

EARTH TREMORS IN CENTRAL JAPAN.

(SECOND PAPER.)

By JOHN MILNE.

[Read December 4th, 1888.]

On November 18th, 1886, I read a paper before the Seismological Society on Earth Tremors in Central Japan (see Trans. Seis. Soc., Vol. XI., p. 1-78). In that paper I described the various tremor indicators which I have used in Japan, concluding with a description of an instrument which gave automatically a continuous record of tremors. The records given in this paper were obtained by the same instrument. They extend from December 22nd, 1886, to February, 1888. At certain times owing to my absence from Tokio the instrument was not working. In the following list these dates have been omitted. The tremors are recorded as indicated on two bands of paper, one running N.N.E. and the other running N.N.W. The letter *T* means tremors of considerable magnitude indicated as a line of perforations from 2 to 5 millimeters broad. *ST* means small tremors forming a line from 1 to 2 millimeters broad. *VST* means very small tremors. A. and P., which are usually prefixed by a numeral indicating hours, mean morning or A.M. and afternoon and night or P.M. In the column headed "Wind," *O* means that in Central Japan there was no wind or only a gentle breeze of force 1 in Central Japan, or wind not exceeding force 3 at not more than one place, and this place was not Tokio when the observations were made; *w* means that there was wind of not more than intensity 2, at not more than two places in Central Japan. *W* means that there was wind of force 2 or of greater than 2 at a number of places. *WT*₃ or *WT*₄ means that there was a strong wind of force 3 or 4 blowing at Tokio only.

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The data referring to wind were obtained from the tri-daily weather maps published by the Meteorological Department of this country, the observations being made at 6 a.m., 2 p.m., and 9 p.m.

The wind intensities are as follows :—

0 = calm	=	0—1.5 meters per second.
1 = light	=	1.5—3.5 meters per second.
2 = moderate	=	3.5—6 meters per second.
3 = strong	=	6—10 meters per second.
4 = gale	=	10—15 meters per second.
5 = heavy gale	=	15—29 meters per second.
6 = hurricane	=	29—104 meters per second.

By Central Japan is meant the country within 200 to 300 miles of Tokio in which area there are eleven observing stations telegraphically connected with the capital.

In the column headed "Remarks" reference is made to the height of the barometer expressed in millimeters at Tokio, and the position of the centre of the barometrical depression.

The reason for giving prominence to wind intensity rather than to any other meteorological phenomena will be understood by a perusal of the results of analyses given in my previous paper. These results were as follows :—

1.—Earth tremors are more frequent with a low barometer than with a high barometer, but even with a low barometer it may often happen that tremors are not observed.

2.—With a high gradient tremors are almost always observed, but when the gradient is small it is seldom that tremors are visible.

3.—The stronger the wind the more likely is it that tremors should be observed.

4.—When there has been a strong wind and no tremors, such wind has very often been local or blowing inland from the Pacific Ocean. We must not overlook the fact that such winds are sometimes accompanied by tremors. Winds of short duration are seldom accompanied by tremors.

5.—When there has been little or no wind in Tokio, and yet

tremors have been observed, in most cases there has been a strong wind in other parts of Central Japan. In the case of winds working up Japan from the S.W. this has been very marked, tremors being felt in Tokio several hours before the arrival of the wind.

When neither wind nor tremors are to be observed in Tokio there is usually a general calm in Central Japan.

6.—From the observations in 1886, Trans. Seis. Soc. Vol. XI. p. 58, we see that there were 10 days out of 45 when there were tremors which could not be accounted for by winds blowing at a distance, and on p. 61 that there were 3 days out of 20 when there were winds which ought to have been accompanied by tremors, while tremors were not observed. By combining these observations we may say that about 80 per cent. of the tremors observed in Tokio may be accounted for as the result of distant or local winds.

From the observations made in 1885 it seems that 50 per cent. of the tremors certainly accompanied strong winds, while 25 per cent. of the remaining tremors *might* have been due to wind. The remaining 25 per cent. of the tremors observed may have been of subterranean origin. These tremors were of *short duration and feeble*. Out of 685 observations when it was calm in Central Japan *slight* tremors were only observed 34 times, that is in less than 5 per cent. of the number of times of observation.

7.—The earthquakes which have been recorded do not appear to be connected with earth tremors more than that each are more frequent at the same seasons.

8.—Earth tremors are as severe upon the summit of a lofty mountain as they are in the plains.

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DATE.	N.N.E. COMPONENT.	N.N.W. COMPONENT.	WIND.	REMARKS.
1886. Dec.				
22	ST	—	w W o	
23	ST	—	o o w	
24	ST 7 to 10 p.	—	o W w	Low bar. North Yezo.
26	NT	—	o o o	
27	NT	—	o o o	
28	NT	—	o w w	
29	NT	—	o w o	
30	ST 5 to noon	—	o W o	Low bar. in North Yezo.
31	VST	—	W w W	Low bar. in North Yezo.
1887. Jan.				
1	NT	—	o o o	
2	VST	—	o w o	Low bar. in North Yezo.
3	2 to midnight at maximum 4 p. strong	—	o W W	At 2 p.m. Tokio wind 1 but heavy wind of 4 and 5 coming up the country from W., same at 9 p.m. Bar. low in North Yezo.
4	ST	—	w W o	Bar. low in North Yezo.
5	ST morning	—	w w o	Bar. low in North Yezo.
6	ST	—	o w o	Bar. low near Tokio.
7	T	—	o W W	At 2 p.m. Tokio wind 1 but heavy wind of 4 and 5 coming up country from W., same at 4 p.m. Bar. low in Yezo.
8	8 a. to 2 p. T	—	o W w	Conditions nearly same as on the 7th.
9	ST	—	o W w	Bar. low in North Yezo. In Tokio bar. high, 770 mm.
10	ST	—	o o o	
11	1 p. maximum at midnight	—	w o w	In afternoon low bar. 758, over Tokio.
12	T	—	W W o	Low bar. N.E. of Tokio. In Tokio 764 and 768.
13	ST	—	o o o	Low bar. in Yezo. In Tokio 769.
14	9 a. to 10 p. T	—	o W W	Low bar. S. of Tokio, 765 to 756.
15	ST	—	WT ₄ W1 ₄ WT ₃	Low bar. N. Yezo. Wind strong to S.W.
16	NT	—	W WT ₃ W	Low bar. N. Yezo. Wind strong to S.W.
17	NT	—	o o o	
18	NT	—	w W w	Bar. low to S.W.
19	NT	—	o o w	
20	NT	—	o o o	
21	NT	—	w w w	
22	NT	—	w o w	
23	NT	—	o o o	
24	NT	—	w w o	
25	ST	—	w WT ₃ WT ₃	Bar. low to S., Tokio 767-763.
26	NT	—	w o o	Bar. low to S. and S.W. Tokio 764-766.
27	NT	—	o o o	Bar. low to S. and N.W.

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DATE.	N.N.E. COMPONENT.	N.N.W. COMPONENT.	WIND.	REMARKS.
1887.				
Jan.				
28	NT	—	o o o	
30	ST	—	W W WT ₄	Bar. low to S.W. and centre passed up E. coast to N.
31	ST	—	WT ₃ w o	Bar. low to N.E.
Feb.				
1	ST	—	W W o	Wind coming up from S.W. Bar. low to North.
2	ST	—	o o o	
3	ST	—	w w o	Tokio bar. 765-754.
4	ST	—	o W W	Tokio bar. 758-759. Wind from W. and N.W.
5	ST	—	WT ₄ W W	Bar. low in N. Tokio bar. 759-760.
6	NT	—	wT ₃ W o	Bar. low in N. Tokio bar. 761-764.
7	NT	—	o o o	Tokio bar. 766-762.
8	NT	—	o WT ₃ o	Bar. low in N. Tokio bar. 758-760.
9	NT	—	w o o	
10	NT	—	o WT ₃ o	
11	ST in morning	—	o o o	Bar. low to N. Tokio bar. 768-769.
12	NT	—	o o o	
13	NT	—	o o o	
14	NT	—	o o o	
15	ST	—	o W W	Bar. low to N. Tokio bar. 760-769.
16	NT	—	WT ₃ o o	
17	NT	—	w o o	
18	NT	—	o w o	
19	ST	—	o o WT ₃	At 2 p. strong wind to S.W.
20	ST	—	o w o	Bar. low to S. of Tokio. Tokio bar. 766-761.
21	ST	—	o w o	Bar. low to S. of Tokio. Tokio bar. 761-763.
22	ST	—	w o o	Bar. low to S. and W. of Tokio. Tokio bar. 765-767.
23	ST	—	o w o	Bar. low to S. and W. of Tokio. Tokio bar. 767-766.
24	ST	—	WT ₃ WT ₃ w	Bar. low to W. of Tokio. Tokio bar. 766-767.
Mar.				
1	NT	—	o WT ₃ w	
2	NT	—	o WT ₃ WT ₃	
3	NT	—	o W w	
4	NT	—	o w w	
5	NT	—	o o o	
6	NT	—	w o o	
7	NT	—	WT ₃ w o	Bar. low to S.W.
8	ST	—	w o w	
9	T maximum at noon.	—	W W W	Bar. centre travelling from S.W. to N.E. over Tokio 738-745.
10	T	—	W W w	
12	ST	—	o W W	Bar. centre on N.W. coast. In Tokio 759-747.

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DATE.	N.N.E. COMPONENT.	N.N.W. COMPONENT.	WIND.	REMARKS.
1887.				
Mar.				
13	NT	—	W W W	Tremors ought to have been recorded.
14	NT	—	o WT ₃ o	
15	ST	T	o W W	Bar. low in Yezo. Tokio 755-760.
16	T and irregular waves.	ST afternoon.	w w o	Bar. low in Yezo. Tokio 765-770.
17	T and irregular waves.	—	o w w	
18	T	T from 8 a. to 4 p.	W W W	Bar. low in North. Tokio 745-750.
19	ST	NT	w w w	Bar. low in Yezo. Tokio 756-763.
20	NT	NT	o o o	
21	NT	NT	o o o	Low bar. near Tokio. Tokio 763-761.
22	ST at midnight.	VST	o o o	
23	NT	NT	o o o	
24	ST and irregular waves.	NT	o WT ₃ o	Bar. low in Yezo.
25	Irregular waves.	NT	o W o	
26	NT	NT	o w o	
27	NT	NT	o W o	
28	T and irregular waves.	NT	W W W	Bar. low in Yezo. Tokio 750-756.
29	T and irregular waves from noon.	T to noon, not working.	W W W	Bar. low in Yezo. Tokio 757-757.
30	T and irregular waves.	NW	WT ₃ W W	Bar. low in Yezo. Tokio 759-761.
April				
1	NT	NT	o o w	
2	ST and irregular waves.	VST	w W W	Bar. depression coming up E. coast. At 9 p. near Tokio. Tokio bar. 763-747.
3	ST	ST	w W W	At 9 p. depression travelled to N. Yezo. Tokio 744-746.
4	ST	VST until 2 p.	W W W	Depression in North. Tokio 748-759.
5	T and irregular waves.	NT	o w w	
6	NT	NT	o W w	Bar. in Tokio 764-760.
7	ST	NT	o w w	" " " 760-764.
9	T maximum 6 p.	ST noon to 6 p.	w W w	" " " 759-759.
10	NT	NT from 2 p. not working.	WT ₃ W w	" " " 763-765.
12	T	ST	w W W	" " " 755-753.
13	ST	NT	o w o	" " " 758-761.
22	T maximum 11 a.	ST	w w o	" " " 756-758.
23	ST	NT	o w o	" " " 759-762. Bar. depression to East.
24	NT	NT	o w o	Bar. in Tokio 764-768.
25	NT	NT	o WT ₃ w	" " " 771-770.
26	NT	NT	o w o	" " " 770-769.
27	NT	NW	o w o	" " " 768-765.
29	T maximum 1 p.	NT	o W w	" " " 766-765. Bar. low to S.W.

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DATE.	N.N.E. COMPONENT.	N.N.W. COMPONENT.	WIND.	REMARKS.
1887. April 30	T and irregular waves.	ST	W W W	Bar. in Tokio 761-750. Bar. low to W. and N.W. of Tokio.
May 1	T at 5 a. and irregular waves.	T 4 a.m. strong afterwards slight.	W w w	Bar. in Tokio 753-761.
2	T and irregular waves.	ST at noon.	w o o	" " " 764-762.
4	T and irregular waves.	NT	o W w	" " " 766-769.
5	T and irregular waves.	NT	o o W	" " " 771-772.
6	ST and irregular waves.	NT	o w o	" " " 771-767.
8	ST	NT	o W o	" " " 758-759.
10	ST	NT	o w o	" " " 759-759.
14	T in morning	T 10-12 a.	W W w	" " " 759-760. Bar. centre passing up E. coast.
16	ST	ST	o W W	Bar. in Tokio 759-756. Low bar. in Yezo.
17	NT	NT	w WT ₃ w	Bar. in Tokio 761-763.
18	NT	NT	WT ₃ o o	" " " 763-765.
19	NT	NT	o WT ₃ WT ₃	" " " 760-765.
21	NT	NT	o w o	" " " 758-758.
22	NT	—	o WT ₃ w	" " " 758-755.
23	ST	ST	o W w	" " " 755-756.
24	NT	NT	o o WT ₃	" " " 757-760.
27	ST and irregular waves.	—	o WT ₃ o	" " " 765-764.
28	NT	NT	o w w	" " " 763-759.
29	NT	NT	w w o	" " " 757-754.
June 3	NT	NT	o w o	
6	Irregular waves.	NW	o w w	Low bar. over-Tokio. Tokio 755-754.
7	NT	NT	o w o	Low bar. near Tokio. Tokio 756-758.
8	NT	T from 11 p.	o w WT ₃	
9	T from 1 a.	Afternoon NW	w o o	
20	T	ST	o w W	Low bar. near Tokio. Tokio 761-747.
21	ST	ST	o WT ₃ o	Tokio 748-755.
22	ST	ST	o w o	Bar. low to W. of Kiushiu. Tokio 756-758.
23	ST	NW	o W W	Low bar. near Tokio.
24	T	ST	o w W	Low bar. near Tokio. Tokio 750-758.
25	ST	NT	o WT ₃ o	Tokio 757-754.
26	NT	NW	o o w	
27	ST	ST	w w WT ₃	
July 22	Irregular waves.	NT	o W o	Wind of force 3 only at 2 places near each other.
24	NT	NT	w W o	Wind of force 3 only at 2 places near each other.
25	Irregular waves.	NT	o W WT ₃	Wind of force 3 only at 2 places near each other.

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DATE.	N.N.E. COMPONENT.	N.N.W. COMPONENT.	WIND.	REMARKS.
1887.				
July				
26	Irregular waves.	NT	o WT ₃ o	
27	Irregular waves.	NT	o o o	
28	Irregular waves.	NW	o W o	Wind of force 3 only at 3 places near each other.
Aug.				
1	Irregular waves.	NW	o w o	
2	NT	NW	o w w	
3	Irregular waves.	NT	o w o	
4	NT	NT	o w w	
19	Irregular waves.	NW	o w o	
22	Irregular waves.	NW	o o o	
29	ST	ST	w W w	
30	NT	NT	w w o	
31	NT	NT	o WT ₃ o	Bar. low to W. and N. Tokio 763-763.
Sept.				
1	NT	NT	o W o	
2	NT	VST	o W o	
4	NT	NT	w w o	
5	NT	NW	o w o	
7	Irregular waves.	NT	o WT ₃ o	
8	NT	NT	o WT ₃ o	
9	NT	NT	o w o	
13	T and irregular waves.	ST	o w W	
14	T	ST	W W W	Bar. low in N. Yezo.
15	ST	ST	W w w	
16	ST irregular waves.	NT	w W o	
18	NT	NT	o o w	
19	NT	NT	o w o	
20	NT	NT	o W W	
21	T irregular waves.	NT	o o w	
22	ST	ST morning afternoon	o o o	
23	T	NW T	W W o	
24	T to 10 a. after	NT	W w o	
25	NT	NT	o w w	
26	T	NT	o w o	
27	ST	ST	o W w	
28	ST	NT	w w o	
29	ST	NT	o o W	
Oct.				
7	VST	VST	W W w	Bar. low in N. Yezo.
24	T	VST	o W w	

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DATE.	N.N.E. COMPONENT.	N.N.W. COMPONENT.	WIND.	REMARKS.
1887.				
Oct.				
25	T	NT	o w o	
26	T	NT	w w w	
27	T	NT	w w o	
28	T	NT	o o o	
29	ST	NT	o o o	
Nov.				
6	VST	T in morning	o o o	
7	ST	NT	o o o	
8	ST	NT	o WT ₃ o	
11	NT	NT	w w o	Bar. low near Tokio.
13	T	ST	o o o	
14	NT	NW	o o o	
18	NT	NW	W w o	
19	NT	NW	o o o	
20	NT	NT	o o o	
21	NT	NT	o o o	
24	ST	NT	o w o	Bar. high over Tokio.
25	T	NT	o o WT ₃	
26	NT	NT	o w w	
27	ST	NT	o o o	
28	NT irregular waves.	NT	o o o	
29	T	NT	o o W	
30	T	NT	W W w	Bar. low over N. Yezo.
Dec.				
1	T	ST	o w o	
2	T	ST	o W w	
3	ST irregular waves.	NT	WT ₃ W o	
4	ST irregular waves.	NT	o o o	
5	ST irregular waves.	NT	w W w	
6	ST irregular waves.	NT	o o o	
7	ST irregular waves.	NT	o o o	
8	ST irregular waves.	ST	o w w	
9	NT	NT	o w o	
10	ST	NT	o o o	
11	ST	NT	W W o	
12	VST	NT	o W w	
13	VST	NT	w o o	
14	NT	NT	o W W	
15	NT	NW	W W w	
16	T	NT	o w o	
17	T	ST	o o w T ₃	
18	T	NT	o o o	
19	ST	NT	WT ₃ w w	

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DATE.	N.N.E. COMPONENT.	N.N.W. COMPONENT.	WIND.	REMARKS.
1887.				
Dec.				
20	ST irregular waves.	NT	w o o	
21	ST	NT	o o o	
22	ST	NT	o o w	
23	VST	NT	w w o	
24	VST	NT	o w W	
25	NT	NT	o W W	
26	VST	NT	w w o	
1888.				
Jan.				
3	NT	NT	w o o	
10	NT	NT	o o o	
11	NT	NT	o w o	
12	VST	NT	o W o	
13	VST	NT	o o o	
14	NT	NT	o W w	
15	NT	NT	o WT ₃ o	
16	VST	NT	o o o	
17	VST	NT	o o w	
18	NT	NT	o o o	
19	NT	NT	w w o	
20	NT	NT	o o w	
22	NT	NT	o o o	
27	NT	NW	o W o	
31	VST	NT	o o o	
Feb.				
1	NT	NT	w W w	
2	NT	NT	w WT ₃ o	
3	NT	NT	o o o	
6	NT	NT	o o o	
8	NT	ST	o o w	
9	NT	NT	w W o	
14	VST	NT	w w o	
15	NT	NT	o w w	
16	NT	NT	o o o	
17	NT	VST	o o o	
18	VST	VST	o WT ₃ o	
20	NT	VST	w W W	
21	NT	VST	w w o	
22	VST	VST	o o w	
23	NT	VST	o WT ₃ o	
24	NT	VST	o W w	
25	NT	NT	o w o	
26	NT	NT	o w w	
27	NT	NT	w W w	
29	NT	NW	o w o	

RESULT OF ANALYSIS.

From a general inspection of the weather maps it is quite clear that, when little or no wind is indicated or when the isobars are few, no tremors are recorded, while on the contrary when the wind is strong at many stations in Central Japan and when the isobars occur in close proximity tremors are almost always recorded. On the Japanese maps the isobars are drawn with intervals of 5 mm. of pressure. On the Italian maps where the intervals are only 1 mm., the relationship between tremors and the frequency of isobars, which when they are numerous indicate a steep gradient, is even more marked than it appears to be in Japan. On the Italian maps which are published under the direction of Professor M. S. de Rossi, the state of the wind is not indicated, but it may be inferred that when the gradients over the Italian Peninsula are steep, wind is blowing somewhere in the Peninsular, and therefore in Italy, as in Japan, tremors are accompanied by wind although the wind may not be blowing at some particular place where tremors are observed. Certainly tremors often occur with a low barometer, but the greater frequency of tremors apparently happens when the gradient is steep no matter whether the barometer is high or whether it is low, and cases may therefore be observed of low barometers unaccompanied by tremors, as for example on May 29th, 1887. Observations like these have inclined me to the opinion that tremors are more closely connected with wind than with barometric pressure.

An examination of the preceding tables shows:—

1. That there are 80 cases of well pronounced tremors having occurred with strong winds blowing in Central Japan. In several instances tremors were observed in Tokio some hours ahead of the wind which was blowing heavily to the S.W. and travelling up the country towards Tokio. (See January 3rd and 7th, 1887, also previous paper).

2. There have been 40 cases of strong wind and no tremors.

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In 34 of these cases the wind has been local or of short duration, that is to say wind was only blowing in Tokio, or it was only observed at one of the tri-daily observations. In the remaining 6 cases (January 16th, February 6th, March 13th, September 20th, December 14th and 25th) if tremors are the result of wind they ought to have been observed.

3. With no wind and no tremors there are 79 cases.

4. With no wind and *small* tremors there are 63 cases. In 39 of these cases the record on one band of paper showed no tremors and therefore these 29 cases might have been classified in the preceding group. On the other band tremors were barely visible. In 8 out of the remaining 26 cases (January 11th, 13th, February 2nd, 3rd, March 16th, 17th, April 7th and 13th) the tremors observed were immediately in advance of a heavy wind, or were tremors continuing after a large wind had passed, at which time tremors had been well pronounced. There are therefore only (26—8) 16 cases when tremors can be said to have occurred when there was no wind, and these cases occur when only one band of paper for receiving records was working.

The above results may be tabulated as follows :

1.—Strong wind and well pronounced tremors.....	80
2.—Strong wind and no tremors 40 cases, which may be subdivided into :—	
Cases where tremors ought to have occurred	6
Cases where the wind was local or of short duration and it is therefore doubtful whether tremors should have been recorded.....	34
3.—With no wind and tremors.....	79
4.—With no wind and <i>slight</i> tremors 63 cases, which may be subdivided into :—	
Cases where tremors were so small that they were only recorded on one band of paper (39 + a possible 16)	55
Cases which may have been due to wind	8
Total.....	262

The conclusion is that out of 86 cases of wind there are only 6 cases when tremors were not observed, while when there was

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no wind generally there were no tremors, or at most tremors so slight that they were barely recorded. A result which agrees with that arrived at previously.

For three months an automatic spark record was kept of tremors which might be due to vertical motion, but as these only occurred when tremors were recorded by the machine already described and were extremely small, the observations were discontinued. The instrument employed was a horizontal lever spring seismograph with an index having a multiplication of about 100.

