected by the irregularity of our earth's surface and such orographic influence affects more strikingly the waves of shallow depth, as in this example, because the height of mountain (Mt. Hiei is 700 m. height) situated near our observatories, is comparable with the height of discontinuous layer. In this example, during the occurrence of the wave, the slight rain intermitted in the calm night. In our locality, this phenomenon is very common when warm southerly upper currents blow.

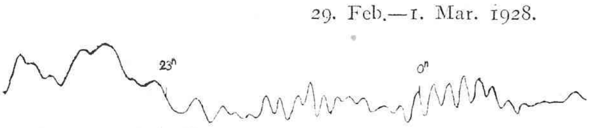
Ex. 4. 23 h. 29th. Feb.—1 h. 1st. Mar. 1928.

Reproduction of the microbarogram : Fig. 9.

Mean period : ca. 3.5 min..

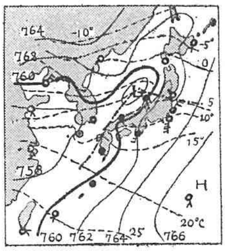
Weather chart : Fig. 10.

Fig. 9



29. Feb.—1. Mar. 1928.

Fig. 10



1928 Feb. 29th. 18h

Remark : Intermediate portion of two cyclones.

Further examples are listed as follows :

Date	Mean period ca.
0 h. — 3 h. 29th. Sept. 1927	15 min.
5 h. — 7 h. 11th. May 1928	10 min.

iii) Examples of "Group A".

Barometric waves often appear at the *anticyclonic protuberance* or the rear of migratory high pressure. Cooling of the surface layer by long wave radiation produces a discontinuous layer. The waves of this class are not so regular as group D or C, but have comparatively long period and large amplitude. Some of the waves of this group appear in fine weather.

Ex. 5. 17 h.—20 h. 10th. Oct. 1925.

Reproduction of the microbarogram: Fig. 11.
Mean period: ca. 10 min..
Weather chart: Fig. 12.

Fig. 11

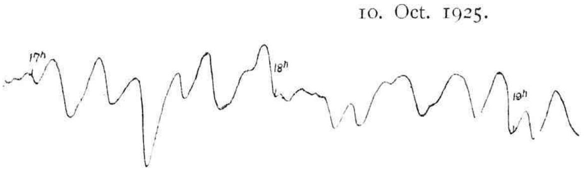
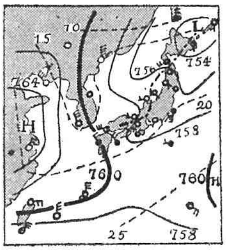


Fig. 12



1925. Oct. 10th. 18h

Ex. 6. 15 h.—18 h. 23rd. May 1927.
Reproduction of the microbarogram: Fig. 13.
Mean Period: ca. 13 min..
Weather chart: Fig. 14.

Fig. 13

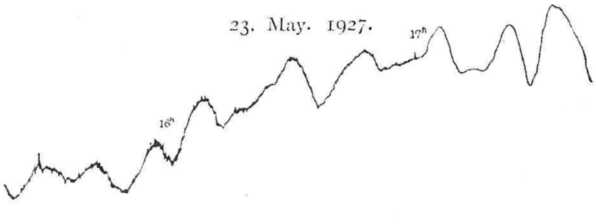
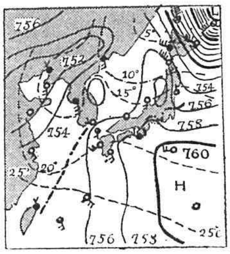


Fig. 14



1927 May 23rd. 18h

Further examples are listed as follows:

Duration	Mean period ca.
17 h. – 20 h. 10th. Oct. 1925	10 min. and 5 min.
0 h. – 1 h. 11th. Oct. 1925	6 min.
19 h. – 21 h. 12th. Oct. 1925	12 min.
0 h. – 1 h. 10th. Jan. 1927	15 min.
20 h. – 21 h. 24th. Mar. 1927	8 min.
11 h. – 14 h. 25th. Feb. 1927	7 min.

iv) Examples of "Group T".

Sometimes we observe waves of pressure along a *trough line* of depression.

Ex. 7. 15 h.—17 h. 8th. Oct. 1927.

Reproduction of the microbarogram: Fig. 15.

Mean period: ca. 5 min..

Weather chart: Fig. 16.

Another example is 9 h.—11 h. 1st. July 1925, the mean period being about 17 min..

Fig. 15

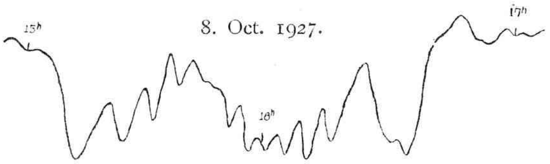
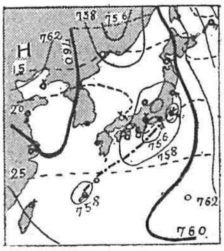


Fig. 16



1927. Oct. 8th. 18h

v) Examples of "Group NE"

Sometimes we obtained the record of barometric-waves in a *north-easterly* wind or when a typhoon was approaching.

Ex. 8. 1 h.—2 h. 15th. Sept. 1924.

Reproduction of the microbarogram: Fig. 17.

Mean period: ca. 12 min..

Weather chart: Fig. 18.

Another example is 0 h.—2 h. 10th. July 1925, mean period about 10 minutes.

Fig. 17

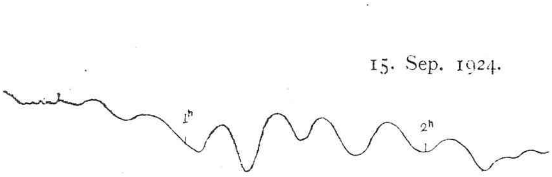
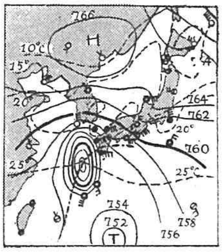


Fig. 18



1924. Sept. 15th. 6h

vi) Additional Note:

Examining the daily microbarograms of the period April 1925—December 1927, we know that group A, group D, and group C occur most frequently and their numbers of occurrence are 36 %, 27 % and 23 % respectively. The other groups happen in 14 % of all.

3. A statistical study of the wave-like oscillations shown by the microbarogram

(i) Introduction

An examination of the daily microbarograms at the Kamigamo Observatory in Kyoto shows that the regular pressure-oscillations occur frequently and that usually they have equal periods in their series though their regularities are not perfect. Such oscillations we call simply "Waves" after N. K. Johnson. In the following, we will describe mainly the statistical study of periods of waves. We cannot simply express on what conditions the waves occur. The barometric waves occur more frequently in cloudy weather but happen also in other cases. In this respect, the relation between other meteorological elements and the occurrences of waves cannot be expressed easily.

(ii) Periods and occurrences of waves

At the Kamigamo Observatory, we have 6464 series which involve 40549 wave-crests in all, in our records during the years 1919–1928. Fig. 19. A shows the percentage-number of waves and of wave-series of various periods within 25 min.. Fig. 19. B shows these numbers within 60 min.. The period of maximum frequency at Kyoto is 6 min..

(iii) Seasonal and diurnal variation of the occurrences of waves

The seasonal variation of the occurrences of waves is shown in Fig. 20. A. In this figure we find that the occurrences are few in summer (July–Sep.); for example the number in August is less than 3 % of all. As for the periodicity of waves, waves with period shorter than 4 min. occur more frequently in the cold season, such waves decreasing regularly as the season tends to become warmer. Waves with periods of 5–8 min. have nearly the same tendency. There is no regularity in distribution of waves with longer periods.

Fig. 19 (A)

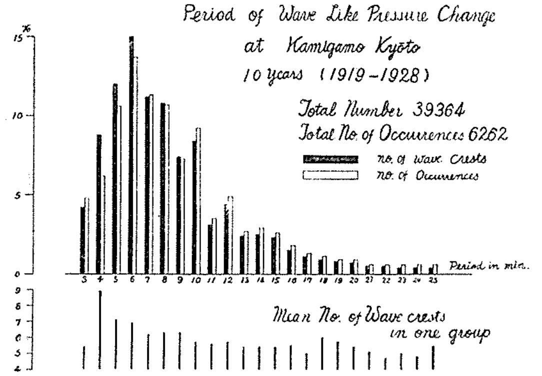
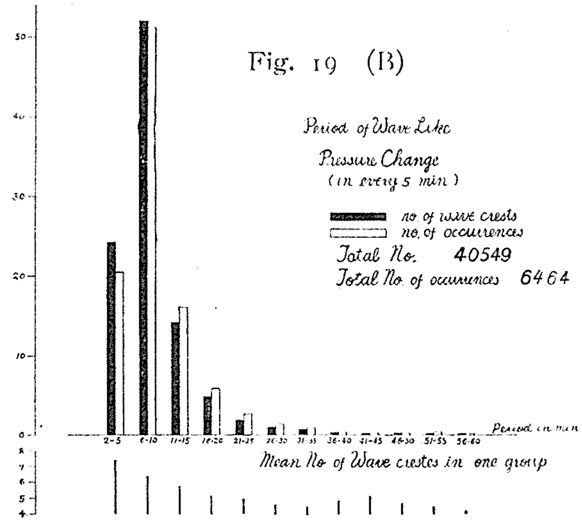


Fig. 19 (B)



In Fig. 20. B, which shows the number of occurrences of these waves in every two hours, we find a maximum frequency in 4–6 h. and minimum in 10–12 h. The forms of diurnal distribution are analogous to these seasonal ones, especially in waves of shorter periods. Waves with periods 5–8 min. or 9–12 min. have the most regular distribution; waves of longer periods indicate less regularity in distribution. The maximum frequency of short periodic wave in the cold season or dawn suggests that these waves are the internal waves, for the discontinuous surface between the surface and upper layers is formed very frequently at these times.

Fig. 20 (A)

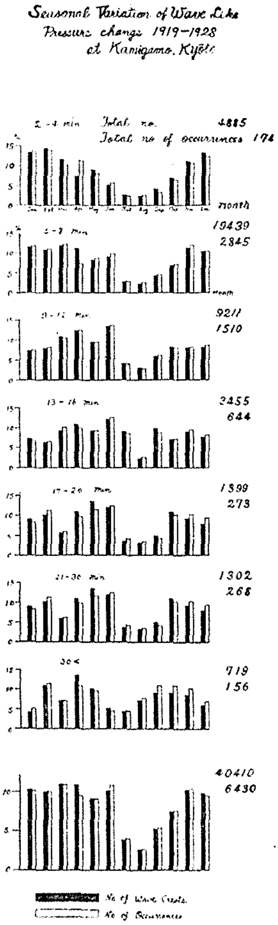
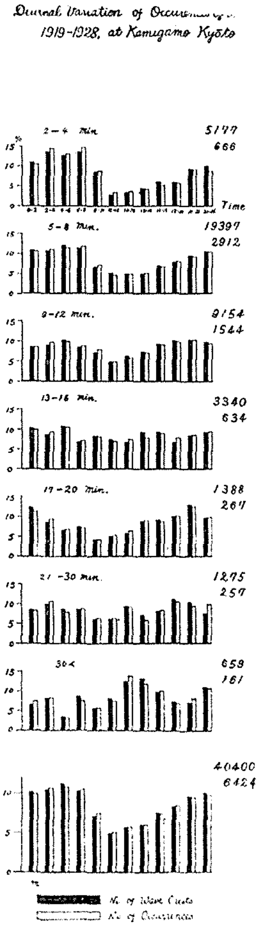


Fig. 20 (B)



(iv) Relation between the weather and occurrences of the waves

Table 1 shows this relation. In cloudy weather we have maximum frequency, and in rainy weather we have next greatest frequency. In fair and clear weather, the percentage is small.

(v) Wind-direction and occurrences of the waves

Table 2 shows this relation. In the northerly wind, we have maximum frequency.

Table 1

Weather and Occurrences of Waves

Period	Clear	Fair	Cloudy	Rain
min. 0-4	1.6 1.6	1.6 0.7	7.6 5.8	4.4 3.5
5-8	4.6 5.3	4.3 3.8	18.5 17.3	11.7 10.9
9-12	1.9 2.1	2.7 2.7	13.0 14.0	5.0 5.2
13-16	1.4 1.6	1.4 1.6	3.9 4.5	3.0 3.7
17-20	0.3 0.5	0.4 0.6	2.3 2.6	1.5 1.5
21-30	0.5 0.6	0.4 0.5	3.2 3.6	1.4 1.7
>30	0.1 0.2	0.4 0.5	1.5 2.1	1.4 1.5
Total	10.4 11.9	11.2 10.4	50.0 49.9	28.4 27.8

Total Number of Waves	8810
Total Number of Occurrences	1280

(1923-1927) at Kyoto.

Table 2

Wind-directions and Occurrences of Waves.

Period	N (NW-NE)	E (NE-SE)	S (SE-SW)	W (SW-NW)	Variable	Calm
min. 0-4	3.7 2.9	2.3 1.4	1.1 0.7	1.9 1.4	2.6 1.6	3.7 3.1
5-8	15.3 13.8	3.6 3.5	4.1 4.2	4.6 4.2	2.9 3.0	8.6 9.9
9-12	9.3 9.9	3.3 2.9	2.3 2.3	2.2 2.3	1.4 1.6	3.6 4.4
13-16	4.9 5.5	1.5 1.7	0.9 1.2	1.1 1.2	0.8 1.1	1.5 1.5
17-20	1.5 1.8	0.6 0.6	0.5 0.5	0.2 0.3	0.5 0.4	0.6 0.7
21-30	2.0 2.3	0.8 1.0	0.2 0.3	0.7 0.8	0.7 0.6	0.9 1.0
>30	1.2 1.6	0.4 0.4	0.4 0.4	1.0 1.3	0.4 0.5	0.2 0.2
Total	37.9 37.8	12.5 11.5	9.5 9.6	11.7 11.5	9.3 8.8	19.1 20.8

Total Number of Waves	7850
Total Number of Occurrences	1160

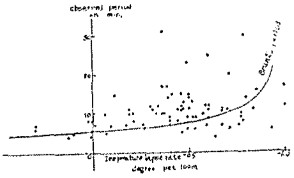
(1923-1927) at Kyoto.

(vi) Observed periods and Brunt's periods

In the former part of this paper, we have seen that Brunt's period, which depends only on the lapse-rate of temperature, coincides with the period of the long wave of the atmosphere in our sense.

But we have no authentic knowledge about the states of the upper air, therefore by using the temperature-records at Mt. Hiei and the Kamigamo Observatory, we estimate the temperature-lapse-rate. The relation between Brunt's period and observed period is shown in Fig. 21. This relation is not complete as N. K. Johnson[1] concludes. This discrepancy is partly due to an error of our estimation of the lapse-rate of temperature. In fact, a difference between the temperature of Mt. Hiei and the Kamigamo does not give the true lapse-rate even approximately when the discontinuous layer lies below the top of Mt. Hiei. On the theoretical side, it is not necessary to have the perfect coincidence between them. Brunt's period is nothing but the most suitable period of the pressure-waves when the lower layer is at rest. This figure shows that the waves of Brunt's period appear very frequently on the microbarograms.

Fig. 21



3. On the propagation of a certain type of atomospheric wave resulting from a limited initial disturbance

(i) Introduction

The generation of the atmospheric waves is an important subject for microbarographic study. To perform the general treatment of the propagation of the wave resulting from a limited initial disturbances, is not an easy matter because the propagating velocity is very complex function of $k\left(=\frac{2\pi}{\lambda}\right)$ where λ is wave length. More difficulty will be met with in the evaluation of integral, if we want a rigorous solution. To illustrate some observed facts qualitatively, an available rough solution can simply be found by putting some allowable assumptions.

(ii) Assumptions and fundamental equations

In our theory of the atmospheric wave, the first principal part of the solution which gives the main effect on the waves of pressure, is possible in a certain range of k. Dealing with this part we can put approximately

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[1] Q. J. R. Met. Soc. **55**. 19 (1929).

$$V \fallingdotseq A-\frac{B}{2}k \quad \dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots (1)$$

where A, B are constants.

To apply Kelvin's group method for finding a rough solution, we introduce

$$V_g=\frac{d\sigma}{dk}, \quad \frac{d\sigma}{dk}=A-Bk, \quad \frac{d^2\sigma}{dk^2}=-B \quad \frac{d^3\sigma}{dk^3}=0$$
$$\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots (2)$$

where V_g is group velocity, $\sigma=\frac{2\pi}{\tau}$, τ is period of the wave.

For initial conditions, we assume

$$\eta=f(x), \quad \frac{d\eta}{dt}=0 \quad \text{when } t=0 \quad \dots\dots\dots\dots\dots\dots (3)$$

where η is displacement of the surface of separations, and when $f(x)$ is even function of x, then

$$f(x)=\frac{1}{\pi}\int_0^{\infty}\phi(k)\cos kx\,dk, \quad \phi(k)=\int_{-\infty}^{+\infty}f(\omega)\cos k\omega\,d\omega.$$

In our case, the waves travelling in positive direction are limited in a certain range between k_1 and k_2. Since this progressive part only is investigated here, the effects of the local change do not enter our consideration.

The displacement at any time t becomes

$$\eta=\frac{1}{2\pi}\int_{k_1}^{k_2}\phi(k)\cos(\sigma t-kx)dk \quad \dots\dots\dots\dots\dots\dots\dots (4)$$

and the pressure change at the ground is given by

$$p=\frac{1}{2\pi}\int_{k_1}^{k_2}\phi(k)p'(k)\cos(\sigma t-kx)dk$$
$$=\frac{1}{2\pi}\int_{k_1}^{k_2}\psi(k)\cos(\sigma t-kx)dk \quad \dots\dots\dots\dots\dots\dots\dots (5)$$

where $\psi(k)=\phi(k)p'(k)$ and $p'(k)$ is the pressure factor, given in the former part.

In our case, $p'(k)$ is slowly varying function with k, therefore, when $\phi(k)$ is also slowly varying function with k, the approximate evaluation of the above integral by group method is possible.

Evaluation may be performed as follows:

$$p=\frac{\psi(k_0)}{2\pi}\left\{\frac{2\pi}{t\left|\frac{d^2\sigma}{dk^2}\right|}\right\}^{\frac{1}{2}}\cos\left\{k_0(x-V_0t)\mp\frac{\pi}{4}\right\}$$

$$=\frac{\phi(k_0)}{\sqrt{2\pi Bt}}\cos\left\{\frac{\left(A-\frac{x}{t}\right)^2}{2B}t-\frac{\pi}{4}\right\} \qquad \ldots\ldots\ldots\ldots(6)$$

where $$k_0=\frac{A-\frac{x}{t}}{B} \quad \text{and} \quad V_0=A-\frac{B}{2}k_0 \qquad \ldots\ldots\ldots\ldots(7)$$

The time of beginning and that of ending of the disturbance are given respectively by

$$t_1=\frac{x}{A-Bk_1},\quad t_2=\frac{x}{A-Bk_2} \qquad \ldots\ldots\ldots\ldots(8)$$

and the duration of disturbance is

$$t_2-t_1=\left(\frac{1}{A-Bk_2}-\frac{1}{A-Bk_1}\right)\equiv ax \qquad \ldots\ldots\ldots\ldots(9)$$

and this is proportional to x.

The periodic term of (6) is

$$\cos\left\{\frac{\left(A-\frac{x}{t}\right)^2}{2B}t-\frac{\pi}{4}\right\}=\cos\left\{\frac{k_0^2B}{2}t-\frac{\pi}{4}\right\} \qquad (10)$$

while $k_0=k_1$ at $t=t_1$ and $k_0=k_2$ at $t=t_2$. Therefore the difference of the values of $\frac{k_0^2Bt}{2}-\frac{\pi}{4}$ at t_1 and t_2 is $\frac{B}{2}\ (k_2^2t_2-k_1^2t_1)$, which becomes by (8),

$$\frac{Bx}{2}\left[\frac{k_2^2}{A-Bk_2}-\frac{k_1^2}{A-Bk_1}\right]\equiv\beta x \qquad \ldots\ldots\ldots\ldots(11)$$

The number of the same phase within the disturbance is

$$\frac{\beta x}{2\pi} \qquad \ldots\ldots\ldots\ldots(12)$$

Therefore the mean period $\bar{\tau}$ is

$$\bar{\tau}=\frac{2\pi a}{\beta} \qquad \ldots\ldots\ldots\ldots(13)$$

which is independent of x.

(iii) Numerical calculation by an example

We assume, $d=0.8$, $U=0$, $n'\fallingdotseq 1.0$, $\overline{k'_{or}H^2}=0.01$, $H=1$ km. and $\frac{\Delta\theta}{\theta}\fallingdotseq\frac{1}{75}$. Then we have $\bar{V}\fallingdotseq 10$ m/s. And also we treat the cases of $n=0.8$, 0.5 and 0.0. Then we have $\overline{k_{or}H^2}=0.70$, 1.75 and 3.50

for $n=0.8$, 0.5 and 0.0 respectively. The solutions of the first principal part are given in Table 3.

Table 3

	$n=0.8$			$n=0.5$				$n=0.0$			
$\varkappa H$	0.0	0.5	1.0	0.0	0.5	1.0	1.1	0.0	0.5	1.0	1.2
w	0.98	0.94	0.88	0.97	0.93	0.86	0.85	0.96	0.93	0.86	0.84
kH	0.86	1.02	1.38	1.36	1.51	1.84	1.91	1.95	2.07	2.37	2.53

In the above case we may put

$$w \doteqdot a-\frac{b}{2}k$$

and two constants a and b are obtained by

$$a=\frac{w_1\overline{k_2H}-w_2\overline{k_1H}}{\overline{k_2H}-\overline{k_1H}} \quad \text{and} \quad b=\frac{2(w_1-w_2)H}{\overline{k_2H}-\overline{k_1H}}$$

Numerical values of a and b are listed in Table 4.

Table 4

	k_1H	k_2H	a	$b'=b/H$
$n=0.8$	0.86	1.38	1.14	0.38
$n=0.5$	1.36	1.91	1.27	0.44
$n=0.0$	1.95	2.53	1.36	0.41

Putting $t=60T$ (T in min.),
$x=10^5X$ (X in km.),
$H=10^5H'$ (H' in km.),
$\bar{V}=10^3\bar{V}'$, $A=a\bar{V}10^3$,
$B=b'\bar{V}'H'10^8$ and $k=10^5K$, we have from (9)

$$\frac{\bar{V}'}{X}(T_2-T_1)=1.67\left\{\frac{1}{a-b'\overline{K_2H'}}-\frac{1}{a-b'\overline{K_1H'}}\right\}$$

and

$$\beta x=\frac{b'X}{2H'}\left\{\frac{\overline{K_2H'^2}}{a-b'\overline{K_2H'}}-\frac{\overline{K_1H'^2}}{a-b'\overline{K_1H'}}\right\}$$

Thus we have the required mean period of the wave which is given in Table 5.

Table 5

	$\frac{\bar{V}'T_1}{X}$	$\frac{\bar{V}'T_2}{X}$	$(T_2-T_1)\frac{\bar{V}'}{X}$	βx	$\bar{\tau}$
$n=0.8$	2.06	2.69	0.63	0.41 X/H'	9.7 min.
$n=0.5$	2.49	3.88	1.39	1.26 X/H'	6.9
$n=0.0$	2.98	5.23	2.24	2.71 X/H'	5.2

(iv) Discussions

(a) By the above-going consideration, it is clear that the mean period of waves is independent of the mode of disturbance and of the distance from the origin of disturbance, if it is observed at a sufficient distance. It depends only on the structure of the atmosphere in which waves propagate. An arbitrariness of the atmospheric structure is very much restricted, while the distance and the mode of disturbance have a wide arbitrariness. This theoretical result furnishes a possible reason why the mean period of waves of pressure on the microbarograms is limited. The results of observation show that these periods lie between 3 min.–20 min. in general and the waves with mean periods of 4 min.–10 min. occur with extremely great frequency.

(b) If we consider such phenomenon starting from so simple disturbance, it is obvious, the period has to decrease gradually. On the microbarographic records such examples are shown to have frequent occurrence, while different types also exist. Although every case is not so simple, the above fact can not give any serious objection against our theory.

(c) The number of wave crests is proportional to the distance from origin. When the mean period becomes small, this number increases, while the amplitude decreases with a factor of $\frac{1}{\sqrt{t}}$ even without another factor. This theoretical result coincides with the fact that the number of wave crests with short periods on the microbarogram is greater than that of comparatively long periods in general, and also the number of wave crests with small amplitude is greater than that with the large amplitude. Waves with very small amplitude are not recorded on the microbarogram; therefore in all cases the number of recorded waves of pressure is limited. Observations show that the number of waves in a series is generally 3–10 and rarely reaches 20. At first, the writer supposed that these barometric waves are formed in a manner similar to the generation of wind ripples, but if it were so, he could not explain a reason why the number of waves is very small. If, on the other hand, we regard these waves as formed by a limited initial disturbance or by analogous cause, the above question does not rise, and some important characters of the waves of pressure on the microbarograms can be explained.

(d) When the waves with approximately constant wave-length are formed by the dispersion of waves, a change of the conditions of the atmosphere occurs suddenly so that the waves with the first principle solution becomes non-propagative. Then the wave with isolated solution becomes powerful, and we have an accidental case in which the wave-length of the waves with the isolated solution coincides with that of the waves formed previously by the action of dispersion. In this accidental case, the waves with the isolated solution solely propagate without dispersion after this change of the condition happened. Of course, such conditions are not satisfied in our actual atmosphere. But when the atmosphere seperates into two domains, one is dispersive, and the other is non-dispersive but has the waves with isolated solution, the wave may be supposed to be propagated in a similar manner to the above artificial case.

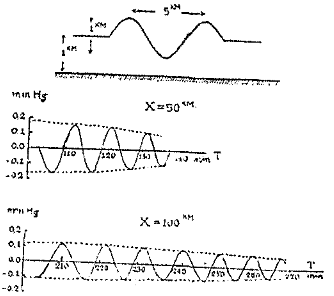
(v) Amplitude of the waves of pressure

Now by an example we shall illustrate that the amplitude of the wave of pressure thus formed is of a right order. From (6) the amplitude of the waves of pressure is $\frac{\phi(k_0)p'(k_0)}{\sqrt{2\pi Bt}}$. We assume that a case of an initial displacement consists of a limited train of harmonic waves. If $f(x)$ is symmetrical with respect to the origin and is zero except a range of $\left(2m+\frac{1}{2}\right)$ wave lengths, and within this interval we assume $\bar{A}\cos k'x$, then we have

$$\phi(k)=2\bar{A}\int_0^{(2m+\frac{1}{2})\pi/k'}\cos k'\omega\cos k\omega\, d\omega=2k'\bar{A}\,\frac{\cos\left\{\left(2m+\frac{1}{2}\right)\frac{\pi k}{k'}\right\}}{k'^2-k^2}\qquad\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots(14)$$

When $k_1<k'<k_2$, this factor becomes appreciable, but becomes non-appreciable when $k'>k_1$ or $k'<k_2$. However although this amplitude factor is also a periodic function of k it does not show any periodic

Fig. 22



character except when m is large, because the value of k is limited in the fixed interval.

We may examine some remaining questions by the following example. Assuming that $n=0.8$, $\overline{k'H}=1.20$, $m=\frac{1}{2}$ and $\bar{A}=500$ m, we have a theoretical curve of pressure change observed at two points 50 km. and 100 km. apart from disturbed origin, as in Fig. 22.

4. Some Discussions

(i) Note on the application of various theories on the microbarographic oscillations

For the analysis of the microbarograms, A. Wegner,[1] F. Trey[2] and W. Schmidt[3] applied Helmholtz's formula or the simplified formula of Stokes. The more genenal formula of Stokes was used in Goldies'[4] method which has a practical advantage for finding some information concerning the discontinuous layer by the observation at the earth's surface only. But the present writer believes that his method has some faults. The wind velocity of the lower layer may be greatly modified by the air viscosity which is not taken into account in his theory. In fact, for the approximate calculation of the change of pressure the frictional terms may be negligible, but these terms can not be neglected for finding the amount of the fluctuations of wind vectors at the bottom of the atmosphere. Thus the observed fluctuations of wind vectors are not available as long as we go by the theory in which the frictional terms are omitted. The writer of this paper believes that the apparent coincidence between Goldies' theory and the observation may be due to the existence of some freedom for selecting the necessary data from the observed facts.

Brunt's period of simple vertical oscillations has been applied by N. K. Johnson,[5] S. Fujiwara[6], and others. The method of estimation

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[1] Beit. z. Phys. d. fr. Atmosph. **2.** 55-72 (1906).
[2] Met. Zs. **36.** 25-28 (1919).
[3] loc. cit. **1.** 85.
[4] Q. J. R. Met. Soc. **51.** 239-246 (1925).
[5] Q. J. R. Met. Soc. **55.** 19-28 (1929).
[6] Center Met. Obs. Japan. Geophy. Mag. **1.** No. 6. 304 (1928).

of the lapse-rate of temperature from the observed period of barometric waves may be available in a very rough sense. But their method is not rigorous. Our theory gives greater accuracy for this subject. To confirm our theory completely by observation, some facilities, which we do not have at present, are needed.

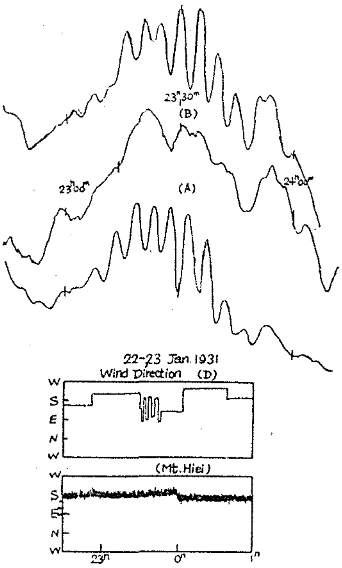
(ii) Comparison of the simultaneous records of three microbarographs in the Kyoto Basin

(*a*) *Influences of topography*

In most cases, our three microbarograms indicate very similar curves. Although the three observatories are not more than 4 km. apart one another, they indicate comparatively different shapes of curve in some occasions, as in Fig. 23. Here the first thing noticeable is the absence of regular waves at B-station. W. Schmidt already noticed similar phenomena at Insburg, and concluded that those are due to local distribution of Föhn. Such phenomenon seems to be an influence of the irregular surface of the earth. In fact, the discontinuous layer considered in many cases is estimated as below 1 km., which is comparable to the height of mountains. The mechanism of the influence, however, is not clear to the writer at present. H. Arakawa[1] endeavoured to explain these phenomena in question by modifying Helmholtz theory of waves. But the present writer believes that it is not so simple as his suggestion.

Fig. 23

22. Jan. 1931.
Microbarogram. (D)



(*b*) *Do stationary waves exist?*

W. Schmidt[2] previously said that sometimes there exist stationary waves, but afterward modifying his opinion, he took the view of the non-existence of stationary waves

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[1] Jap. J. Met. **10**. No. 12. 821 (1932).

[2] Brit. Ass. Rep. 543-544 (1910).

from the theoretical and observational standpoint. Our theory also comes to the same conclusion. If no difficulties were in finding the velocity of waves by a method of phase-identification, this problem could be solved very easily from the observational side. Actually, the present writer has met with many cases of waves, yet he can not determine exactly the state of propagation generally. But sometimes the propagating state was determined and he obtained several examples of clearly progressive waves, but no example which can be definitely identified as stationary.

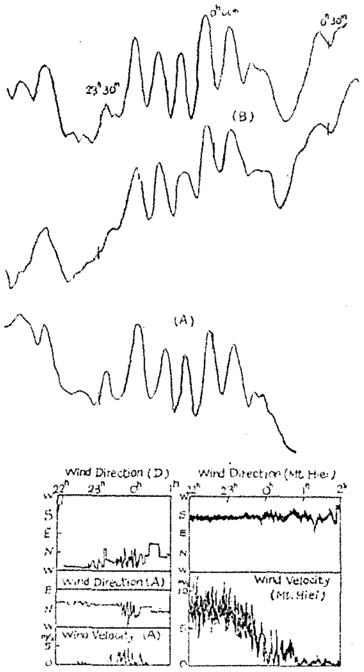
(iii) Relation between waves of pressure and other meteorological elements

(*a*) *Waves of pressure and oscillations of wind*

The correspondence of these is already discussed in the preceding part of this paper. In our observation at Kyoto, we have only a few examples of waves of pressure accompanied by oscillations of the wind. In Fig. 24 we give an example belonging to this type. In many a case, however, we have waves of pressure without oscillations of the wind. This is partly due to the low sensibility of our anemograph, but frequently we experienced no appreciable change of wind vector while the waves of pressure were recorded.

Fig. 24

25–26. Jan. 1931.
Microbarogram (D)



(*b*) *Appearances of undulated cloud and the waves of pressure*

We see many reports[1] of the waves of pressure recorded when undulated clouds appear overhead.

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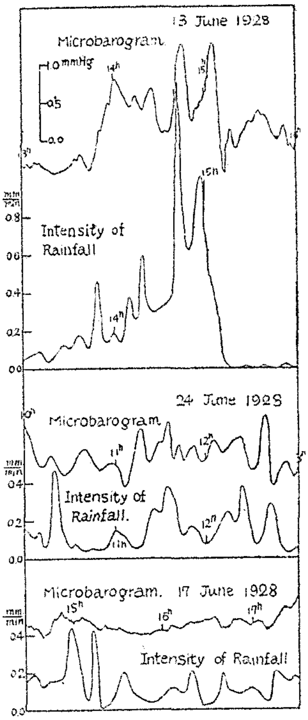
[1] Wegner: loc. cit. **1.** 102.
Kopp: Beit. z. Phys. d. fr. Atmosph. **13.** 198–217 (1927).
Y. Isimaru: Chuō Kishodai Ihō. **4.** Japan.
H. Arakawa: Jap. J. Met. **10.** No. 12. 727 (1932).

Usually wave clouds in a high or middle layer of the atmosphere appear with a short period (less than 1 min.). Such short periodic waves are beyond the scope of this paper. Wave clouds with longer wave-length, several kilometers or more affect the curves of pressure, but the writer has no example of them. We obtained the waves of pressure apparently without any wave clouds overhead.

(c) *Pluviographic and microbarographic oscillations*

H. Clayton's[1] opinion of the origin of the periodic change of the intensity of rainfall is not identified from our observations. For example, in Fig. 25 the fluctuations on the pluviogram are not always accompanied by the waves of pressure. Hence the pluviographic oscillation must occur by another way.

Fig. 25



(d) *Will the appearance of the waves of pressure with longer period be prognostic phenomena of rain?*

Taking the period of the waves of pressure as an index of the stability of the atmospheric layer, Dr. S. Fujiwara[2] said that the appearance of oscillations of pressure with period more than 10 min. is a prognostic phenomenon of rain. Some discussions in this line had been done by Devies[3] and Y. Miyayama.[4] The present writer concludes that this relation is not perfect and that from our experiences at Kyoto they are nearly independent phenomena.

(iv) On the atmospheric waves of different kinds

The writer concludes that the great part of the waves of pressure shown by our microbarograms are due to the internal gravitational wave at the surface of discontinuity. But

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[1] Harvard Ann. **11**. Appendix.

[2] loc. cit. **6**. 102.

[3] Met. Mag. **64**. 191–192 (1929).

[4] Jap. J. Met. **9**. No. 4. 164 (1932).

in rare cases some different types of waves had been recorded. As for latter types of waves we have two well-known papers of G. I. Taylor[1] and F. J. W. Whipple.[2] Those waves propagate nearly with sound velocity and are taken to be an external waves of the atmosphere. The oscillations of cyclones to which S. Takaya[3] drew our attention are also omitted here, because their real existence is not yet ascertained.

Section II

On the Type of Microbarographic Depression

1. Typical examples of the type of microbarographic depression

On the microbarograms, we often find a curve which is similar to that of cyclonic depression on an ordinary barogram. Yet the duration of the variation is half an hour or so, and the deviation of pressure is about 1–4 mm. Hg. Though, at first sight, it seems to be a cyclone of a minor scale, it is doubtful. The pressure curve of this kind will be herein called "Microbarographic Depression-Type."

Ex. 1. 19 h. 17th. December 1929.

The reproduction of the microbarogram shown in Fig. 26 represents a depression of about 1 mm. Hg depth at 19 h. 18 m. Its velocity of propagation will be found by the phase-identification at three different stations, if we assume the depression propagates with unchanged form. But the assumption is not probable because its form varies rapidly. Yet this assumption may be admitted for the phase-identification between considerably near stations. Moreover, there are some instrumental errors, so it is not easy to perform the identification perfectly. In this example, three phases can be identified as the figure shows, and even though the time differences do not coincide precisely, it will be reasonable to take the propagation vector as 8 m. p. s. toward ENE.

In spite of the rapid variation of pressure, we cannot find any appreciable phenomena of the other meteorological elements. According to the data in Fig. 26 the wind-direction varies from east to west;

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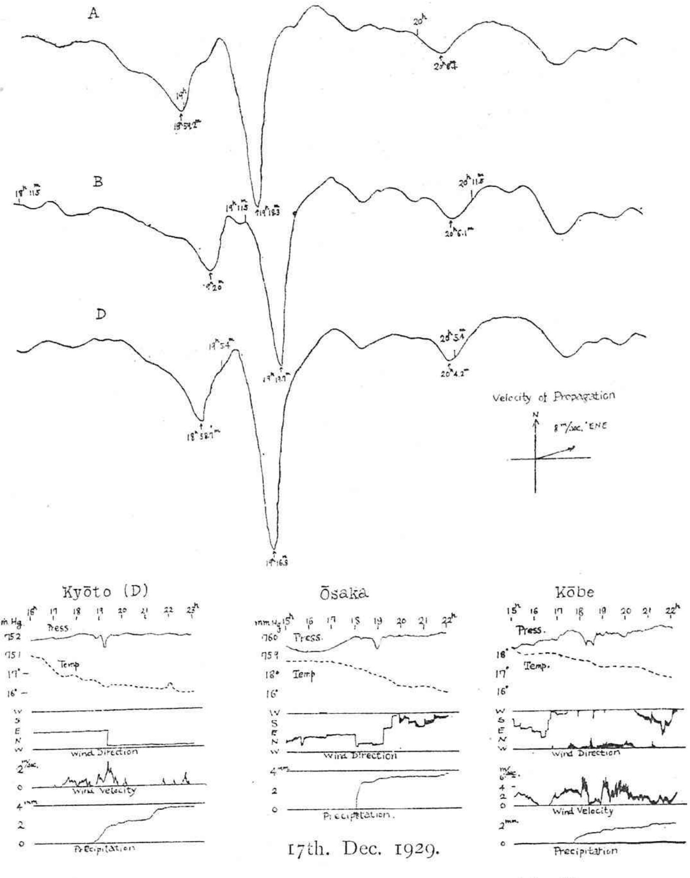
[1] Proc. Roy. Soc. London. **126**. p. 169–183 (1930).

[2] Q. J. Roy. Met. Soc. **56**. 287–340 (1930).

[3] Mem. Imp. Marine Obs. **3**. No. 4. (1929).

Fig. 26

17th. Dec. 1929.

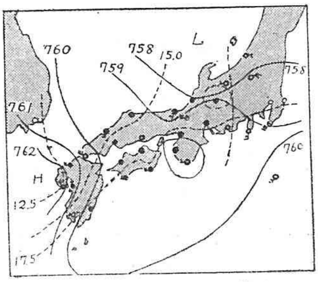


17th. Dec. 1929.

17th. Dec. 1929.

17th. Dec. 1929.

Fig. 27



1929. Dec. 17th. 18^{h}

the wind-velocity is very small, rising to 2 m. p. s. only when the depression passes, at which time the rain ceases. The air-temperature does not vary. As the result of such pressure-variation, the barometric gradient must be considerably large, but the wind-velocity is too small to maintain this gradient. Accordingly, we may understand that it is impossible to regard this type as a revolving fluid. Fig. 27 shows the weather chart at 18 h. of this day.

Ex. 2. 18 h. 4th. April 1923.

At 18 h., a curve which is similar to that of Ex. 1. is recorded. (See Fig. 28). In the course of this day, the wave-like pressure-change happens continuously. Among these fluctuations, this single depression is observed just before rain stops. There are some cases as this example in which the depression happens just before or after the rain stops. In Fig. 28 disturbances of pressure are also remarkable at the Yagi Meteorological Station, yet the form of the disturbance is different from that of Kyoto. On the weather chart of Fig. 29. a juxtaposition of warm and cold air is represented near a discontinuous

Fig. 28

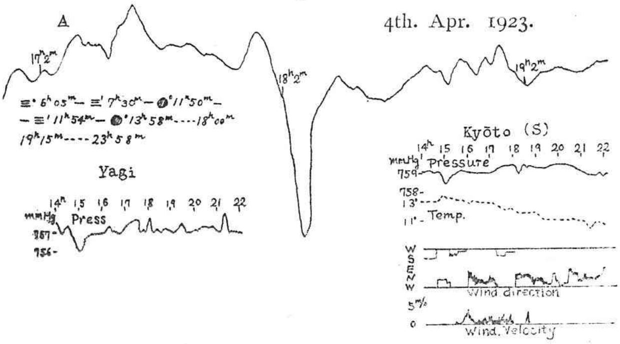
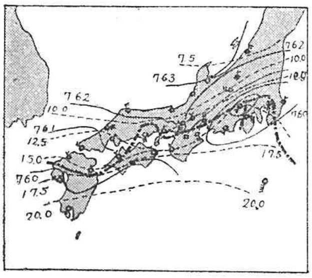


Fig. 29



1923. Apr. 4th 18h

line at a rear part of the secondary cyclone. It is supposed that this is a sort of disturbance or wave generated at the contact layer of the warm and cold air.

Ex. 3. 15 h. 5th. June 1920.

In Fig. 30, we see an almost symmetrical curve of pressure-depression. A barometric trough of typhoon passed at about 14 h. and the depression appeared one hour later. Main rainfall stopped and became very slight after the passage of this depression. Essentially, this is a position where a squall appears, and a small secondary depression at the rear of the single depression on our microbarogram is similar to the depression followed by the head of a squall. From

Fig. 30

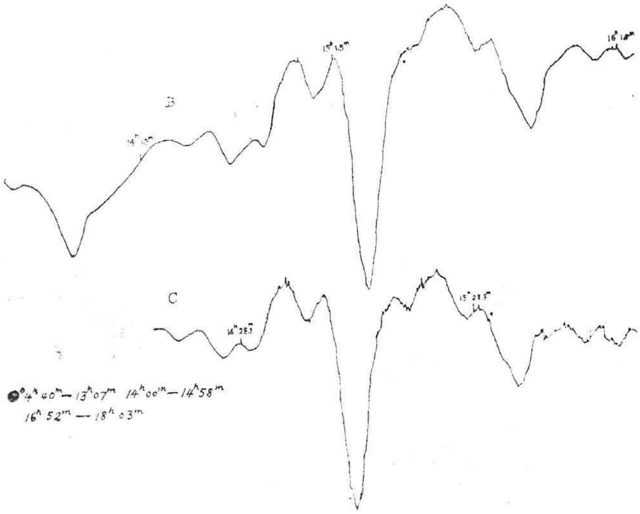
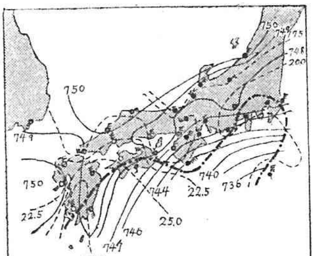

5th. Jun. 1920.

Fig. 31



1920. June 5th 14^h

these circumstances, it seems to us that something happens about the passage of squall-line, and this may be a phase of the pressure-change associated with the squall-line. Weather chart is represented in Fig. 31.

Ex. 4. 5 h. 30 m. 25th. Feb. 1927.

This example of a single depression is not symmetrical as the former one. (Fig. 32). The disturbance is observed at the tail of the eastward migratory anticyclone as seen on the weather chart shown in Fig. 33. It is cloudy and begins to snow from 13 h. 45m. We observe many such disturbances at the tail of anticyclone. Seeing the records at many observatories, we suppose this depression propagating towards NE at the rate of about 25 m. p. s.

Fig. 32

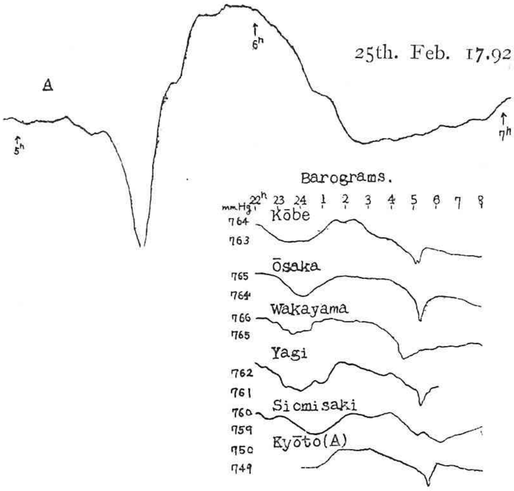
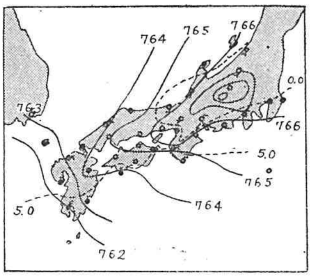


Fig. 33



1927. Feb. 25th 6h

Ex. 5. 7 h. 4th May 1923.

The pressure-curve shown in Fig. 34, is almost similar to that of Ex. 4, but appears at the rear of a cyclone. (See weather chart Fig. 35). It ceases to rain at the end of this disturbance. After a while, the westerly wind begins to blow hard and the weather settles. While the weather is changing, there are many cases of this type like this example.

Ex. 6. 8 h. 28th. May 1926.

After 8 h., a single depression is recorded as shown in Fig. 36. At about 10 h. this depression is accompanied by waves of about 5 min. period. We suppose that these waves are due to the existence

Fig. 34

4th. May. 1923.

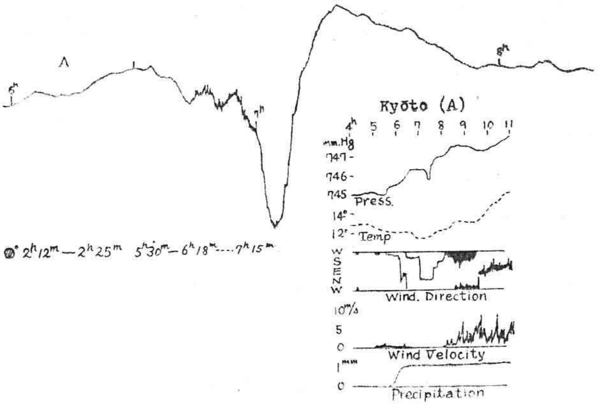
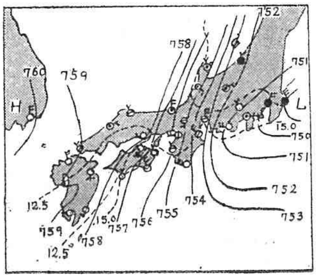
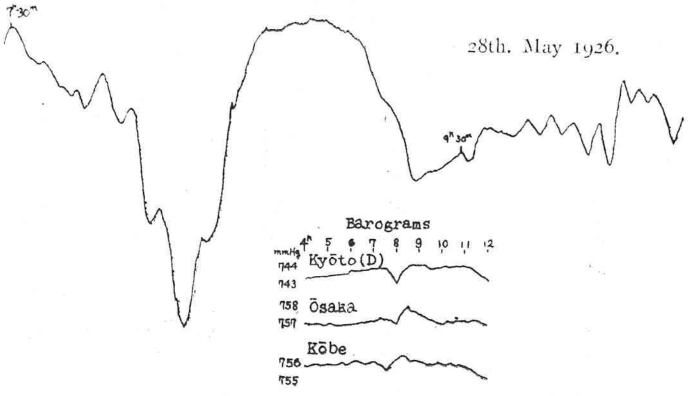


Fig. 35



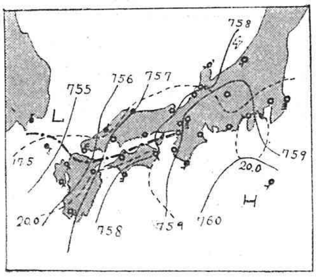
1923. May 4th. 6h

Fig. 36



28th. May 1926.

Fig. 37



1926. May 28th. 6h

of a surface-layer, and the waves of a larger scale are due to the disturbance at a considerably high upper layer (ca. 3 km. ?). The wave velocity is determined to be ca. 15 m. p. s. towards ESE from the data of Kyoto, Osaka and Kobe, but it is uncertain. The weather is cloudy and fine rain begins at 8 h. It seems to us from the weather chart (Fig. 37) that this disturbance appears at the tail of anticyclone along the isobar of 758 mm.

Ex. 7. 6 h. 30 m. 10th. Jan. 1928.

At half past 6 h., a single depression passes, and before and after this time, wave-like oscillation appears. (Fig. 38). On the weather chart, (Fig. 39) there is a discontinuous line which contains

Fig. 38

10th. Jan. 1928.

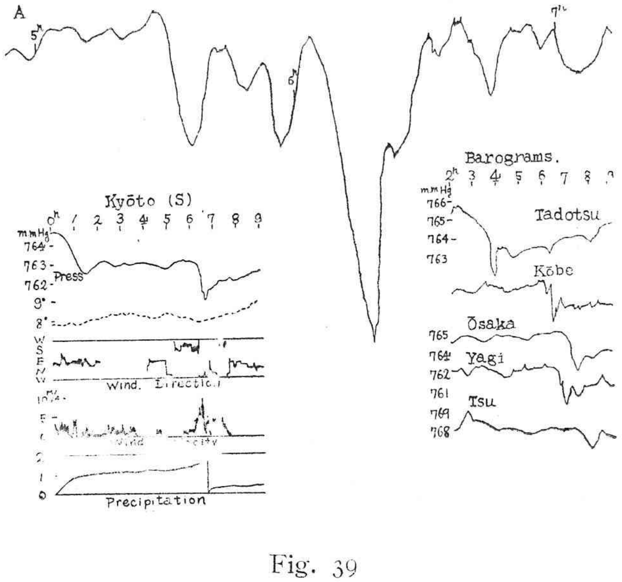
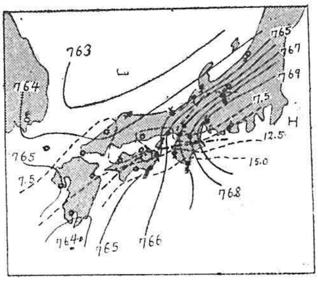


Fig. 39



1928. Jan. 10th 6h

a secondary cyclone in the southern part of the main cyclone. Therefore this disturbance is generated along this line. At the time when it passes, the wind-direction varies rapidly from S to NW and the wind-velocity increases to ca. 6 m. p. s. Rain stops after the passage of this line. Though this disturbance may propagate with varying velocity and form, we can estimate that this propagates from NW

Fig. 40

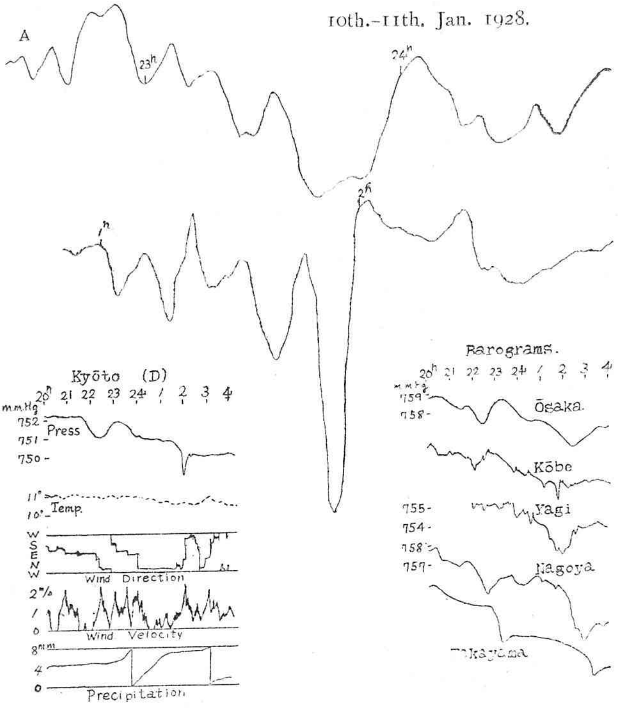
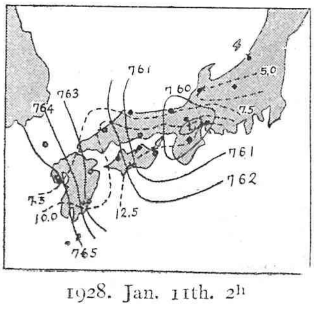


Fig. 41



1928. Jan. 11th. 2h

Fig. 42

26th. Sept. 1929.

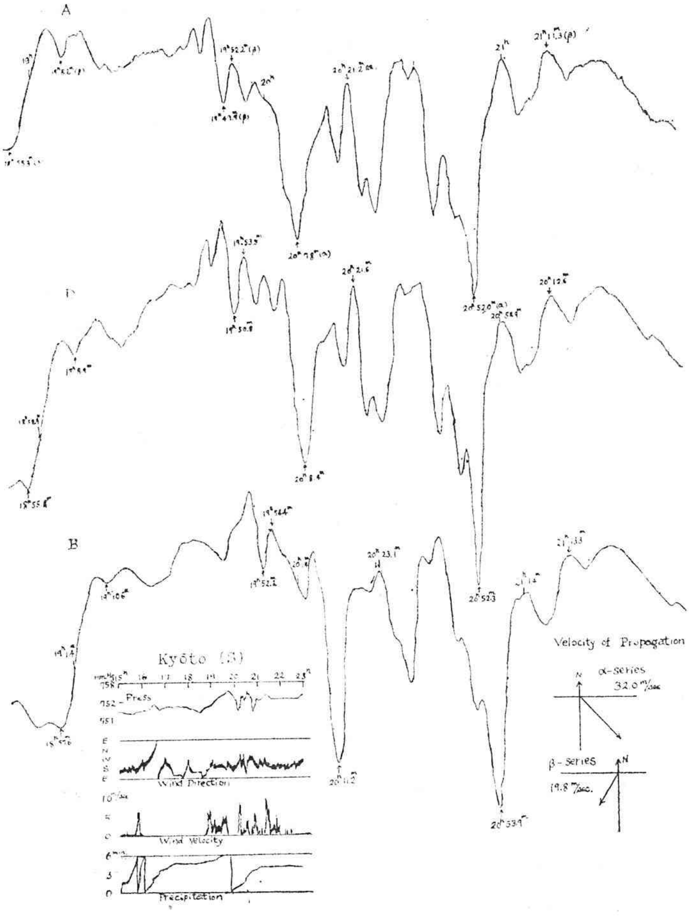
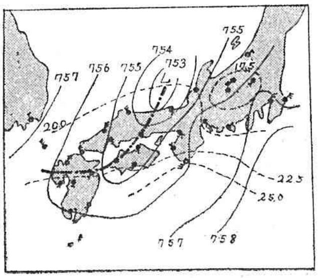


Fig. 43



1929. Sept. 26th. 18h

to SE at the rate of 18 m. p. s. passing through the vicinity of Kyoto.
Ex. 8. 2 h. 11th. Jan. 1928.

At a little before 2 h., a single depression passes (Fig. 40) near the center of a shallow cyclone (Fig. 41), accompanied by continual

Fig. 44

24th. Apr. 1922.

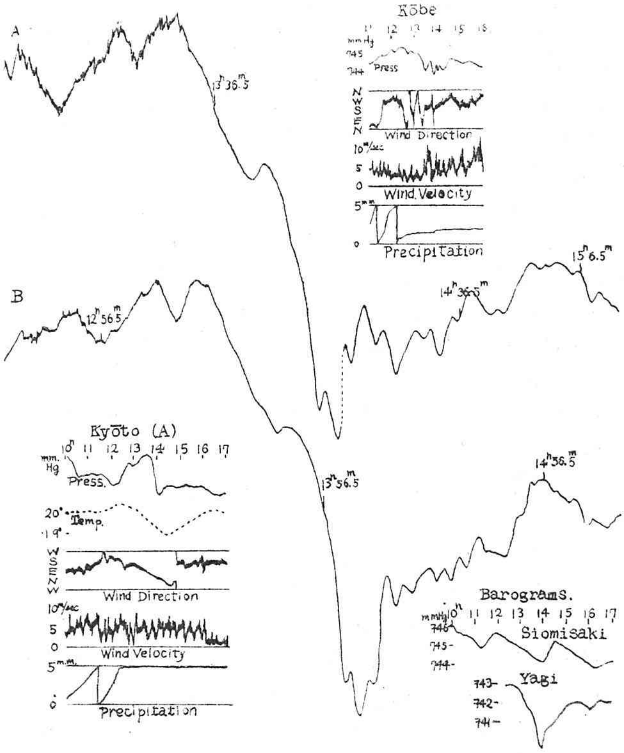
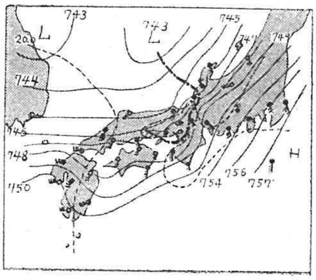


Fig. 45



1922. Apr. 24th. 14h

rain. Wind-direction veers, but wind-velocity does not increase, as the case of Ex. 7. It contains considerably wave-like oscillations. Seeing this fact, it is impossible to regard this type as a single vortex. The disturbance is recorded conspicuously by Sprung's barograph at Kobe, but not recorded at the other observatories. It is uncertain whether the fact depends on the lack of sensibility of Richard's barograph or the absence of the disturbance.

Ex. 9. 20 h.–21 h. 26th. Sep. 1929.

In this example, very irregular disturbances of pressure are observed in the rear part of the upper front at 19 h. There are three remarkable depressions among them, but two of them are of peculiar shape. (See Fig. 42). Remarkable disturbances (α-series) propagate from NW to SE at the rate of 32 m. p. s., and the small wave-like oscillations (β-series) from NE to SW at the rate of 20 m. p. s. The small disturbance may be an oscillation of the surface layer, whereas the primary travelling pressure-change takes the simple form of the previous example. In Fig. 42, it is obvious that the form of the disturbance varies rapidly. Rain stops after the occurrence of this disturbance. Fig. 43 shows that this disturbance happens near a discontinuous line in the south-western part of the cyclone.

Ex. 10. 14 h. 24th. April 1922.

At about 12 h., a minor squall passes and at half past 13 h., the pressure falls rapidly at the rear of barometric trough, and there occurs a single depression. (See Fig. 44). This example is also a pressure-change observed along a discontinuous line of cyclone of Fig. 45. From the fact that the curve at Tadotu in Fig. 38 of Ex. 7 is similar to that of Kyoto in this example, we can conclude that all sorts of different forms of pressure-curve which belong to this type appear as merely the partial phases of pressure-disturbances which happen along a discontinuous line.

Ex. 11. 6 h. 11th. June 1919.

At just before 6 h., a single depression is recorded. (See Fig. 46). This is a typical example in which the V-shaped depression developes at the south-western tail of a shallow depression, and owing to it, thunder showers and pressure-disturbances occur. (See Fig. 47). At Fukui and Turuga, thunder showers are also observed. From these records, it is clear that this line propagates from WNW to ESE at the rate of ca. 20 m. p. s. in the neighbourhood of Kyoto.

Ex. 12. 16 h. 3rd. June 1919.

On our barogram at Kyoto, the base of the depression is parted

Fig. 46

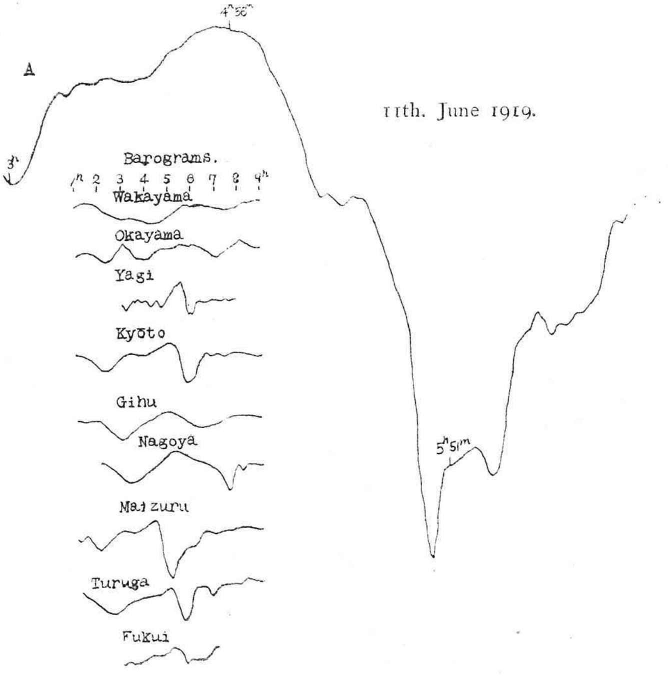
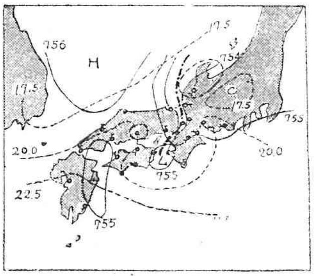


Fig. 47



1919. June 11th. 6h

in two, and at Osaka, the depression is consisted of two parts conspicuously. (See Fig. 48). This curve is similar to that of Fig. 32 in Ex. 4 at Kobe. When we compare the records of the other stations on that day, we can find some curves which are similar; for instance, the curves at Maizuru and Toyooka are nearly similar to that of Fig. 44. At 18 h., there is a secondary cyclone on the discontinuous line near Yagi. (See Fig. 49, *a*). Fig. 49, *b* is an isochronous chart which shows that this depression propagated from NW to SE at the rate of ca. 15 m. p. s.

Meteorological data of Kyoto are

●° $13^h13^m-16^h55^m$, S. 1.5 m/s at 16^h, W. 3.2 m/s at 17^h, and N 2.2 m/s at 18^h.

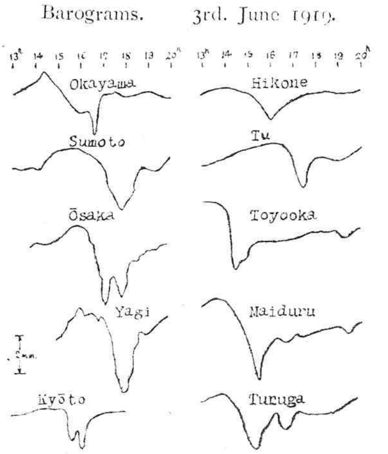
and of Osaka

N→SE at 16^h30^m, SE 17.8 m/s at 17^h15^m

SE→N at 17^h50, N 15.6 m/s at 18^h.

And whirl wind is observed.

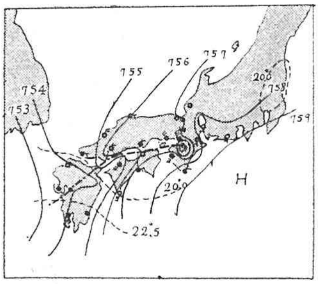
Fig. 48

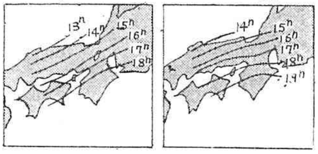


Barograms. 3rd. June 1919.

Fig. 49, *a*

1919. June 3rd. 18^h





b Isochronous chart of sudden Depression

c Time when Rain stopped

From these facts we know that even in a region of prevailingly weak winds as Kyoto, the wind blows hard above the surface layer. It rains before this disturbance at every place; but after it, it ceases to rain. The time when rain stops is illustrated in Fig. 49, *c*, and this isochronous line is parallel to that of Fig. 49, *b*. Hence, this disturbance happens just before the establishment of steady weather.

2. Statistical study of the type of microbarographic depression

Now we examine statistically all these records for eleven years from 1919 to 1929 which belong to this type. In the first place, we classify them by the pressure-distribution.

A-Type: A-Type happens at the tail of an anticyclone migrating eastward. Generally, this type occurs before bad weather, because it is followed in most cases by cyclones. But some of them which belong to this type appear in good weather. The results of our statistical study show that more than half of depressions of this type are recorded in rainy weather. But since this type occurs even in clear weather, we cannot say definitely that this phenomenon is always accompanied by rain or cloud. The discontinuous surface which is the essential condition for the formation of microbarographic depression may be formed in the anticyclonic zone mentioned above between the north-easterly surface current and the upper current from the south.

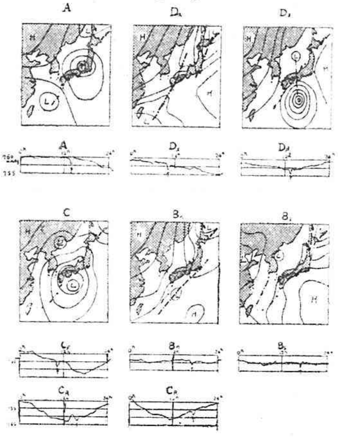
D-Type: As D-Type, we classify cases in which a discontinuous line of a distant cyclone appears, but no cyclone exists near the observatory which is situated at the central portion of low pressure zone of col-shaped isobar. Since the juxtaposition of warm and cold air, which is very natural for the formation of the microbarographic depression, is essential in this case, we have a great number of records of this type in our statistics. D_α-Type consists of discontinuous lines oblique to the latitude circle, and in this case we find depressions with many other disturbances during bad weather. D_β-Type occurs when the discontinuous line is nearly perpendicular to the latitude circle. As this line passes rapidly, the depression is observed just before the recovering of weather. As a whole, this type appears in bad weather (cloudy or rainy), but rarely in good weather.

C-Type: This is a case when the disturbances are supposed to belong to a cyclone whose center passes near our observatory. C_F-Type consists of single depressions appearing before the center of a cyclone; and C_R-Type, when they occur after it.

B-Type: B-Type happens on the border of an anticyclone. B_N-Type is a winter type in which there is an anticyclone in the north, while B_S-Type is a summer type with an anticyclone in the south. In both of these cases, also, it seems to us there is a juxtaposition of warm and cold air along this border.

The chief characteristics of the distri-

Fig. 50



bution of pressure and those of the barograms are shown in Fig. 50, and the number of occurrences are tabulated as follows:

Type	A	D	C	B	Total
No. of Occurrence	22	46	38 (C_F21 ; C_R 17)	31	137
When it rains	10	30	33(12)*	24(6)*	97
When it does not rain	12	16	5	7	40

( )* *is the number of occurrences of this depression at the end of main rain-fall.*

According to these results, though the occurrence of disturbances of this kind is not necessarily accompanied by rain, they appear, without exception, at the line of contact of warm and cold air.

The time-relation of the occurrences of this type is as follows:

Hours	22h–2h.	2h–6h.	6h–10h.	10h–14h.	14h–18h.	18h–22h.	Total
No. of Occ.	22	28	24	24	23	28	149

Thus they are distributed uniformly. The seasonal variation is as follows:

Month	Jan.	Feb.	Mar.	Apr.	May.	Jun.	Jul.	Aug.	Sep.	Oct.	Nov.	Dec.
No. of Occ.	11	12	14	9	13	15	16	5	11	9	14	20

December has maximum while August has minimum. However they are distributed according to the seasons almost uniformly:

Season	Spring	Summer	Autumn	Winter
No. of Occ.	36	36	34	43

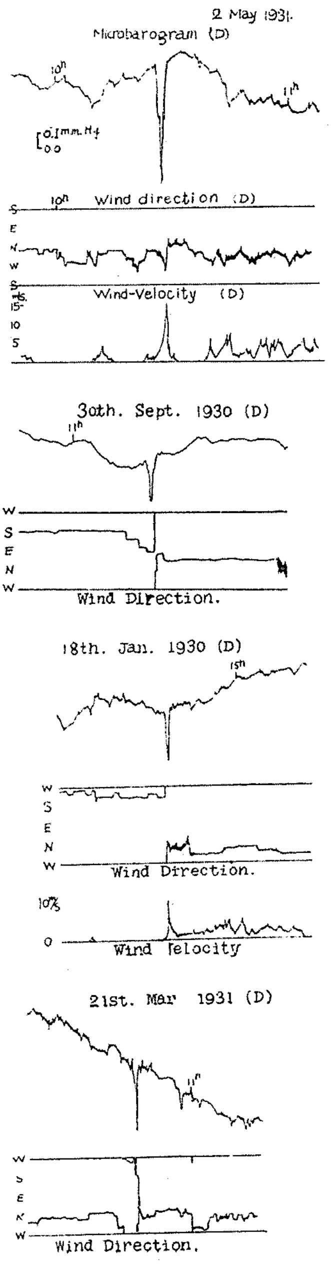
3. Microbarographic depression type of the second kind (record of small whirl-wind)

When a small whirl-wind passes through our observatory, we always observe some corresponding change in pressure, wind velocity, and direction. In our locality, the whirl-wind observed often has very small scale, and usually it passes only one of the three observatories. "Microbarographic Depression Type of the Second Kind" is such a minor rapid depression of pressure recorded on our microbarogram by a small whirl-wind; and this type is to be clearly distinguished from the former type which is named "Microbarographic Depression Type of the First Kind." The Second Kind appears often in fair weather with strong solar radiation and is of thermal origin. It is observed frequently at our Special Meteorological Institute (D-station) which is situated on a level land, but very rarely at the Kamigamo Observatory (A-station) which is situated on the top of a small hill. Thus this phenomenon is identical to a whirl-wind or tornado on a very small scale. Sometimes we see the same kind in windy day. Some of them are small whirl-winds of dynamical origin. When this kind is observed at A-station, it belongs to the latter

Table 6

Month	No. of Occ.	Hours	No. of Occ.
Jan.	1	0-2	2
Feb.	5	2-4	0
Mar.	2	4-6	0
Apr.	3	6-8	1
May	8	8-10	3
Jun.	7	10-12	13
Jul.	0	12-14	12
Aug.	5	14-16	4
Sep.	5	16-18	2
Oct.	1	18-20	2
Nov.	2	20-22	0
Dec.	0	22-24	0

Fig. 51



one in almost all cases. Fig. 51 shows typical examples of this kind. And Table 6 gives its distribution of frequency of the appearance of this kind at D-station for two years 1929–1930.

4. Some discussions on "Microbarographic Depression Type of the First Kind"

Reports or discussions on this type of depressions are very rare. So far as the writer knows at present, W. N. Shaw is the only meteorologist who payed any attention to the subject. It seems, at first sight, to be a cyclone on a minor scale, just as the second kind of this type is a miniature whirl-wind. But the conditions of the wind, while this type is being recorded, are not identical with those commonly associated with cyclones. In fact, the greater part of instances of it appear on days which are nearly "calm," and the change of the vector of the wind is not the same as after the passing of a cyclone. In this respect, W. N. Shaw says; (Manual of Meteorology, part IV 1919);

> "Fluctuations such as are indicated in this figure occur in what may be called thundery weather but at some hundred miles away from the locality where the thunderstorm is taking place. The largest of those represented in the figure was accompanied by heavy clouds and a few drops of rain but nothing more. It seems hardly possible to regard them otherwise than as local whirls of air, though we have no actual evidence of wind-velocity in favour of that view, because there seems no explanation of the maintenance of the pressure-distribution for the duration indicated in the diagram on any other hypothesis." (p. 149–150)

Our observations also support this opinion. But afterward he seems to have come round to the view that it is due to the result of revolving fluid, for he says in the Manual of Meteorology Vol. IV, 1931;

> "The air-current of 50 miles per hour that carried the train from Petersfield to Cambridge was not indicated at the surface at any of the stations, nor was there any notable wind while the two depressions were passing. The current must have been in the upper air carrying the local spins in the same way that a travelling cloud carries water-spouts." (p. 277)

The determination of the nature of the depression of this type has been one of the most puzzling questions in the writer's research on microbarographic observations. Although it is impossible, at present, for the writer to attain to a definite conclusion, he may reasonably assert that it occurs not only as a result of revolving fluid, but also, in some cases, on account of the internal gravitational waves of the atmosphere. In order to corroborate this view, facts deduced from the study of the typical examples previously given are enumerated below :—

(i) Though the barometric traces at some stations near the trough-line of cyclone are not identical with each other in individual phase, we find at a glance some remarkable similarity between them. Such fluctuations of pressure generally appear with line-front, which either coincides with a discontinuous line or lies near it. This fact is the contrary when we assume that it is due to the revolving fluid, for it must have a circular distribution.

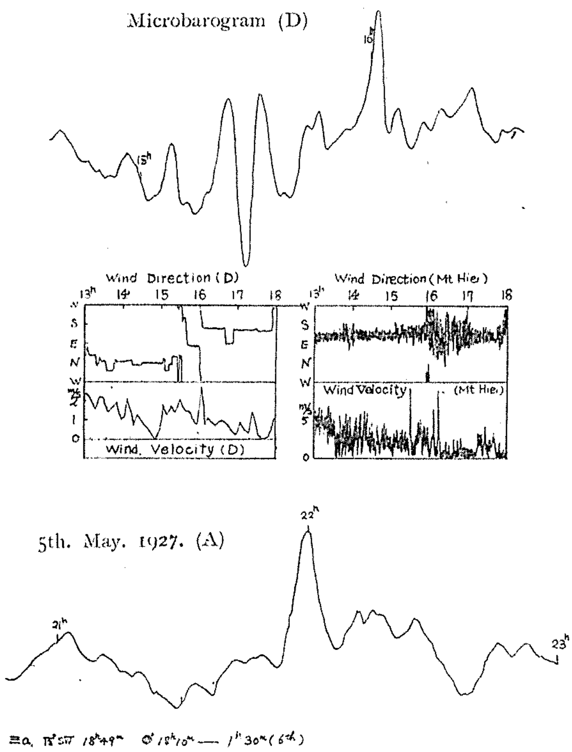
(ii) In almost all cases, these phenomena happen in cloudy days when the lower layer of the atmosphere is usually covered by cloud-sheet. This condition suggests the existence of a discontinuous surface. It often appears in so-called thundery weather as W. N. Shaw says. Therefore, when it is recorded, it is to be supposed that some violent phenomena such as a thunderstorm or a squall are happening near by, though not directly attacking our observatory.

(iii) Sometimes a single depression of pressure in question can be found among the wave-like change of pressure on our micro-barograms. And in some cases this single depression is regarded as one particular wave, among the series of waves, whose amplitudes for some reason are greatly intensified. Moreover we can find some intermediate type between this and the waves of pressure illustrated in Section I of this paper.

(iv) On other occasions, we see a reverse curve of this depression type, which indicate "Microbarographic Anticyclone." Such anticyclone on a small scale can not be caused by rotating fluid, while it is possible for the anticyclone in ordinary sense. If we regard this as a result of the internal waves at the surface of discontinuity, an illustration for its generation becomes easier. Fig. 52 shows an example of this class.

(v) As for the conditions of the wind, there is no evidence for the existence of the revolving fluid in general. Our wave theory also demands some considerable change of wind vector to maintain its sharp pressure gradient that must exist when the single depression is passing. Even though a considerable change of the wind is not necessary for the wave with high propagation velocity, the actual change of it is very small. But we have some examples where a considerable change of wind vector is observed at the top of Mt. Hiei, while no appreciable change is observed at our institute situated at

Fig. 52



30th. Apr. 1932

Microbarogram (D)

5th. May. 1927. (A)

the bottom of the basin of Kyoto, when a single depression of this type is passing. Fig. 52 shows an example to illustrate this point.

From above mentioned view points, we suppose that these fluctuations are due to some disturbance of the surface of discontinuity caused by a sudden replacement of two air masses, cold and warm, or to a sudden impulse caused by a violent motion such as thunder-squall. The wave motion caused by a limited initial disturbances has been treated in the preceding part of this paper (see § 4. Section. I. part II). If we observe it at sufficient distance from the disturbed origin, we obtain the waves of pressure at this locality. On the other hand, if we observe it at a point not far from the origin, and when the dispersive power of the wave is not strong, the microbarograph may record this type. Now we shall show a possibility of the above view by a very rough calculation. Rigorous and precise discussions are out of the writer's power at present. Here we treat a case when the main term of the fluctuation of pressure is[1]

$$p=\frac{1}{2\pi}\int_{k_1}^{k_2}\psi(k)\cos k(x-Vt)dk$$

and

$$V=A-\frac{B}{2}k.$$

If its dispersive power is not strong we have approximately,

$$p\fallingdotseq\frac{\psi(\bar{k})}{2\pi}\int_{k_1}^{k_2}\cos\left[k(x-At)+\frac{\bar{k}^2Bt}{2}\right]dk$$

where

$$\bar{k}=\frac{k_1+k_2}{2}.$$

Then we have

$$p\fallingdotseq\frac{\psi(\bar{k})\sin\frac{(k_2-k_1)}{2}(x-At)}{\pi(x-At)}\cos\left[\bar{k}(x-At)+\frac{\bar{k}^2Bt}{2}\right]$$

where

$$\psi(\bar{k})=p'(\bar{k})\phi(\bar{k}).$$

If we select a case of

$$\phi(\bar{k})\fallingdotseq2k'D\frac{\cos\left\{\left(2m+\frac{1}{2}\right)\frac{\pi\bar{k}}{k'}\right\}}{k'^2-\bar{k}^2}$$

and

$$m=\frac{1}{2}\qquad\qquad k'=\bar{k},$$

then we have

$$\phi(\bar{k})=\frac{3\pi D}{2k'}.$$

Therefore we finally get

$$p=\frac{3p'(\bar{k})D}{2k'(x-At)}\sin\left[\frac{k_2-k_1}{2}(x-At)\right].$$
$$\times\cos\left[\bar{k}(x-At)+\frac{\bar{k}^2Bt}{2}\right].$$

This expression shows that the amplitude of the waves is

---

[1] All the notations are the same as § 4. Section I. part II.

$$\frac{3p'(\bar{k})D}{2k'(x-At)}\sin\left[\frac{k_2-k_1}{2}(x-At)\right],$$

which has a maximum at $x=At$.
Moreover this indicates the oscillation of beat form.

When

$$n=0.9 \quad n'\doteqdot 1.0 \quad \overline{k'_{or}H^2}=0.01 \quad H=3\text{ km} \quad \frac{\Delta\theta}{\theta}\doteqdot\frac{1}{30}$$

$$\bar{V}\doteqdot 30 \text{ m. p. s.} \quad \text{and } U=0 \quad U'/\bar{V}=0.8,$$

we have

$a=1.08$ $\quad k_1=0.198\times 10^{-5}$

$b'=0.36$ $\quad k_2=0.528\times 10^{-5}$

$A=3.29\times 10^{3}$ $\quad \overline{k_1H}=0.60$

$B=3.27\times 10^{8}$ $\quad \overline{k_2H}=1.59$

and

$$p=-\frac{3}{2}\,\frac{0.071D}{30K(X-A'T)}\cdot$$

$$\times\sin\left[\frac{K_1-K_2}{2}(X-A'T)\right].$$

$$\times\cos[\bar{K}(X-A'T)+\bar{K}^2B''T]$$

where $\bar{K}=0.367$, $A'=1.97$, $B'=1.96$, $B''=\frac{B'}{2}=0.98$ and in the above expression D is expressed in meters. Putting $D=500$ m., we have at last

$$p_{\text{mm.}Hg}=4.88\frac{\sin[0.165(X-1.97T)]}{X-1.97T}\cdot$$

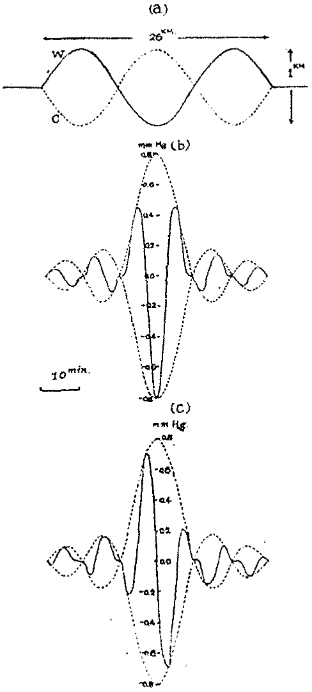
$$\times\cos[0.363(X-1.97T)+0.129T].$$

The amplitude of this wave is

$$4.88\frac{\sin[0.165(X-1.97T)]}{X-1.97T}$$

which is indicated by dotted line in Fig. 53. Its period is about 19.3 min., and it has maximum value at $X=1.97T$. The period of individual waves is 10.7 min. This approximate solution can represent various shapes of the curve. For instance when

Fig. 53



$$\cos[0.363(X-1.97T)+0.129T]=-1$$

and

$$X=1.97T_0$$

we have a microbarographic depression of the symmetrical type. When

$$\cos[0.363(X-1.97T)+0.129T]=0$$

and $X=1.97T_0$ the oscillation will be of the asymmetrical type of this kind, as is illustrated by Fig. 53 and Table 7.

Table 7

Case	cos(,,)=0	cos(,,)=−1	cos(,,)=0	cos(,,)=1	unit.
C	$X=24$ $T=12.2$	48 24.3	72 36.5	98 48.6	km. min.
W	$X=72$ $T=36.5$	98 48.6	24 12.2	48 24.3	km. min.
Fig.	Upset of 53.c	53.b	53.c	upset of 53.d	

Thus the writer believes that this simple theory may give some comprehensive illustration for these curious characters of this type, though the above calculations are not exact. F. Yamasaki[1] gave an example of this kind under the title, "Fluctuation of Pressure with Beat-Form," which also may be taken as an example of ours, while H. Arakawa's[2] theory for it is not satisfactory to the present writer.

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[1] Jap. J. Met. **9.** No. 10. 567 (1932).

[2] Jap. J. Met. **9.** No. 10. 545 (1932).