Synodic-monthly Variation of Seismic Frequency in Japan.

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With Plates X-XVII.

I. Introduction.

1. The relations between the periodic fluctuations of earthquake frequency and the external agencies, which have already been discussed by several seismologists, may be supposed to be most distinctly shown when the earthquakes treated are confined into certain localities, as a few recent investigators have done.

2. Dr. Omori was the first to discuss fully the after-shocks of great earthquakes, the advantage in considering these shocks with respect to the problem above mentioned being that they are numerous and ought to be readily affected by external agencies. Thus treating, besides the 1462 earthquakes observed in Tōkyō, 1270 after-shocks of the great Mino-Owari earthquake of 1891, and 799 after-shocks of the Nemuro earthquake of 1894, he arrived at the conclusion that earthquakes occurred most frequently within a few hours after the meridian passages of the moon and least frequently about 6 hours later[1], the result being similar to that obtained by Dr. Knott[2] who made an analytical study of 7000 Japanese earthquakes contained in Professor Milne's Catalogue. Dr. Oldham's result of the discussion of 1274

1. This volume, pp. 27–40.
2. Proceedings of the Royal Society of London, vol. VX.

after-shocks of the great Assam earthquake of 1897 is that the shocks were most frequent between 10 and 11 p.m., and again between 6 and 7 a.m.[1] This is very similar to the conclusion arrived at by Dr. Omori, who, treating 18279 seismic observations at 26 Meteorological Stations in Japan obtained many important results, from which it appears that the seismic frequency is more affected by the barometric pressure than by the direct influence of the sun such that the curve of diurnal seismic frequency follows closely that of barometric pressure, large seismic numbers corresponding to high pressures.[2]

3. An interesting study on the distribution of seismic occurrences with respect to the relative position of the sun and moon has been undertaken also by Dr. Knott, who arrived at the conclusion that the seismic frequency reaches its maximum at the times of the conjunction and opposition of the sun and moon, and its minimum at the times of quadrature.[3]

4. The treatment, similar to that last mentioned, having been very easy with respect to the Japanese historical earthquakes contained in our Committee's Catalogue, in which the dates of occurrences are given both in Japanese synodic and European calendars, I have taken up the problem again and found that the maximum seismic frequency occurred not only at the times of the conjunction and opposition of the sun and moon, but also at the times of quadrature. This latter conclusion is found to be the same in the case of the recent Japanese earthquakes observed at the different Meteorological Stations. A detailed account is given in the following Chapters.

II. Synodic-daily distribution of the Japan historical earthquakes.

5. The Earthquake Investigation Committee Catalogue contains

1. Journal of the Asiatic Society of Bengal, vol. LXXXI.
2. Publications of the Imp. Earthquake Inv. Comm. in Foreign Laguages, No. 8.
3. Dr. Knott: On Lunar Periodicities in Earthquake Frequency. Proceedings of the Royal Society of London.

a list of 1898 earthquakes, a large disturbance and its after-shocks being reckoned as a single number.[1] These earthquakes are classed according to the intensity as *destructive, strong,* or *small,* each of which corresponds approximately to *violent, strong,* and *weak* or *slight* of the scale adopted by the Central Meteorological Observatory.

6. A few words must be said of Japanese synodic calendar. The first day of the lunar month is approximately the time of the conjunction of the sun and moon, while the 16th is the time of opposition. As a complete synodic month is almost equal to 29.53 mean solar days, months consisting of 29 and 30 days come alternately, or in other words the 30th day numbers 53 % of any other day during a sufficiently long period. Hence I multiplied, for the use of drawing the frequency curve, the factor 100/53 into the seismic number in the 30th, in order to raise the datum of this day into equal weight as in the other days.

7. Let us now turn our attention to Tables I and II. The first of these relates to the earthquakes all over Japan, while the second relates to the 1317 earthquakes recorded in Kyoto.[2] The column with the heading "sum with weight" is *filled up* with the sums of small, strong, and destructive earthquakes of successive days each multiplied with the factors 1, 2, and 3 respectively. The last column with the heading "reduced" consists of numbers of the corresponding days in the former column divided by the daily average of the numbers in that column.

1–2. In a few cases, date of occurrences is unknown.

TABLE I.

SYNODIC-DAILY DISTRIBUTION OF EARTHQUAKES RECORDED IN JAPAN, BETWEEN 416 AND 1860, A. D.

Synodic day.	Small.	Strong.	Destructive.	Sum without weight.	Sum with weigh'.	Reduced.
1	66	14	8	88	118	1.40
2	71	5	5	81	96	1.14
3	55	9	5	69	88	1.04
4	45	11	5	61	82	0.97
5	50	8	7	65	87	1.03
6	46	12	5	63	85	1.01
7	56	8	12	76	108	1.28
8	37	11	3	51	68	0.81
9	39	8	8	55	71	0.84
10	44	10	4	58	76	0.90
11	45	8	3	56	70	0.83
12	43	6	12	61	91	1.08
13	70	8	2	80	92	1.09
14	54	10	6	70	92	1.09
15	48	6	8	62	84	1.00
16	55	7	6	68	87	1.03
17	48	10	2	60	74	0.88
18	50	9	3	62	77	0.91
19	47	9	5	61	80	0.95
20	33	9	7	49	72	0.85
21	41	11	6	58	81	0.96
22	45	11	5	61	82	0.97
23	47	1	11	59	82	0.97
24	46	11	8	65	92	1.09
25	56	9	7	72	95	1.13
26	37	7	11	55	84	1.00
27	46	14	6	66	92	1.09
28	39	4	5	48	62	0.74
29	44	12	4	60	80	0.95
30	24	4	3	31	77	0.91
Sum.	1427	232	182	1871	2525	—

TABLE II.

SYNODIC-DAILY DISTRIBUTION OF EARTHQUAKES RECORDED AT KYOTO, BETWEEN 416 AND 1860, A. D.

Synodic day.	Slight.	Strong.	Large.	Sum without weight.	Sum with weight.	Reduced.
1	44	10	1	55	67	1.26
2	51	4	1	56	62	1.16
3	42	4	0	46	50	0.94
4	35	10	2	47	61	1.14
5	40	7	1	48	57	1.07
6	33	8	3	44	61	1.14
7	45	6	2	53	63	1.18
8	22	7	1	30	39	0.73
9	34	8	2	44	56	1.05
10	32	4	0	36	40	0.75
11	38	3	1	42	47	0.88
12	35	2	5	42	54	1.01
13	50	7	0	57	64	1.20
14	41	9	1	51	63	1.18
15	34	4	2	40	48	0.90
16	42	5	1	48	55	1.03
17	36	7	0	43	50	0.94
18	40	5	2	47	56	1.05
19	33	6	0	39	45	0.84
20	29	5	2	36	45	0.84
21	34	6	0	40	46	0.86
22	34	9	3	46	61	1.14
23	39	0	1	40	42	0.79
24	34	8	5	47	65	1.22
25	45	8	1	54	64	1.20
26	28	7	1	36	45	0.84
27	37	12	0	49	61	1.14
28	31	2	0	33	35	0.66
29	34	10	2	46	60	1.12
30	13	3	1	17	42	0.79
Sum	1085	186	41	1312	1604	—

8. The *weighted* numbers of earthquakes of successive days, when drawn in curves (figs. 1–2), indicate two distinct pairs of maxima on the 1st and 14th, and the 7th and 24th. The method of drawing curves here adopted is as follows:—Let x represent the synodic days, and y the actual seismic number of the corresponding day. Marking down on a section paper so many points (×) corresponding to the different sets of x and y, the curve is obtained by drawing a continuous free-hand line, which passes through the mean positions of every two consecutive points (×) tangentially to the broken line connecting directly the points themselves.[1]

9. As regards the causes of the two pairs of maxima, the first is probably due to the combined tidal effort of the sun and moon, and the second to the resultant of tidal and barometric pressures. For the explanation, the reader is referred to Chapter IV.

III. Synodic-daily distribution of the seismic observations at the different Meteorological Stations.

10. I shall now proceed to discuss the distribution of earthquakes observed at the different Japanese Meteorological Stations. As regards the full description of the observations at these stations, the reader is referred to Dr. Omori's paper on "annual and diurnal variations of seismic frequency in Japan."[2] As the monthly frequency is decidedly affected by the after-shocks of a certain large earthquake, I excluded them together with those earthquakes which occurred within a complete synodic month after that earthquake. For this reason, the observations at Nemuro, Gifu, Nagoya, etc., which have been taken into consideration were considerably reduced in number. The exclusions are given in Table III, which besides gives the observations at the 22 Meteorological Stations. My examination relates also to the obser-

1. See Dr. Omori: Publications of the Imp. Earthquake Inv. Comm. in Foreign Languages, No. 8.

2. Loc. cit.

vations at 8 other stations, but, the materials in these cases having been very scanty, a definite result could not be obtained.

11. Tables IV–XXV are constructed in the same way as Tables I–II, the "sum" or the "seismic number" being used in the same meaning as the "sum without weight" in the first two tables.

TABLE III.

EARTHQUAKE OBSERVATION AT THE 22 METEOROLOGICAL STATIONS.

Meteorological Station.	Date of commencement of earthquake observations taken into account.	Time interval between Dec. 1902 and the date in the former column.		Date after which observations are excluded for a complete month.	No. of earthquake observations taken into account.
		years.	months.		
Tokyo.	Jan. 1876	27	0	Oct. 28, 1891; June 15, 1896.	2464
Nemuro.	March 1894	8	9	March 22, 1894.	755
Nagoya.	Jan. 1894	9	0	Jan. 10, 1894.	799
Gifu.	Jan. 1894	9	0	Jan. 10, 1894.	938
Ishinomaki.	Jan. 1886	17	0	———	1307
Fukushima.	May 1889	13	8	Aug. 9, 1901.	476
Osaka.	July 1882	20	6	Oct. 28, 1891.	293
Mito.	Jan. 1900	3	0	———	557
Fukuoka.	Aug. 1898	4	5	Aug. 12, 1898; Feb. 20, 1900; April 9, 1900.	410
Oita.	Jan. 1887	16	0	———	243
Miyako.	March 1883	19	10	———	923
Aomori.	Jan. 1882	21	0	March 22, 1894; Oct. 22, 1894; April 20, 1896; June 15, 1896; Aug. 31, 1896; Aug. 9, 1900.	631
Hakodate.	Jan. 1873	30	0	———	336
Akita.	Jan. 1883	20	0	Aug. 31, 1896.	400
Utsunomiya.	Feb. 1891	11	11	———	677
Maebashi.	Dec. 1896	6	1	———	270
Yamakata.	Dec. 1889	13	1	Aug. 31, 1896.	235
Niigata.	April 1886	16	9	———	228
Nagano.	Jan. 1889	14	0	———	418
Hikone.	Jan. 1894	9	0	Jan. 10, 1894.	289
Wakayama.	Sept. 1879	23	4	———	472
Kagoshima.	March 1885	17	10	———	527

Total number of earthquake observations = 13678.

TABLE IV.

SYNODIC-DAILY DISTRIBUTION OF EARTHQUAKES OBSERVED AT TŌKYŌ.

(Jan. 1876—Dec. 1902.)

Synodic day.	Slight.	Weak.	Strong.	Sum.	Reduced.
1	78	3	0	81	0.97
2	68	10	0	78	0.94
3	89	6	0	95	1.13
4	70	7	0	77	0.92
5	69	4	1	74	0.88
6	89	7	0	96	1.14
7	80	6	1	87	1.04
8	76	1	0	77	0.92
9	83	7	2	92	1.10
10	75	2	0	77	0.92
11	82	7	0	89	1.06
12	65	5	1	71	0.85
13	70	5	0	75	0.89
14	63	5	0	68	0.81
15	63	6	0	69	0.82
16	70	11	0	81	0.97
17	84	6	2	92	1.10
18	76	11	3	90	1.07
19	84	7	2	93	1.11
20	75	3	1	79	0.94
21	74	7	2	83	0.99
22	86	8	1	95	1.13
23	88	7	0	95	1.13
24	81	9	0	90	1.07
25	67	1	1	69	0.82
26	73	6	1	80	0.95
27	67	3	1	71	0.85
28	74	11	0	85	1.01
29	93	5	0	98	1.17
30	54	3	0	57	1.30
Sum.	2266	179	19	2464	—

TABLE V.

SYNODIC-DAILY DISTRIBUTION OF EARTHQUAKES OBSERVED AT NEMURO.

(March 1894—Dec. 1902.)

Synodic day.	Slight.	Weak.	Strong.	Sum.	Reduced.
1	23	5	0	28	1.10
2	25	6	0	31	1.22
3	16	4	0	20	0.79
4	31	2	0	33	1.30
5	17	4	0	21	0.83
6	30	3	0	33	1.30
7	22	5	0	27	1.06
8	21	1	0	22	0.86
9	33	1	0	34	1.36
10	21	4	0	25	0.98
11	27	2	0	29	1.14
12	20	0	1	21	0.83
13	20	2	0	22	0.86
14	20	0	1	21	0.83
15	18	3	0	21	0.83
16	22	2	0	24	0.94
17	15	0	0	15	0.59
18	33	6	0	39	1.53
19	25	4	0	29	1.14
20	22	3	0	25	0.98
21	18	3	0	21	0.83
22	26	3	0	29	1.14
23	17	1	0	18	0.71
24	25	1	0	26	1.02
25	24	6	0	30	1.18
26	18	1	0	19	0.75
27	26	3	0	29	1.14
28	23	2	0	25	0.98
29	21	8	0	29	1.14
30	7	2	0	9	0.67
Sum.	666	87	2	755	—

TABLE VI.

SYNODIC-DAILY DISTRIBUTION OF EARTHQUAKES OBSERVED AT NAGOYA.

(Jan. 1894—Dec. 1902.)

Synodic day.	Slight.	Weak.	Strong.	Sum.	Reduced.
1	17	1	0	18	0.69
2	23	0	0	23	0.88
3	22	1	0	23	0.88
4	28	3	0	31	1.19
5	21	1	0	22	0.84
6	26	1	0	27	1.03
7	16	1	0	17	0.65
8	23	2	0	25	0.96
9	25	2	0	27	1.03
10	19	0	0	19	0.73
11	36	0	0	36	1.38
12	32	1	0	33	1.26
13	20	1	0	21	0.80
14	25	3	0	28	1.07
15	26	4	0	30	1.15
16	27	0	0	27	1.03
17	20	2	0	22	0.84
18	23	1	0	24	0.92
19	23	0	1	24	0.92
20	27	0	0	27	1.03
21	38	1	0	39	1.49
22	18	2	0	20	0.76
23	14	2	0	16	0.61
24	30	3	0	33	1.26
25	29	0	0	29	1.11
26	44	2	0	46	1.76
27	31	2	0	33	1.26
28	21	0	0	21	0.80
29	28	2	0	30	1.15
30	8	0	0	8	0.57
Sum.	740	38	1	779	—

TABLE VII.

SYNODIC-DAILY DISTRIBUTION OF EARTHQUAKES OBSERVED AT GIFU.

(Jan. 1894—Dec. 1902.)

Syncdic day.	Eqke sound.	Slight.	Weak.	Strong.	Sum.	Reduced.
1	1	22	3	0	26	0.82
2	1	23	2	0	26	0.82
3	4	34	2	1	41	1.29
4	0	30	2	1	33	1.04
5	0	36	5	1	42	1.33
6	1	31	2	0	34	1.07
7	1	36	0	0	37	1.17
8	0	24	4	0	28	0.88
9	0	34	2	0	36	1.14
10	1	25	1	0	27	0.85
11	4	28	3	0	35	1.10
12	1	30	3	0	34	1.07
13	4	16	6	0	26	0.82
14	3	36	3	1	43	1.36
15	0	23	2	0	25	0.79
16	1	27	3	0	31	0.98
17	0	23	4	0	27	0.85
18	1	31	1	0	33	1.04
19	3	27	1	0	31	0.98
20	1	31	0	0	32	1.01
21	4	20	3	0	27	0.85
22	0	22	0	0	22	0.69
23	2	25	1	0	28	0.88
24	1	32	4	0	37	1.17
25	3	26	1	0	30	0.95
26	3	30	3	0	36	1.14
27	2	31	1	0	34	1.07
28	1	23	0	0	24	0.76
29	0	35	2	0	37	1.17
30	1	14	1	0	30	0.95
Sum.	44	825	65	4	938	—

TABLE VIII.

SYNODIC-DAILY DISTRIBUTION OF EARTHQUAKES OBSERVED AT ISHINOMAKI.

(Jan. 1886—Dec. 1902.)

Synodic day.	Intensity not stated.	Slight.	Weak.	Strong.	Sum.	Reduced.
1	13	30	2	0	45	1.02
2	7	24	2	2	35	0.79
3	9	22	4	1	36	0.82
4	11	31	1	1	44	1.00
5	7	34	4	0	45	1.02
6	11	18	5	0	34	0.77
7	12	35	3	1	51	1.16
8	9	26	6	0	41	0.93
9	10	26	1	0	37	0.84
10	13	41	1	1	56	1.27
11	7	22	8	1	38	0.86
12	10	35	1	0	46	1.04
13	11	31	1	0	43	0.98
14	14	19	3	1	37	0.84
15	23	30	7	0	60	1.36
16	19	34	1	1	55	1.25
17	18	28	5	0	51	1.16
18	8	39	2	2	51	1.16
19	13	27	2	1	43	0.98
20	12	22	1	0	35	0.79
21	12	23	4	1	40	0.91
22	12	24	1	3	40	0.91
23	16	29	2	0	47	1.07
24	15	29	3	0	47	1.07
25	13	42	2	0	57	1.29
26	15	35	5	0	55	1.25
27	12	24	0	2	38	0.86
28	14	25	3	0	42	0.95
29	13	24	4	0	41	0.93
30	5	11	1	0	17	0.73
Sum.	364	840	85	18	1307	—

TABLE IX.

SYNODIC-DAILY DISTRIBUTION OF EARTHQUAKES OBSERVED AT FUKUSHIMA.

(May. 1889—Dec. 1902.)

Synodic day.	Slight.	Weak.	Strong.	Sum.	Reduced.
1	18	0	0	18	1.13
2	14	0	0	14	0.88
3	14	1	0	15	0.94
4	15	1	0	16	1 00
5	10	2	0	12	0.75
6	12	0	0	12	0.75
7	18	0	0	18	1.13
8	16	0	0	16	1.00
9	13	0	0	13	0.81
10	22	0	0	22	1.37
11	11	1	0	12	0.75
12	18	2	0	20	1.25
13	23	0	0	23	1.44
14	21	0	0	21	1.31
15	19	0	0	19	1.19
16	15	0	0	15	0.94
17	16	1	0	17	1.06
18	19	0	0	19	1.19
19	13	0	0	13	0.81
20	10	0	0	10	0.63
21	17	0	1	18	1.13
22	13	1	0	14	0.88
23	17	0	0	17	1.06
24	19	2	0	21	1.31
25	19	0	0	19	1.19
26	17	0	0	17	1.06
27	10	0	0	10	0.63
28	14	0	0	14	0.88
29	16	0	0	16	1.00
30	5	0	0	5	0.56
Sum.	464	11	1	476	—

TABLE X.

SYNODIC-DAILY DISTRIBUTION OF EARTHQUAKES OBSERVED AT OSAKA.

(July 1882—Dec. 1902.)

Synodic day.	Slight.	Weak.	Strong.	Sum.	Reduced.
1	10	2	0	12	1.2
2	12	1	0	13	1.3
3	9	0	0	9	0.9
4	8	1	2	11	1.1
5	3	1	0	4	0.4
6	8	2	0	10	1.0
7	10	0	0	10	1.0
8	8	0	0	8	0.8
9	7	0	0	7	0.7
10	6	0	0	6	0.6
11	9	1	0	10	1.0
12	16	1	0	17	1.7
13	8	0	0	8	0.8
14	7	1	0	8	0.8
15	6	0	0	6	0.6
16	4	0	0	4	0.4
17	9	0	0	9	0.9
18	6	0	0	6	0.6
19	7	1	0	8	0.8
20	14	0	0	14	1.4
21	7	1	0	8	0.8
22	8	2	0	10	1.0
23	6	3	1	10	1.0
24	15	2	0	17	1.7
25	7	0	0	7	0.7
26	15	0	2	17	1.7
27	9	0	0	9	0.9
28	16	1	1	18	1.8
29	8	2	0	10	1.0
30	5	2	0	7	1.3
Sum.	263	24	6	293	—

TABLE XI.

SYNODIC-DAILY DISTRIBUTION OF EARTHQUAKES OBSERVED AT MITO.

(Jan. 1900—Dec. 1902.)

Synodic day.	Slight.	Weak.	Strong.	Sum.	Reduced.
1	22	0	0	22	1.16
2	11	1	0	12	0.63
3	20	1	0	21	1.11
4	16	2	0	18	0.95
5	13	0	1	14	0.74
6	22	0	0	22	1.16
7	14	4	0	18	0.95
8	17	0	0	17	0.90
9	9	0	0	9	0.48
10	15	3	0	18	0.95
11	22	1	2	25	1.32
12	19	0	0	19	1.01
13	26	0	0	26	1.37
14	23	2	1	26	1.37
15	17	4	0	21	1.11
16	16	2	0	18	0.95
17	26	2	0	28	1.48
18	27	2	0	29	1.53
19	11	1	0	12	0.63
20	9	1	0	10	0.53
21	8	2	0	10	0.53
22	20	1	0	21	1.11
23	14	0	0	14	0.74
24	18	4	0	22	1.16
25	13	2	0	15	0.79
26	24	4	1	29	1.53
27	14	0	0	14	0.74
28	15	1	0	16	0.85
29	20	0	1	21	1.11
30	10	0	0	10	1.01
Sum.	511	40	3	557	—

TABLE XII.

SYNODIC-DAILY DISTRIBUTION OF EARTHQUAKES OBSERVED AT FUKUOKA.

(Aug. 1898—Dec. 1902.)

Synodic day.	Slight.	Weak.	Strong.	unfelt.	Sum (unfelt excluded).	Reduced.
1	13	0	0	0	13	0.93
2	12	0	0	0	12	1.86
3	14	0	0	0	14	1.00
4	20	0	0	0	20	1.43
5	17	0	0	0	17	1.21
6	10	0	0	0	10	0.71
7	11	0	0	0	11	0.79
8	8	0	0	4	8	0.57
9	11	0	0	0	11	0.79
10	12	0	0	4	12	0.86
11	16	0	0	14	16	1.07
12	13	0	0	2	13	0.93
13	10	1	0	2	11	0.79
14	12	0	0	9	12	0.86
15	15	0	0	4	15	1.07
16	16	0	0	1	16	1.14
17	13	0	0	4	13	0.93
18	22	0	0	11	22	1.57
19	17	0	0	11	17	1.21
20	16	0	0	0	16	1.14
21	12	1	0	0	13	0.93
22	17	0	0	0	17	1.21
23	16	2	2	0	20	1.43
24	16	0	0	0	16	1.14
25	7	0	1	0	8	0.57
26	11	0	0	0	11	0.79
27	16	0	0	0	16	1.14
28	11	0	0	2	11	0.79
29	9	0	0	0	9	0.64
30	10	0	0	0	10	1.36
Sum.	403	4	3	68	410	—

TABLE XIII.

SYNODIC-MONTHLY DISTRIBUTION OF EARTHQUAKES OBSERVED AT OITA.

(Jan. 1887—Dec. 1902.)

Synodic day.	Slight.	Weak.	Strong.	Sum.	Reduced.
1	7	3	1	11	1.34
2	15	1	0	16	1.95
3	8	2	0	10	1.22
4	5	1	1	7	0.85
5	7	0	0	7	0.85
6	4	2	0	6	0.73
7	8	6	0	14	1.71
8	5	2	0	7	0.85
9	6	1	0	7	0.85
10	10	2	0	12	1.46
11	9	3	0	12	1.46
12	3	2	0	5	0.61
13	7	3	0	10	1.22
14	6	0	0	6	0.73
15	5	1	0	6	0.73
16	6	1	0	7	0.85
17	2	3	0	5	0.61
18	8	3	0	11	1.34
19	5	0	0	5	0.61
20	1	0	0	1	0.12
21	7	4	0	11	1.34
22	4	1	0	5	0.61
23	7	2	1	10	1.22
24	5	2	0	7	0.85
25	5	3	1	9	1.10
26	7	0	0	7	0.85
27	4	1	0	5	0.61
28	7	3	0	10	1.22
29	9	2	0	11	1.34
30	3	0	0	3	0.73
Sum.	185	54	4	243	—

TABLE XIV.

SYNODIC-MONTHLY DISTRIBUTION OF EARTHQUAKES OBSERVED AT MIYAKO.

(March 1883—Dec. 1902.)

Synodic day.	Seismic number.	Reduced.	Synodic day.	Seismic number.	Reduced.	Synodic day.	Seismic number.	Reduced.
1	28	0.89	11	29	0.92	21	18	0.57
2	27	0.86	12	24	0.76	22	36	1.14
3	34	1.08	13	26	0.83	23	43	1.37
4	29	0.92	14	25	0.80	24	32	1.02
5	29	0.92	15	23	0.73	25	38	1.21
6	33	1.05	16	31	0.99	26	39	1.24
7	47	1.50	17	30	0.95	27	19	0.60
8	49	1.56	18	40	1.27	28	27	0.86
9	27	0.86	19	21	0.67	29	37	1.18
10	44	1.40	20	17	0.54	30	21	1.24

Total seismic number = 923.

TABLE XV.

SYNODIC-MONTHLY DISTRIBUTION OF EARTHQUAKES OBSERVED AT AOMORI.

(Jan. 1882—Dec. 1902.)

Synodic day.	Seismic number.	Reduced.	Synodic day	Seismic number.	Reduced.	Synodic day.	Seismic number.	Reduced.
1	20	0.92	11	24	1.10	21	23	1.06
2	23	1.06	12	20	0.92	22	21	0.97
3	18	0.83	13	18	0.83	23	19	0.87
4	21	0.97	14	21	0.97	24	11	0.51
5	23	1.06	15	27	1.24	25	18	0.83
6	28	1.29	16	21	0.97	26	20	0.92
7	22	1.01	17	23	1.04	27	20	0.92
8	27	1.24	18	23	1.04	28	18	0.83
9	20	0.92	19	20	0.92	29	21	0.97
10	15	0.69	20	24	1.10	30	22	1.89

Total seismic number = 631.

TABLE XVI.

SYNODIC-MONTHLY DISTRIBUTION OF EARTHQUAKES OBSERVED AT HAKODATE.

(Jan. 1873 – Dec. 1902.)

Synodic day.	Seismic number.	Reduced.	Synodic day.	Seismic number.	Reduced.	Synodic day.	Seismic number.	Reduced.
1	12	0.97	11	16	1.29	21	16	1.29
2	7	0.56	12	9	0.73	22	12	0.97
3	12	0.97	13	16	1.29	23	8	0.65
4	12	0.97	14	13	1.05	24	6	0.48
5	15	1.21	15	7	0.56	25	19	1.53
6	20	1.61	16	16	1.29	26	10	0.81
7	8	0.65	17	12	0.97	27	10	0.81
8	14	1.13	18	10	0.81	28	18	1.45
9	13	1.05	19	10	0.81	29	16	1.29
10	9	0.73	20	13	1.05	30	7	1.05

Total seismic number = 366.

TABLE XVII.

SYNODIC-MONTHLY DISTRIBUTION OF EARTHQUAKES OBSERVED AT AKITA.

(Jan. 1883—Dec. 1902.)

Synodic day.	Seismic number.	Reduced.	Synodic day.	Seismic number.	Reduced.	Synodic day.	Seismic number.	Reduced.
1	6	0.43	11	9	0.66	21	12	0.88
2	15	1.10	12	10	0.73	22	16	1.17
3	18	1.32	13	10	0.73	23	21	1.54
4	15	1.10	14	10	0.73	24	18	1.32
5	15	1.10	15	15	1.10	25	13	0.96
6	20	1.47	16	16	1.17	26	16	1.17
7	19	1.40	17	14	1.03	27	13	0.96
8	16	1.17	18	18	1.32	28	6	0.43
9	3	0.22	19	10	0.73	29	18	1.32
10	12	0.88	20	8	0.59	30	8	1.10

Total seismic number = 400.

TABLE XVIII.

SYNODIC-MONTHLY DISTRIBUTION OF EARTHQUAKES OBSERVED AT UTSUNOMIYA.

(Feb. 1891—Dec. 1902.)

Synodic day.	Seismic number.	Reduced.	Synodic day.	Seismic number.	Reduced.	Synodic day.	Seismic number.	Reduced.
1	10	0.43	11	27	1.17	21	19	0.83
2	17	0.74	12	29	1.26	22	18	0.78
3	24	1.04	13	25	1.09	23	30	1.30
4	22	0.96	14	15	0.65	24	32	1.39
5	26	1.13	15	22	0.96	25	23	1.00
6	22	0.96	16	18	0.78	26	33	1.44
7	35	1.52	17	21	0.91	27	23	1.00
8	15	0.65	18	24	1.04	28	24	1.04
9	14	0.61	19	22	0.96	29	31	1.35
10	24	1.04	20	18	0.78	30	14	1.13

Total seismic number=677.

TABLE XIX.

SYNODIC-MONTHLY DISTRIBUTION OF EARTHQUAKES OBSERVED AT MAEBASHI.

(Dec. 1896—Dec. 1902.)

Synodic day.	Seismic number.	Reduced.	Synodic day.	Seismic number.	Reduced.	Synodic day.	Seismic number.	Reduced.
1	7	0.76	11	13	1.41	21	5	0.54
2	8	0.87	12	8	0.87	22	8	0.87
3	8	0.87	13	13	1.41	23	12	1.30
4	9	0.98	14	10	1.09	24	13	1.41
5	6	0.65	15	11	1.20	25	11	1.20
6	10	1.09	16	5	0.54	26	11	1.20
7	12	1.30	17	13	1.41	27	10	1.09
8	4	0.43	18	13	1.41	28	6	0.65
9	5	0.54	19	11	1.20	29	8	0.87
10	4	0.43	20	9	0.98	30	7	1.41

Total seismic number=270.

TABLE XX.

SYNODIC-MONTHLY DISTRIBUTION OF EARTHQUAKES OBSERVED AT YAMAGATA.

(Dec. 1889—Dec. 1902.)

Synodic day.	Seismic number.	Reduced.	Synodic day.	Seismic number.	Reduced.	Synodic day.	Seismic number.	Reduced.
1	11	1.39	11	7	0.89	21	10	1.27
2	9	1.14	12	7	0.89	22	6	0.76
3	8	1.01	13	8	1.01	23	13	1.65
4	5	0.63	14	7	0.89	24	7	0.89
5	13	1.65	15	10	1.27	25	8	1.01
6	7	0.89	16	7	0.89	26	11	1.39
7	17	2.15	17	7	0.89	27	6	0.76
8	5	0.63	18	11	1.39	28	5	0.63
9	4	0.51	19	9	1.14	29	8	1.01
10	3	0.38	20	2	0.25	30	4	0.89

Total seismic number=235.

TABLE XXI.

SYNODIC-MONTHLY DISTRIBUTION OF EARTHQUAKES OBSERVED AT NIIGATA.

(April 1886—Dec. 1902.)

Synodic day.	Seismic number.	Reduced.	Synodic day.	Seismic number.	Reduced.	Synodic day.	Seismic number.	Reduced.
1	2	0.26	11	10	1.30	21	7	0.91
2	5	0.65	12	6	0.78	22	12	1.56
3	10	1.30	13	8	1.04	23	14	1.82
4	2	0.26	14	4	0.52	24	8	1.04
5	5	0.65	15	7	0.91	25	8	1.04
6	4	0.52	16	4	0.52	26	7	0.91
7	7	0.91	17	14	1.82	27	2	0.26
8	2	0.26	18	21	2.72	28	2	0.26
9	9	1.17	19	11	1.43	29	14	1.82
10	7	0.91	20	12	1.56	30	4	0.91

Total seismic number=228.

TABLE XXII.

SYNODIC-MONTHLY DISTRIBUTION OF EARTHQUAKES OBSERVED AT NAGANO.

(Jan. 1889—Dec. 1902.)

Synodic day.	Seismic number.	Reduced.	Synodic day.	Seismic number.	Reduced.	Synodic day.	Seismic number.	Reduced.
1	16	1.10	11	7	0.48	21	13	0.90
2	22	1.52	12	11	0.76	22	15	1.03
3	12	0.83	13	11	0.76	23	9	0.62
4	13	0.90	14	5	0.35	24	16	1.10
5	21	1.45	15	14	0.97	25	17	1.17
6	17	1.17	16	17	1.17	26	16	1.10
7	18	1.24	17	15	1.03	27	16	1.10
8	9	0.62	18	25	1.73	28	11	0.76
9	12	0.83	19	20	1.38	29	14	0.97
10	6	0.41	20	11	0.76	30	9	1.17

Total seismic number=418.

TABLE XXIII.

SYNODIC-MONTHLY DISTRIBUTION OF EARTHQUAKES OBSERVED AT HIKONE.

(Jan. 1894—Dec. 1902.)

Synodic day.	Seismic number.	Reduced.	Synodic day.	Seismic number.	Reduced.	Synodic day.	Seismic number.	Reduced.
1	8	0.82	11	12	1.22	21	10	1.02
2	11	1.12	12	12	1.22	22	10	1.02
3	9	0.92	13	7	0.71	23	11	1.12
4	8	0.82	14	15	1.53	24	8	0.82
5	5	0.51	15	12	1.22	25	9	0.92
6	10	1.02	16	7	0.71	26	11	1.12
7	11	1.12	17	9	0.92	27	10	1.02
8	12	1.22	18	11	1.12	28	7	0.71
9	11	1.12	19	10	1.02	29	14	1.43
10	6	0.61	20	7	0.71	30	6	1.12

Total seismic number=289.

TABEE XXIV.

SYNODIC-MONTHLY DISTRIBUTION OF EARTHQUAKES OBSERVED AT WAKAYAMA.

(Sept. 1879—1902.)

Synodic day.	Seismic number.	Reduced.	Synodic day.	Seismic number.	Reduced.	Synodic day.	Seismic number.	Reduced.
1	15	0.94	11	12	0.75	21	17	1.06
2	13	0.81	12	12	0.75	22	14	0.87
3	19	1.19	13	12	0.75	23	12	0.75
4	21	1.31	14	18	1.12	24	21	1.31
5	16	1.00	15	17	1.06	25	20	1.25
6	16	1.00	16	10	0.62	26	23	1.44
7	15	0.94	17	7	0.44	27	20	1.25
8	14	0.87	18	8	0.50	28	25	1.56
9	17	1.06	19	15	0.94	29	20	1.25
10	18	1.13	20	17	1.06	30	8	0.94

Total seismic number=472.

TABLE XXV.

SYNODIC-MONTHLY DISTRIBUTION OF EARTHQUAKES OBSERVED AT KAGOSHIMA.

(March 1885—Dec. 1903.)

Synodic day.	Seismic number.	Reduced.	Synodic day.	Seismic number.	Reduced.	Synodic day.	Seismic number.	Reduced.
1	17	0.96	11	30	1.69	21	15	0.84
2	16	0.90	12	12	0.67	22	9	0.51
3	19	1.07	13	27	1.52	23	11	0.62
4	19	1.07	14	24	1.35	24	16	0.90
5	29	1.63	15	26	1.46	25	16	0.90
6	10	0.56	16	20	1.13	26	11	0.62
7	8	0.45	17	21	1.18	27	23	1.29
8	23	1.29	18	21	1.18	28	10	0.56
9	15	0.84	19	22	1 24	29	22	1.24
10	16	0.90	20	12	0.67	30	7	0.73

Total seismic number=527.

12. Drawing the frequency curves (figs. 3–24) in the way already explained, we notice firstly, that in most cases there occur two distinct pairs of maxima, one about the times of the conjunction and opposition of the sun and moon, and the other at intermediate times; and secondly, that the first pairs of maxima is pronounced at certain stations, and the second pair at some other stations, while at the remaining stations the two pairs develop equally well. The relation expressed in the second statement may possibly be due to the fact that the observed earthquakes were mostly of inland origin, or of submarine, or of both origins. With this view, I have grouped the different stations into three sets (*A*), (*B*), and (*C*), according as their observations related mostly to inland earthquakes, both inland and submarine, and submarine respectively. Table XXVI shows this arrangement and grouping; the frequency curves at the different stations have also been arranged in the same order. The numbers in the right hand columns of the table are the days at which the frequency curve reaches their maximum height, days relating to more pronounced being printed with fat letters.

TABLE XXVI.

Group.	Meteorological stations.	Day of Maximum Seismic Number.			
A	Nagoya.	**2**	**18**	6	26
	Fukuoka.	**30**	**18**	4	23
	Niigata.	30	**18**	11	23
	Tokyo.	**30**	**18**	7	**23**
	Kagoshima.	29	**14**	**4**	—
B	Gifu.	29	**14**	—	25
	Osaka.	**28**	**12**	—	—
	Nagoya.	4	15	**11**	**21,25**
	Wakayama.	**28**	14	**4**	20
	Aomori.	**30**	**15**	**7**	20
	Oita.	**2**	18	**9**	24
	Hikone.	29	14	8	—
C	Maebashi.	**30**	**15**	**7**	**24**
	Mito.	30	**14**	6	**26**
	Hakodate.	**28**	—	**6**	21
	Nemuro.	—	18	**9**	26
	Yamagata.	1	15	**7**	23
	Fukushima.	2	**13**	7	**24**
	Ishinomaki.	1	**16**	10	**25**
	Utsunomiya.	**29**	**12**	**6**	**24**
	Akita.	30	**17**	**6**	**23**
	Miyako.	30	17	**8**	**24**
	Average.	30	15	7	23

13. Let us now compare the frequency curves in the two extreme cases, namely, those of Nagano and Miyako. The former station which is situated in the high land of Shinano, about 180 km. distant from the Pacific coast is disturbed mostly by local shocks, earthquakes which occurred in the Pacific basin having been registered there only when the disturbance was very strong at the origin. In the frequency curve, we notice one distinct pair of maxima on the 2nd and 18th. The seismic number in each of these days is about 3 times of the

minimum and 1.6 times of the daily average. Another pair of maxima occurred on the 6th and 26th.

14. Miyako is, on the other hand, situated on the Pacific coast bordering the earthquake region which runs parallel to the coast line at a distance of some 100 to 200 km. from it. Earthquakes which were felt at Miyako originated mostly in this zone, with a few exceptions of shocks which occurred in the eastern part ot Mutsu province. The frequency curve has a pair of the pronounced maxima on the 8th and 24th, the seismic number in each of these days amounting to 2 times or more of the minimum and 1.5 times of the daily average. A pair of minor maxima occurred on the 30th and 17th.

15. Thus we see that the days of maximum seismic number for the two stations coincide almost with each other, the only difference being that the days of pronounced pair in one station is replaced by those of minor pair in the other. The state of things is very similar between the frequency curves to the stations (*A*) and (*C*), though the difference is not so distinctly marked as in the two typical stations. It will also be seen that the stations in the group (*B*) stand between the two other groups so far as the above-mentioned characteristic is concerned.

16. For the sake of comparison, I give another example of the distribution of submarine earthquakes. Among the earthquakes contained in the Earthquake Inv. Comm. Catalogue there are 28 large ones which were accompanied by destructive sea-waves, and 62 others which were not apparently accompanied by sea-waves but which may be inferred, on account of the disturbed area, to have originated at sea coast places or under the sea. These two sorts of earthquakes are tabulated as follows:—

TABLE XXVII.

Synodic day.	Number of earthquakes.			Synodic day.	Number of earthquakes.		
	With sea-waves.	Without sea-waves.	Sum.		With sea-waves.	Without sea-waves.	Sum.
1	0	2	2	16	2	3	5
2	0	2	2	17	0	0	0
3	0	0	0	18	0	2	2
4	2	1	3	19	1	3	4
5	1	6	7	20	0	2	2
6	0	2	2	21	1	3	4
7	1	6	7	22	2	3	5
8	1	0	1	23	2	6	8
9	0	4	4	24	1	3	4
10	0	1	1	25	3	3	6
11	0	1	1	26	3	3	6
12	1	1	2	27	1	0	1
13	0	0	0	28	1	3	4
14	2	2	4	29	0	1	1
15	1	1	2	30	1	0	1
				Sum.	28	62	90

From this table, it will be seen that the greatest number of the submarine earthquakes occurred about the 23rd, and the next greatest about the 7th and the 16th, the state of things being very similar to the fact remarked in connection with the observations at the different Meteorological Stations.

IV. Causes of the four maxima in the frequency curves.

17. The existence of two maximum seismic numbers at the times of the conjunction and opposition of the sun and moon, being due to the joint effect of these two heavenly bodies, does not require further discussion. The following may be an explanation for the existence of the other pair at the 7th and 23rd.

18. According to Dr. Omori, the barometric pressure has marked influence upon the seismic frequency in Japan; the curves showing the time variations of the two quantities being similar to each other. Now the barometric pressure which reaches in its diurnal variation

its maximum at 9h and 22h, will interfere with the tidal force helping or cancelling the latter according as high-water or low-water occurs at these times. In Tokyo, the synodic days corresponding to the former case are the 7th and 22nd, the days corresponding to the latter are the 12th and 27th. Allowing an hour or two for time difference of occurrences of maximum tidal and barometric pressures at other localities, the days 6th–9th and 21st–24th are ones in which the resultant of the two influences becomes most effective. Thus we may look for the maximum seismic numbers about the 7th and 22nd which correspond roughly to the actual maxima in question.[1]

Although the diurnal variation of seismic frequency follows generally that of barometric pressure, yet we see in several cases that the former variation does not necessarily follow the latter. Thus in the curves of diurnal variation of seismic frequency for Nemuro and Nagoya we notice several maxima in the following hours, those in the first column relating to the more pronounced maxima.

Nemuro	4.0–11.5 (a.m.).	5.0—7.0 (p.m.).
Nagoya	1.5 (a.m.), 4.5 (a.m).	10.0 (p.m.).

If there are causes which influence the seismic occurrences of these regions at such hours, they will interfere with the tidal force and will give rise to a great number of seismic occurrences at the days when high-water and the assumed causes take place at the same time. These days are found in cases of Nemuro and Nagoya as follows:—

Nemuro	1–10, 16–25.	3–6, 17–20.
Nagoya	10,25; 13,28.	7,21.

On comparing these days with the days of actual maximum seismic number, we see at once that a tolerably fair correspondence exists between the two as it is indicated in figs. 18 and 10, in which the days found from deduction are given in larger letters along the axis of x.

1. This explanation was suggested to me by Dr. Honda of the Physical Institute of the Sc. Coll., Imp. Univ. Tokyo.

20. With the above-stated view, I have constructed the following table in which the days of actual and deduced maximum seismic numbers are so arranged as to be readily comparable. From the table, it will be seen how tolerably well the days found by the two different methods agree with each other.

Station.	Time of high-water, relative to that of Tokyo Bay.	Hour of occurrence of maximum in diurnal seismic variation.	Synodic days in which hours in the above column and of high-water coincide.	Synodic days of actual maximum seismic number.	Hour of occurrence of maximum in diurnal seismic variation.	Synodic days in which hours in the above column and of high-water coincide.	Synodic days of actual maximum seismic number.	Hour of occurrence of maximum in diurnal seismic variation.	Synodic days in which hours in the above column and of high-water coincide.	Synodic days of actual maximum seismic number.
Tokyo.	0	h 9.5h am.	7,22	6,22						
Kagoshima.	h +1.0	1.5 am,pm.	10,26	11,27	6.5(slight) am,pm.	1,16	?	10.5(slight) am,pm.	7,23	8,24
Gifu.	+0.6	4.5 am.	13,28	14,29	0.5(slight) pm.	10,24	9,24	9.0 pm.	6,20	5,19
Nagoya.	+0.6	1.5(large) am.	10,25	11,26	4.0 am.	14,28	15,29	10.0(slight) pm.	6,21	4,21
Wakayama.	0	4,5(slight) am.	14,29	14,28	7.0(slight) pm.	4,18	4,20	10.5 pm.	8,23	10,24
Aomori.	−1.0(?)	1.5 am.	11,27	11,26	9.5 am.	7,24	8,26	6.0 pm.	3,19	6,20
Nemuro.	−1.6	4.0 am.	1,16	2,18	11.5 am.	10,25	9,25	5–7 pm.	3–6,17–20.	4–6,17–19
Fukushima.	−1.0	9.5 am.	7,24	7,24	7.0 pm.	4,21	4,21			
Ishinomaki.	−1.3	2.5 p.m.	13,28	15,25						
Utsunomiya.	−0.5(?)	9.0 am.	6,23	7,26	7.5 pm.	4,21	5,23			
Miyako.	−1.0	1.5(slight) am.	12,26	(?),26	9.5 am.	8,23	8,23	6.0 am.	3,18	3,18

V. Conclusion.

21. Earthquake occurrences in Japan, when they are distributed

in synodic days, reach the greatest number at two pairs of times, namely :—

Firstly, at the times of the conjunction and opposition of the sun and moon, the combined effort of the two heavenly bodies being the cause ;

Secondly, at the times of quadrature, the combined effort of the moon and barometric pressure being the cause.

22. I have confined myself to the study of the historical earthquakes in Japan, and the recent earthquakes registered by ordinary Gray-Milne type seismographs at the 22 Meteorological Stations in Japan. In the next occasion, I wish to study the synodic monthly distribution of the earthquakes which originated only in the immediate vicinity of Tokyo, and further the relation of the occurrence of each earthquake with the tidal and barometric pressures of successive days.

Nov. 9th, 1903.

Seismological Institute.

Explanation of Figures.

Figs. 1–2 show the synodic monthly distribution of historical earthquakes.

Figs. 3–24 show the synodic monthly distribution of the instrumental observations of recent earthquakes.

For figs. 1-24:

x = Japanese synodic day.

y = actual number of seismic observations at the corresponding day.

Number in larger letters along the axis of x in figs. 6, 7, 8, &c. indicates the day of *deduced* maximum seismic number (Chapter IV).

Fig. 1. Japan.

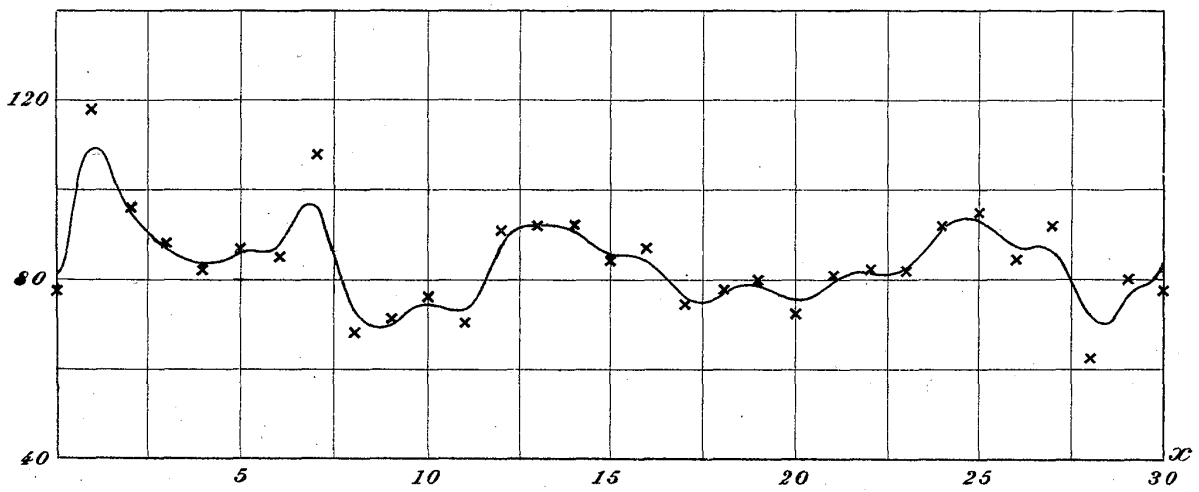

Fig. 2. Kyoto.

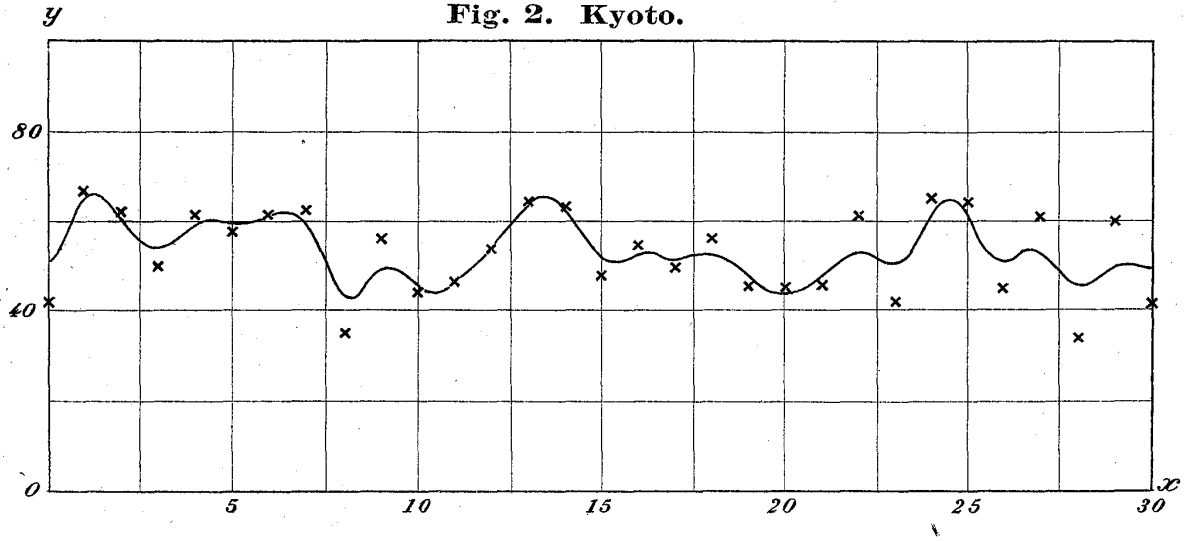

Fig. 3. Nagano.

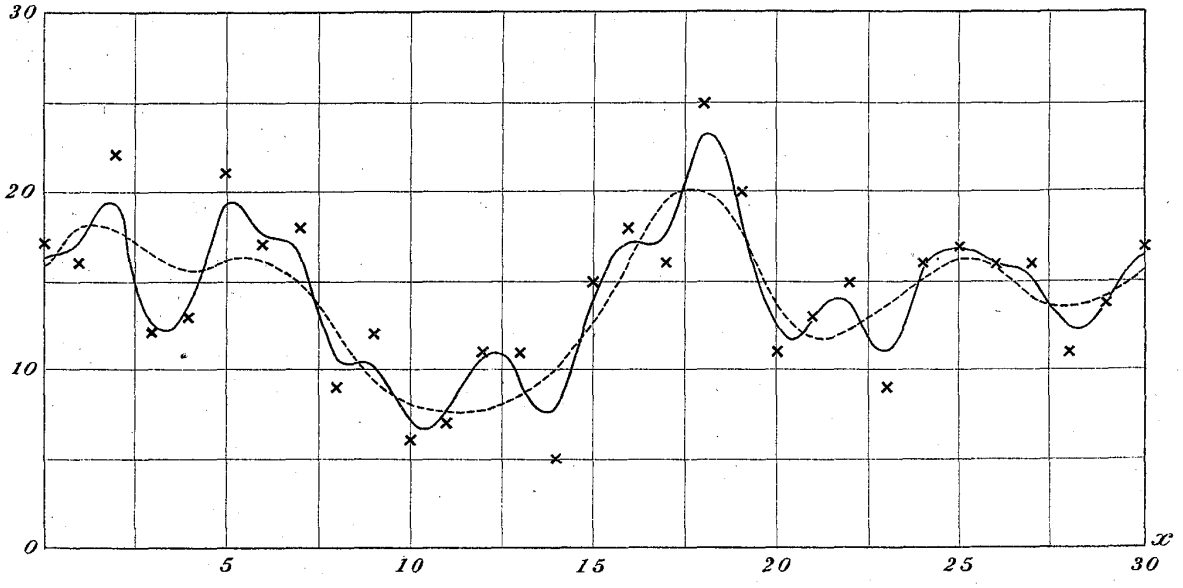

Fig. 4. Fukuoka.

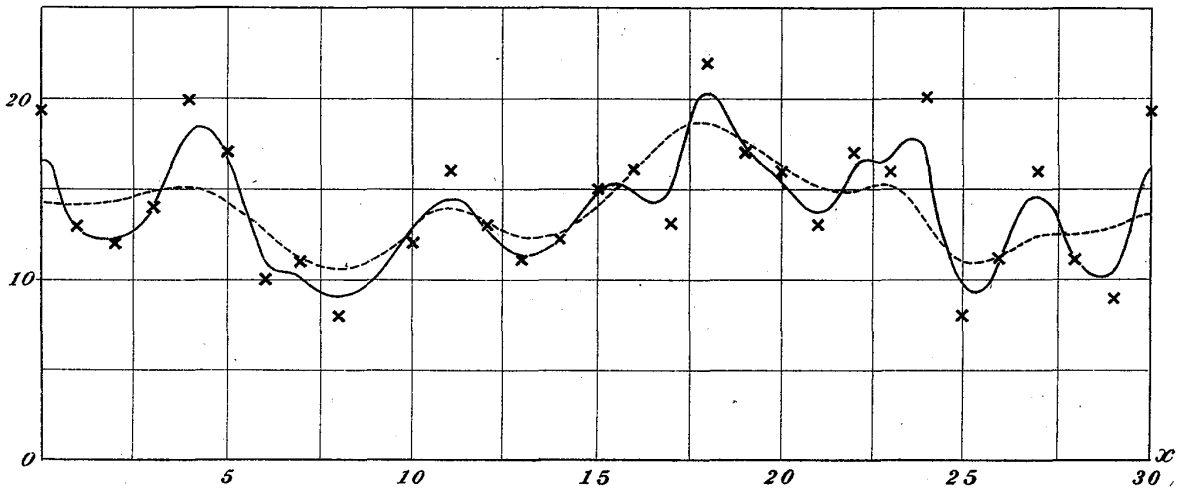

Fig. 5. Niigata.

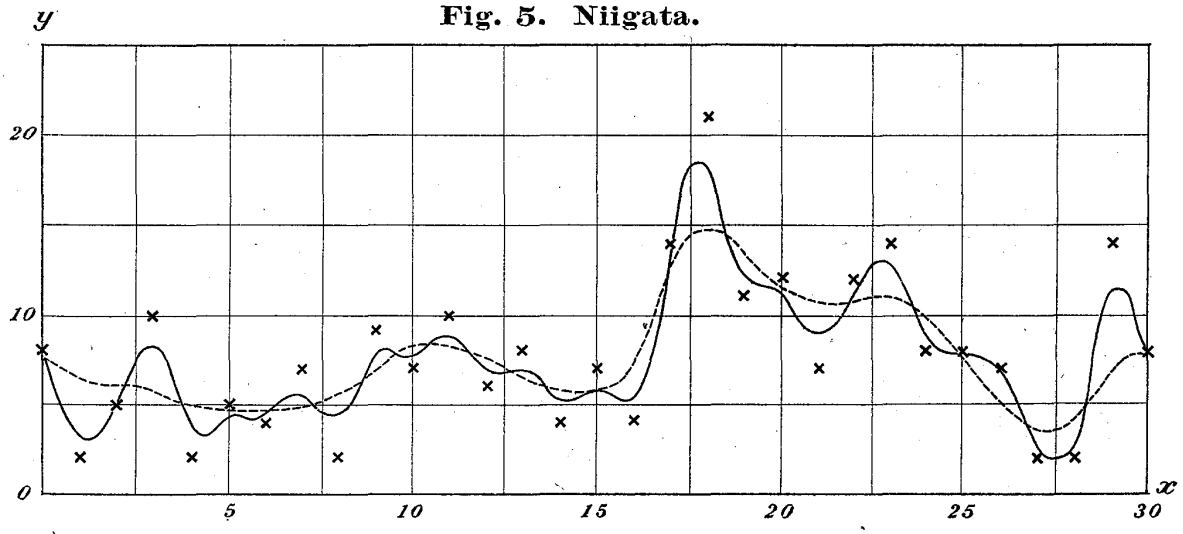

Fig. 6. Tokyo.

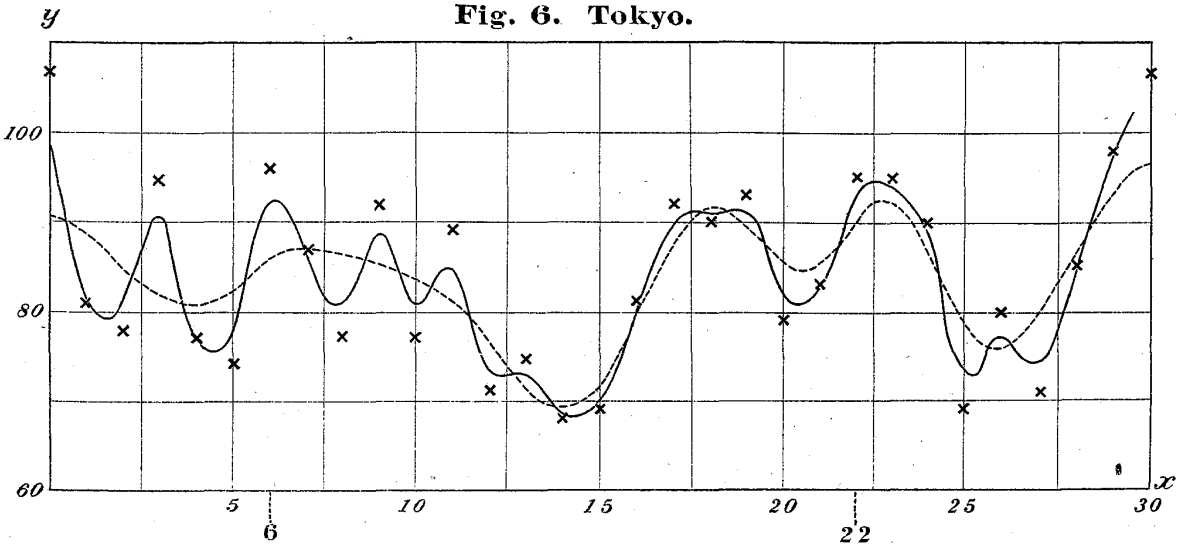

Fig. 7. Kagoshima.

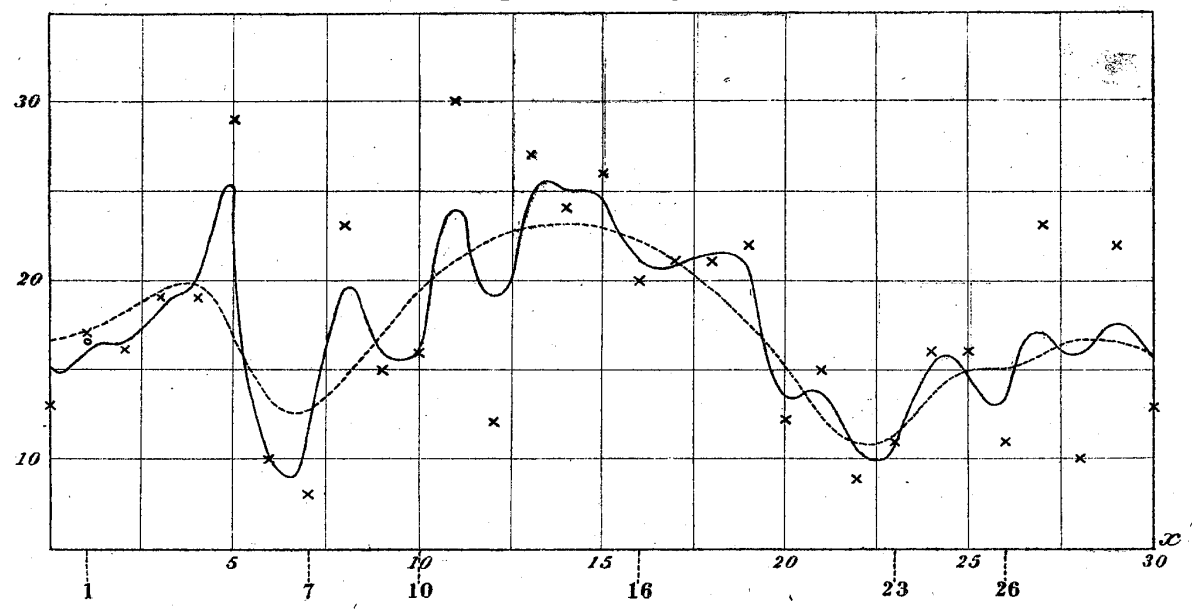

Fig. 8. Gifu.

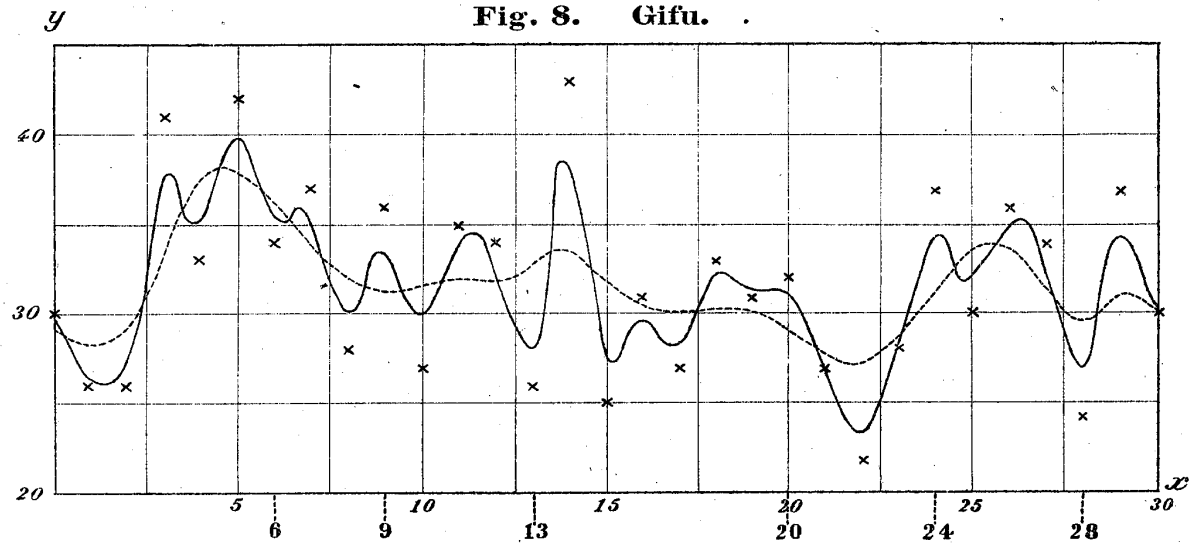

Fig. 9. Osaka.

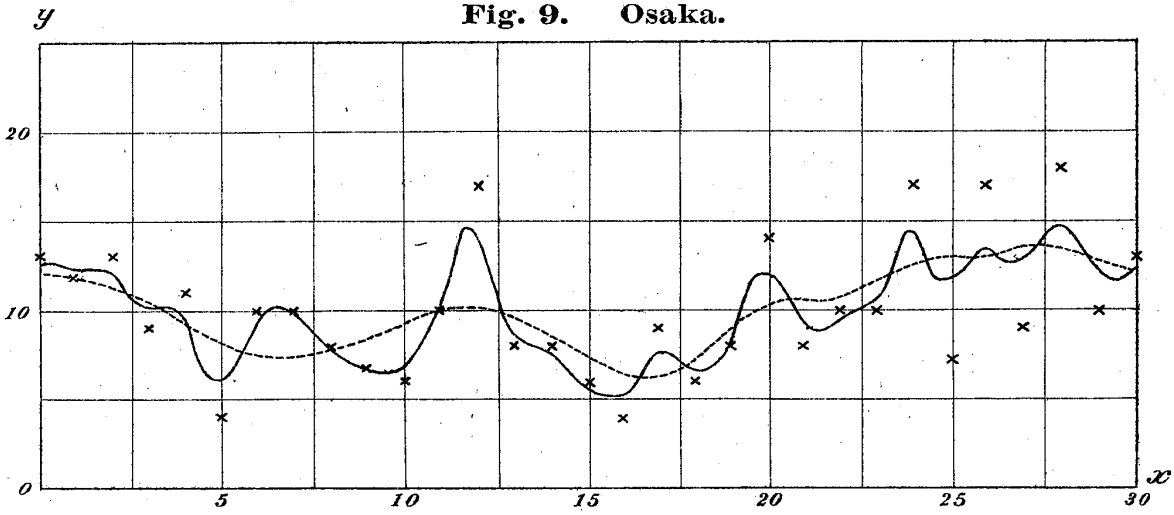

Fig. 10. Nagoya.

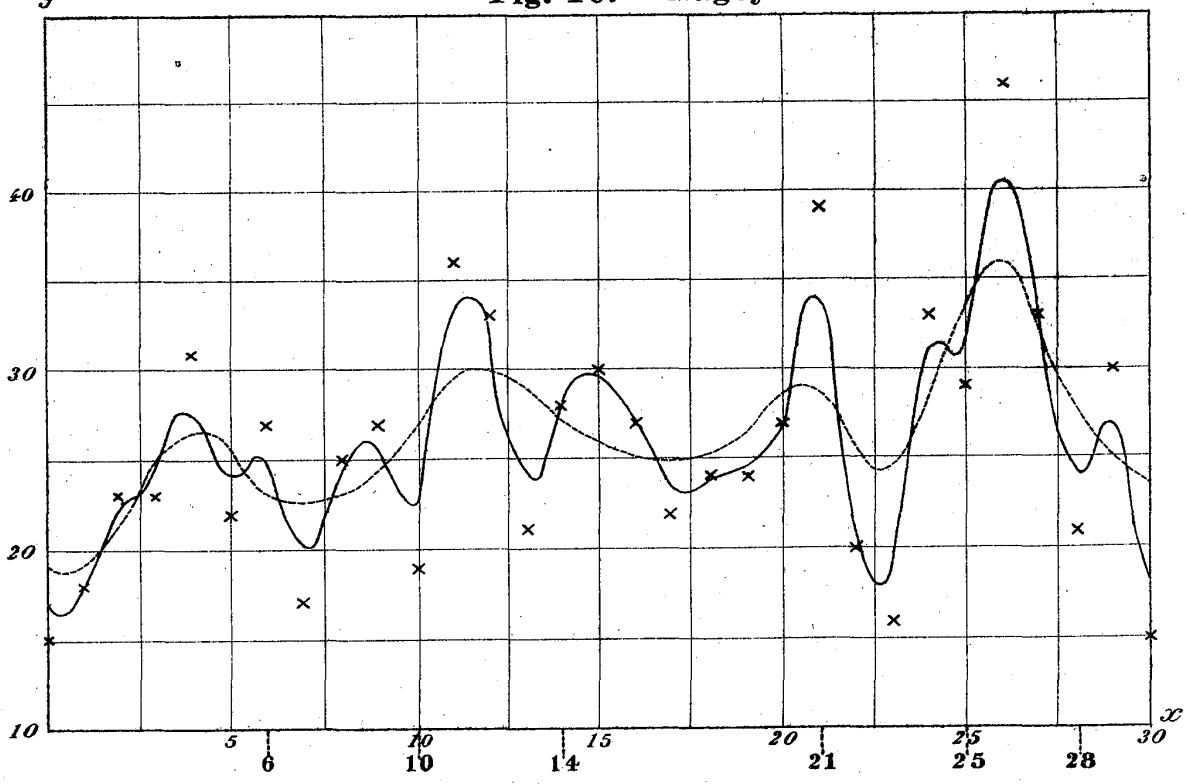

Fig. 11. Wakayama.

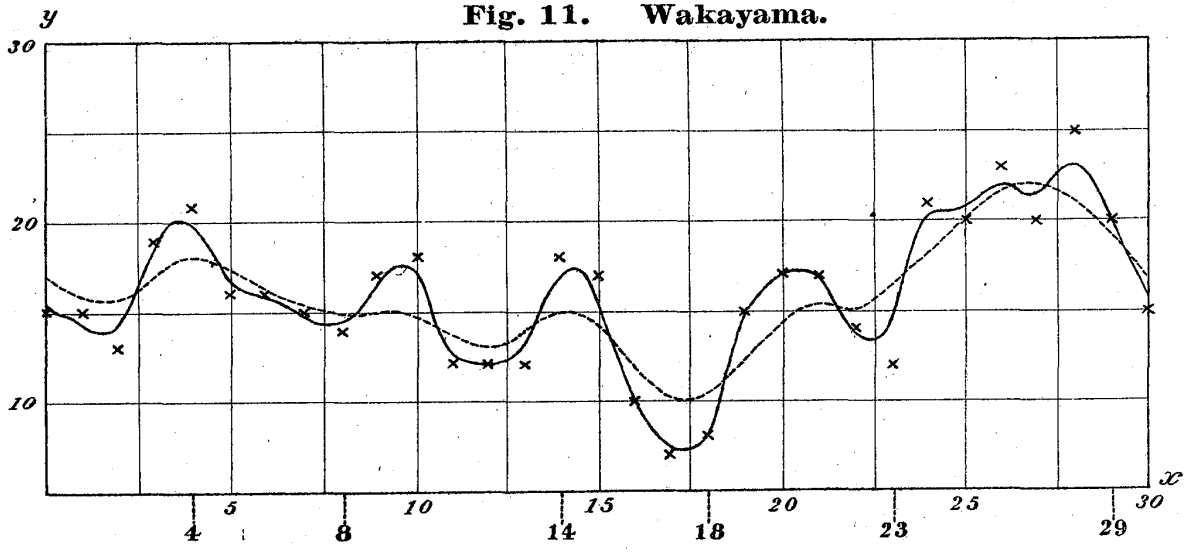

Fig. 12. Aomori.

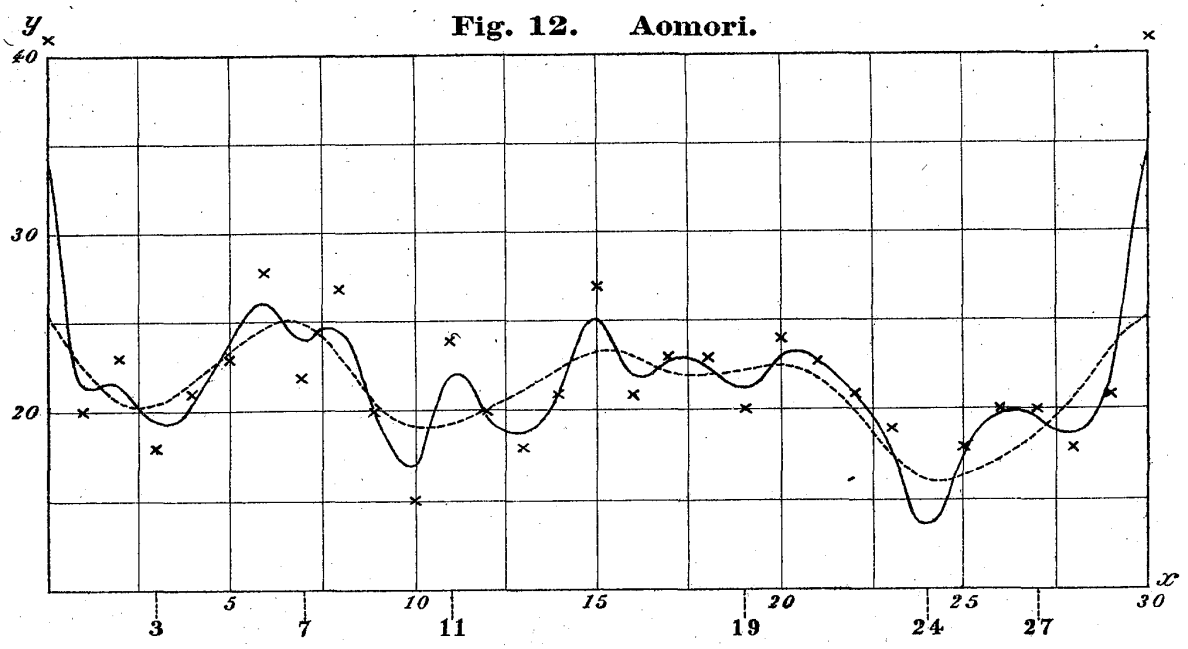

Fig. 13. Oita.

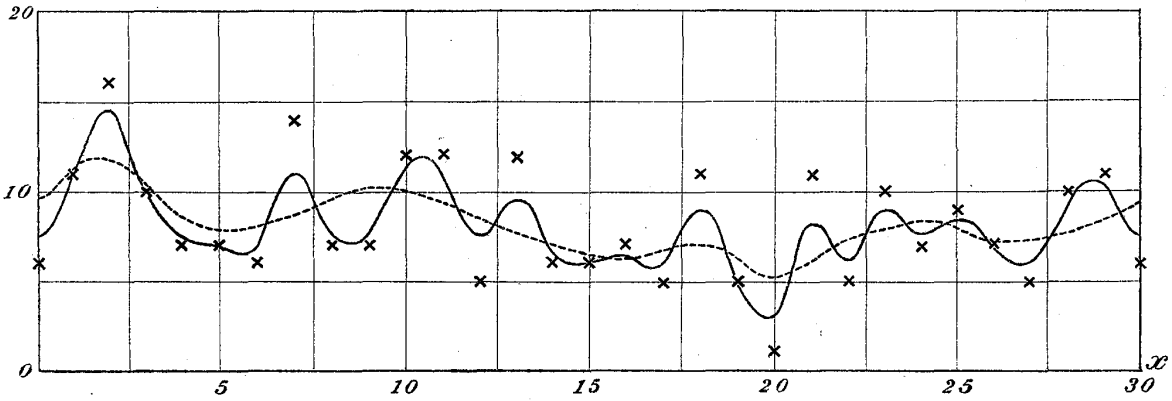

Fig. 14. Hikone.

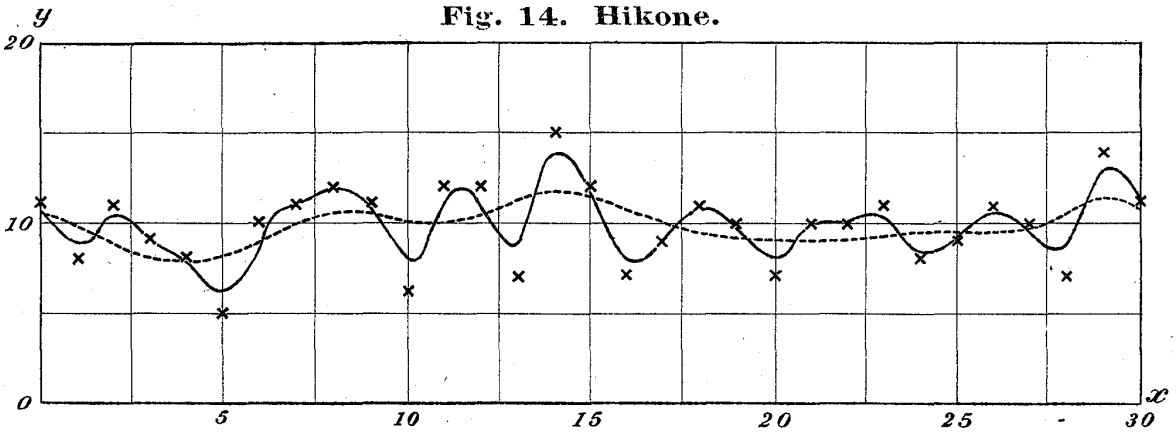

Fig. 15. Maebashi.

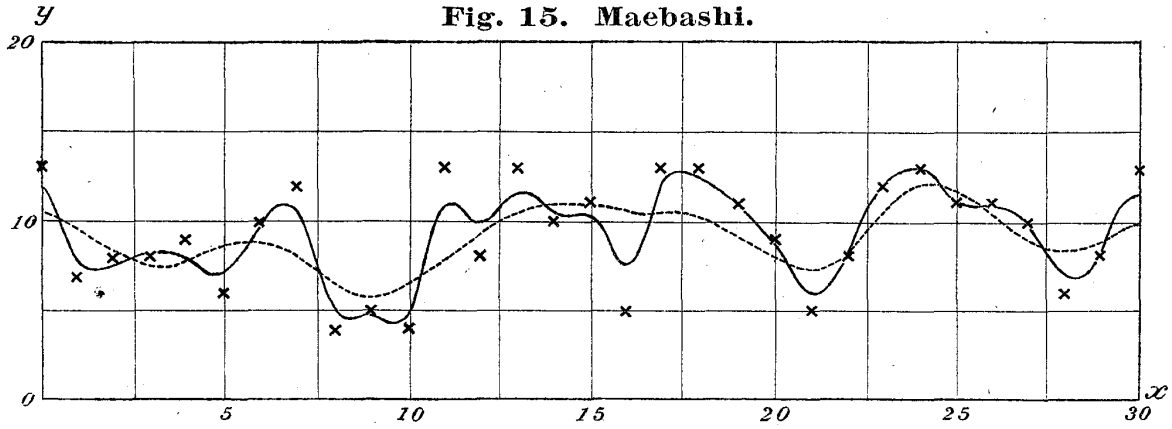

Fig. 16. Mito.

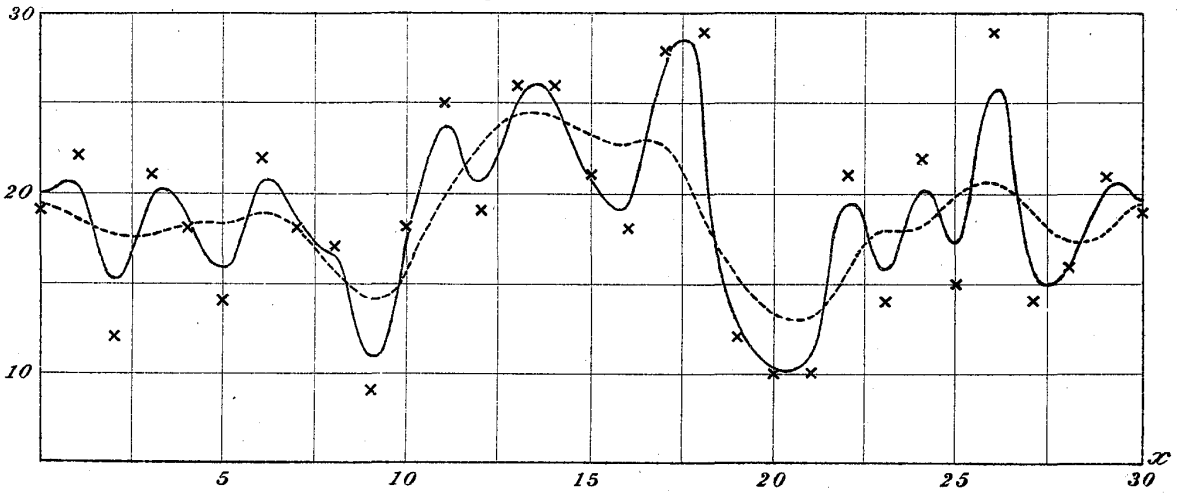

Fig. 17. Hakodate.

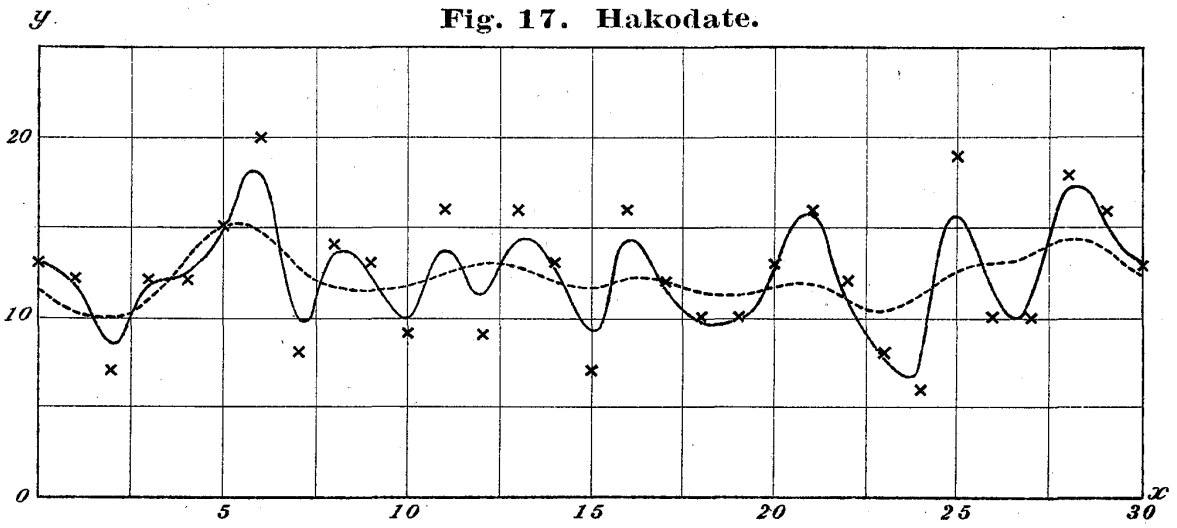

Fig. 18. Nemuro.

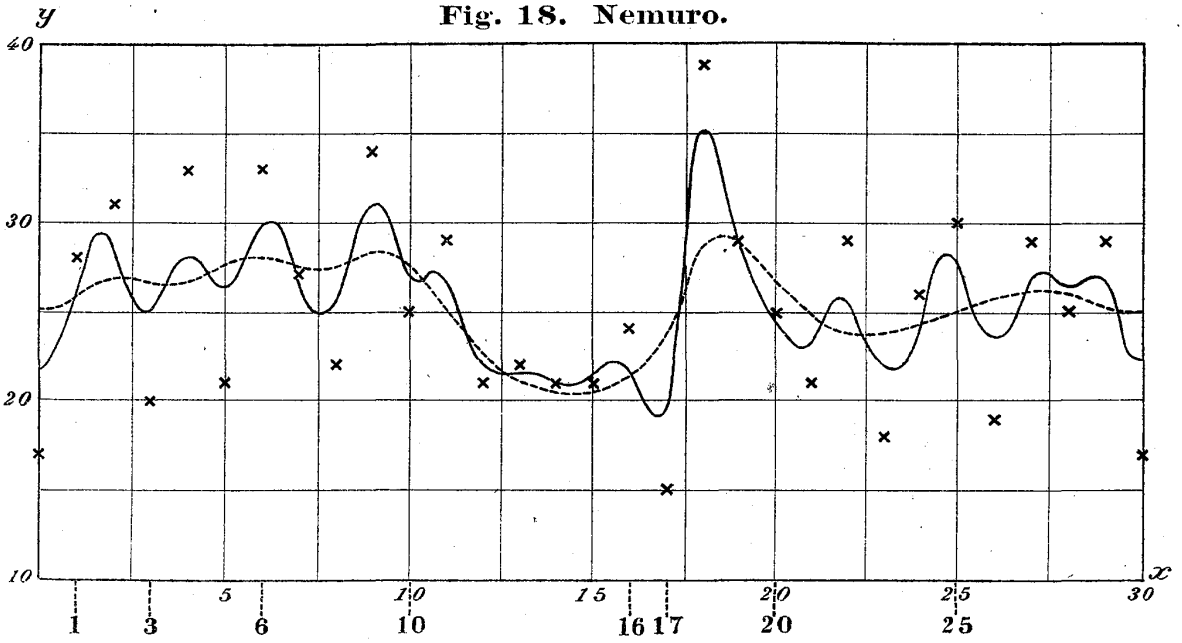

Fig. 19. Yamagata.

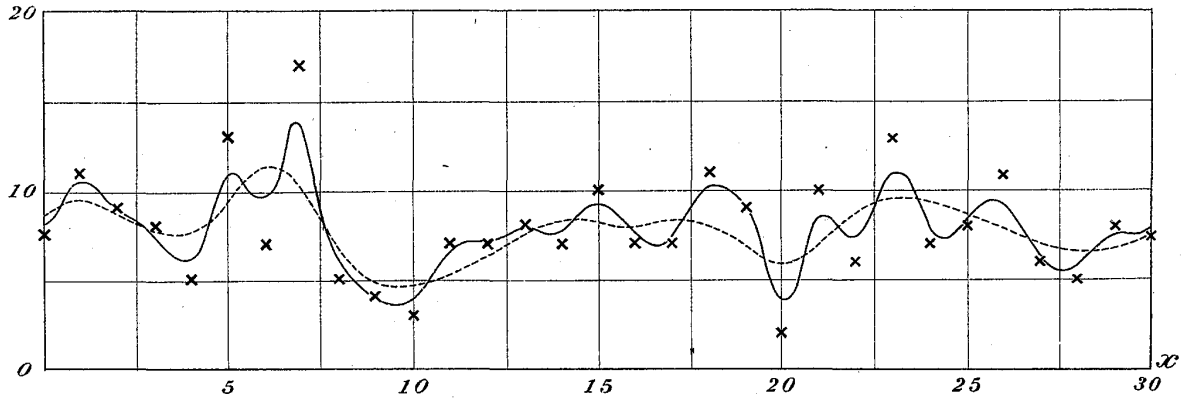

Fig. 20. Fukushima.

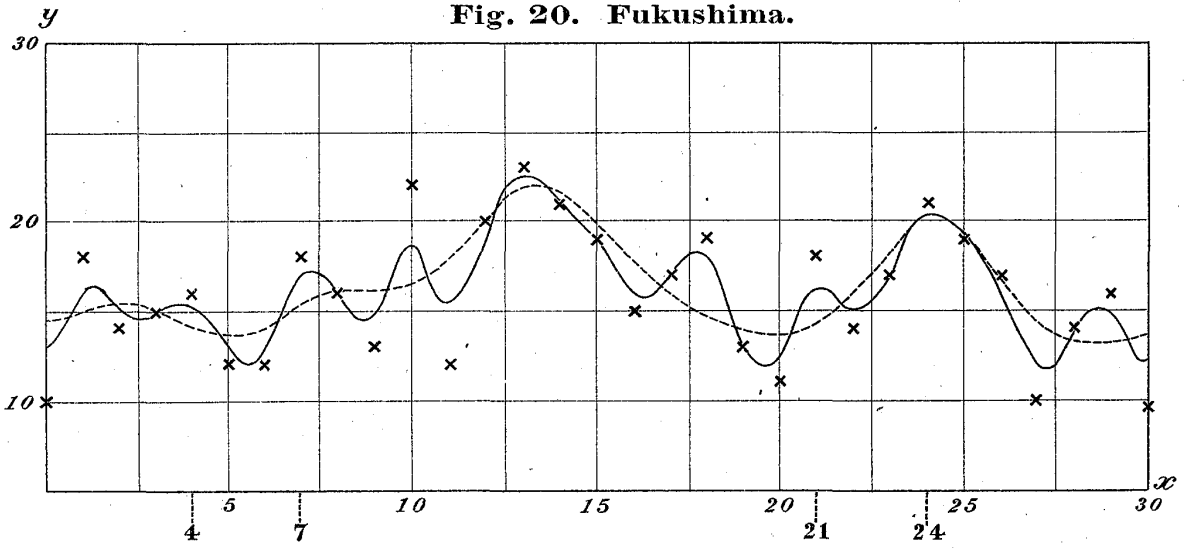

Fig. 21. Ishinomaki.

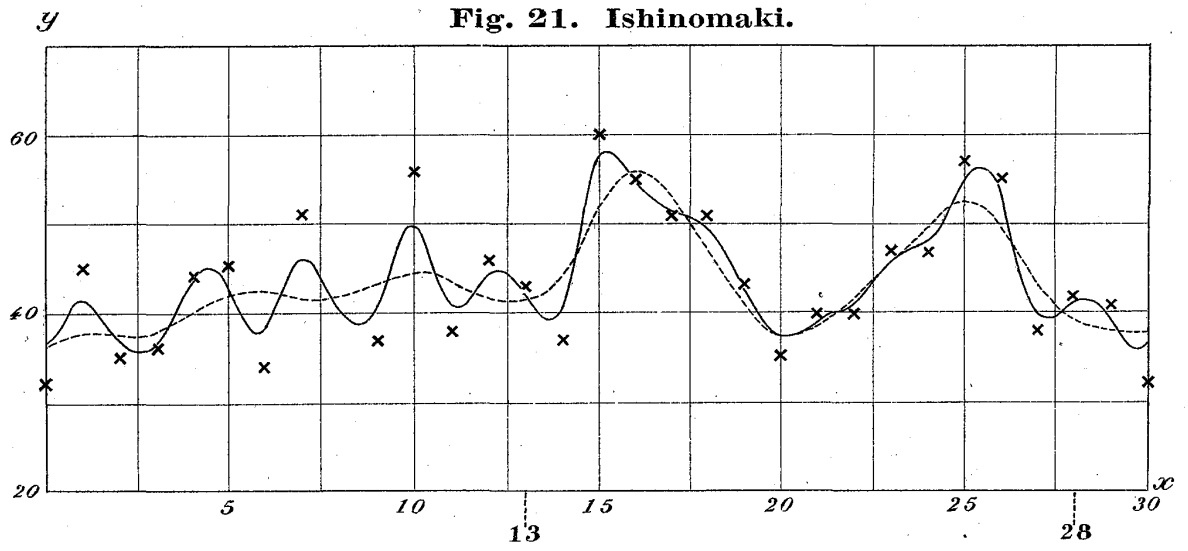

Fig. 22. Utsunomiya.

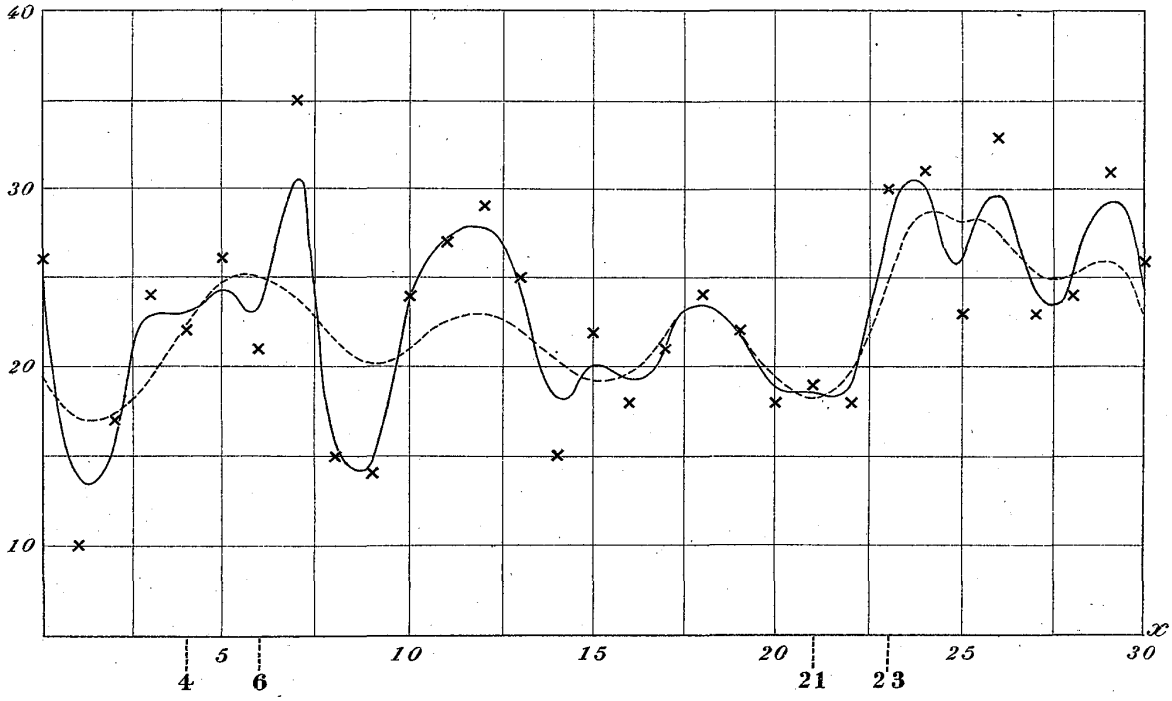

Fig. 23. Akita.

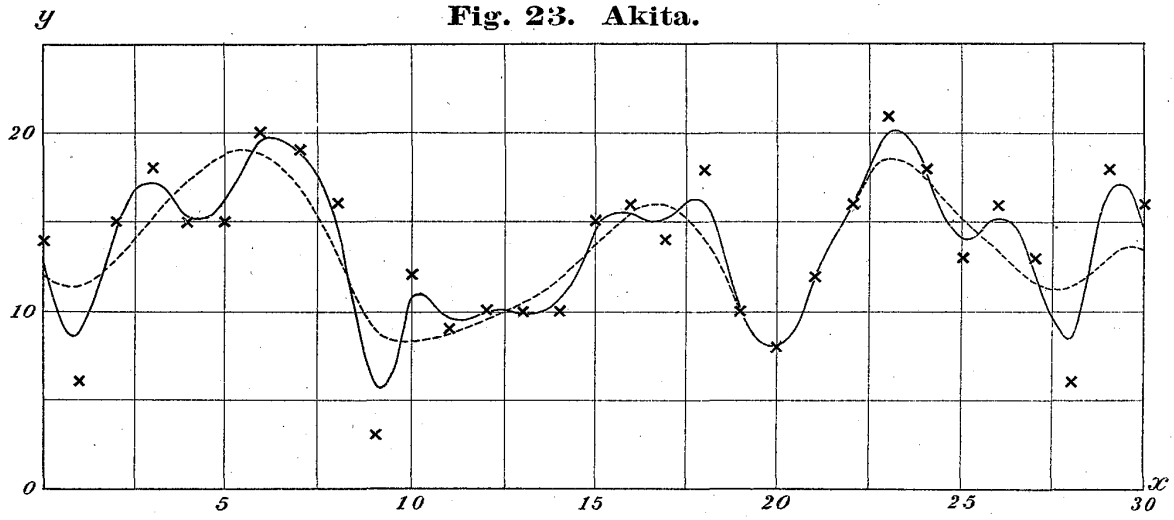

Fig. 24. Miyako.