On the Annual Variation of the Height of Sea-Level along Japanese Coasts. *2nd Paper.*

By

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With Pls. XIV-XIX.

Introductory. In a previous note* I have considered the relation to the barometric pressure and the seismic frequency of the annual variation during 1902 of the height of sea-level at Ayukawa and Misaki, which are situated on the Pacific coast of the Main Island. The present paper treats of the same relation for these two places during the year 1903, and also gives the discussion of the sea-level observations during 1904 made at Choshi (province of Shimosa) on the Pacific side, and at the four Japan-Sea coast stations of Otaru, Iwasaki, Wajima and Hamada. The data relating to the mean monthly heights of sea level at Choshi are based on the report of the meteorological observatory at that town, while those relating to all the other places have been furnished by the Survey Department of the General Staff of the Imperial Army; the tidal measurement at each place being made by means of an automatically recording mareograph. The approximate positions of the different stations, which are shown in Fig. 1 (Pl XIV), are as follows.

* The "Publications of the Earthquake Inv. Comm.", No. 18.

Stations.	Latitude (N).	Longitude (E).
Otaru.	43° 13′	141° 01′
Iwasaki.	40 36	139 55
Ayukawa.	38 18	141 31
Chōshi	35 44	140 50
Misaki.	35 10	139 37
Wajima (Wajima-zaki).	37 25	136 54
Hamada (Sotonoura).	34 55	132 05

Height of sea-level at Ayukawa and Misaki, in 1903. Table I gives the mean relative monthly heights of sea surface for 1903 at Ayukawa (province of Rikuzen) and Misaki (province of Sagami), while Table II gives the mean monthly atmospheric pressure for the same year deduced from the barometric observations at the meteorological observatories of Ishinomaki and Yokosuka, respectively near to the two mareograph stations above named.

Table I. Mean Monthly Relative Heights of Sea Level at *Ayukawa* and *Misaki.* **1903.**

Month.	Ayukawa.	Misaki.	*Mean.*
January.	131 mm	101 mm	116 mm
February.	75	60	68
March.	12	0	6
April.	0	19	10
May.	116	102	109
June.	187	185	186

Month.	Ayukawa.	Misaki.	*Mean.*
July.	257 mm	183 mm	220 mm
August	233	206	220
September.	246	190	218
October.	220	220	220
November.	166	191	179
December.	187	133	160

Table II*. Mean Monthly Barometric Heights at Ishinomaki and Yokosuka. **1903.**

Month.	Ishinomaki.	Yokosuka.	*Mean*
January.	700 mm + 62.4 mm	700 mm + 62.7 mm	700 mm + 62.6 mm
February.	62.7	63.0	62.9
March.	64.2	63.9	64.1
April.	63.3	63.1	63.2
May.	60.0	60.1	60.1
June.	56.1	55.9	56.0
July.	56.5	57.1	56.8
August.	58.8	58.9	58.9
September.	61.2	60.6	60.9
October.	63.3	62.5	62.9
November.	63.4	63.1	63.3
December.	61.3	61.8	61.6

The 2nd and 3rd columns of Table III give the relative monthly values of the heights of sea surface and of the atmos-

* Reduced to sea level and the freezing point.

pheric pressure, respectively meaned from the Ayukawa and Misaki mareograph observations (Table I) and from the Ishinomaki and Yokosuka barometric readings (Table II), the figures indicated in the 4th column being the relative total amount of pressure expressed in height of water column at the sea bottom itself, obtained by adding the aqueous and the atmospheric pressures as above deduced. From Figs. 2 and 3 (Pl. XV), it will be seen that the annual variation of the height of sea surface is on the whole opposite to that of the atmospheric pressure; the sea water being lowest in March, and the barometric height maximum in the same month. The total pressure at the sea bottom varied relatively between 110 and 308 mm, the maximum and minimum occurring respectively in Octobor and March.

Table IV gives the data for 1902, meaned from Ayukawa and Misaki, as well as the total pressure at the sea bottom averaged from the two years 1902 and 1903. As will be seen from Fig. 8, the annual variation of the latter quantity presents the maximum in October and the minimum in March and April, the amount of fluctuation being 194 mm of water column, or 14.3 mm of mercury, which is about $1\frac{1}{2}$ times that of the fluctuation of the monthly mean of the barometric pressure.

Table III. Mean Relative Monthly Heights of Sea Level and Barometric Pressure. ***Ayukawa*** and ***Misaki***. **1903**.

Month.	Height of Sea Level.	Barometric Pressure.	Total Pressure at Sea Bottom.*
	mm	mm	mm
January.	110	6.6	200
February.	62	6.9	156
March.	0	8.1	110 (min.)
April.	4	7.2	112

* Expressed in column of water.

Month.	Height of Sea Level.	Barometric Pressure.	Total Pressure at Sea Bottom*.
	mm	mm	mm
May.	103	4.1	159
June.	180	0.0	180
July.	214	0.8	225
August.	214	2.9	253
September.	212	4.9	279
October.	214	6.9	308 (max.)
November.	173	7.3	272
December.	154	5·6	230

Table IV. Mean Relative Monthly Heights of Sea Level and Barometric Pressure. ***Ayukawa*** and ***Misaki***. **1902** and **1903**.

Month.	Height of Sea Level. 1902.	Barometric Pressure. 1902.	Total Pressure at Sea Bottom.* 1902.	Total Pressure at Sea Bottom.* 1902-1903 (mean.)
	mm	mm	mm	mm
January.	125	5.1	194	197
February.	0	8.3	111 (min.)	134
March.	46	6.0	128	119 (min.)
April.	74	4.0	128	120 (min.)
May.	142	3.2	185	172
June.	171	0.2	174	177
July.	186	0.0	186	206
August.	205	2.6	240	247
September.	248	2.5	282	281
October.	210	7.9	317 (max.)	313 (max.)
November.	141	9.3	267	270
December.	207	4.8	272	251

* Expressed in column of water.

Comparing Figs. 2 and 3 with the figures in the 1st paper (the *Publications*, No. 18), we see that the relation of the variation of the height of sea surface to that of the atmospheric pressure remained essentially identical in the two years of 1902 and 1903, the only difference being that the epoch of the lowest water and highest barometer occurred in 1902 in February, and in 1903 in March.

In 1902, the amount of the fluctuation of the mean monthly values of the height of sea surface was 248 mm, while that of the atmospheric pressure was equivalent to 126 mm of column of water; these two numbers being in the ratio of 197 : 100. In 1903, the amount of fluctuation of the height of sea water was somewhat smaller, namely, 214 mm, that of the atmospheric pressure being also smaller and equivalent to 110 mm of water column. These two latter nnmbers are in the ratio of 195 : 100, which is nearly equal to that for 1902.

Observation at Choshi (1904)*.* The following table gives the mean monthly values of the relative height of sea surface and the atmospheric pressure at Choshi, near the Cape Inuboe, in the province of Shimosa.

Table V. Mean Monthly Height of Sea Surface and Barometric Pressure at ***Choshi. 1904.***

Month.	Height of Sea Surface.	Barometric Pressure.‡
January.	27 mm	700 mm + 62.6 mm
February.	0	63.6

* This account of the Choshi observation was also given in the "Tokyo Sugaku Butsuri Gakkwai Kiji Gaiyo," Vol. I.

‡ With gravity, sea level, and freezing point corrections.

Month.	Height of Sea Surface.	Barometric Pressure.
March.	75 mm	62.1 mm
April.	27	63.4
May.	78	59.3
June.	48	57.8
July.	130	57.7
August.	190	58.5
September.	236	58.3
October.	215	61.4
November.	72	61.2
December.	33	61.9

The above figures relating to the height of sea level and the barometric pressure have been deduced from the reading at 6 a.m. each day, during the year 1904. As will be seen from the above table, which is illustrated in Figs. 4 and 5 (Pl XVI), the sea surface was highest in September and lowest in February, while the barometric pressure was highest in February and lowest in June to September; the annual variation of the two quantities being approximately the reverse of each other, as was the case with Ayukawa and Misaki.

The difference between the mean monthly maximum and minimum heights of the sea surface was 236 mm, while that of the atmospheric pressure was equivalent to 86 mm of water column; these two numbers being in the ratio of 275 : 100.

Japan Sea coast*. The annual variation of the height of sea surface considered in the preceding §§ relates to three places

* An account of the Japan Sea coast observations has been given in the "Tokyo Sugaku Butsuri Gakkwai Kiji Gaiyo," in 1905.

on the Pacific coast of Japan. Let us now consider the same subject relative to the Japan Sea coast, there being on the latter the following four mareograph stations :—

(i) Hamada, in the province of Iwami;
(ii) Wajima, on the northern coast of the Peninsula of Noto;
(iii) Iwasaki, on the western coast of the province of Mutsu;
(iv) Otaru, in the province of Shiribeshi (Hokkaido).

Table VI gives the mean monthly values of the distance between the sea surface and the datum line in the mareogram at each of the above mentioned places; Table VII giving the mean monthly barometric pressures during the same year observed at the meteorological observatories of Hamada, Wajima, Aomori, and Sapporo. The two last cities have been chosen on account of their proximity respectively to Iwasaki and Otaru, there being no meteorological observatory at these two latter places. Finally, Table VIII gives the mean monthly values of the relative height of sea surface and of the atmospheric pressure, deduced from Tables VI and VII respectively.

Table VI. Mean Relative Monthly Position of the Sea Surface.
Japan Sea coast. 1902.

Month.	Relative distance between the sea surface and the datum line of the Mareogram.				
	Hamada.	Wajima.	Iwasaki.	Otaru.	*Mean.*
January.	307 mm	226 mm	180 mm	159 mm	218 mm
February.	396	330	317	278	330
March.	319	305	277	225	282

Month.	Relative distance between the sea surface and the datum line of the mareogram.				
	Hamada.	Wajima.	Iwasaki.	Otaru.	*Mean.*
	mm	mm	mm	mm	mm
April.	307	289	211	162	242
May.	149	154	135	119	139
June.	117	109	136	93	114
July.	83	69	112	103	92
August.	34	25	79	79	54
September.	0	0	0	70	18
October.	112	73	107	0	73
November.	206	180	170	66	156
December.	192	158	155	89	149

Table VII. Mean Monthly Barometric Pressure*.

Japan Sea coast. 1902.

Month.	Hamada.	Wajima.	Aomori.	Sapporo.
	mm	mm	mm	mm
January.	764.4	763.6	760.3	757.22
February.	66.5	66.1	63.3	60.09
March.	62.5	63.1	61.6	59.27
April.	60.6	61.2	58.4	55.20
May.	57.5	58.7	58.3	56.32
June.	54.4	56.1	56.1	62.23
July.	55.0	55.7	56.0	55.06
August.	55.8	57.4	59.0	57.78
September.	56.5	57.1	58.7	57.90
October.	63.8	64.2	64.3	62.24
November.	65.1	65.7	65.1	62.79
December.	62.5	62.2	61.1	59.66

* Reduced to the freezing point and the sea level.

Table VIII. Comparison of the Height of Sea Surface with the Barometric Pressure.

***Japan Sea coast.* 1902.**

Month.	Relative Height of Sea Surface.	Relative Barometric Pressure.	Relative Total Pressure at the Sea Bottom.
	mm	mm	mm
January.	112	5.94	193
February.	0	8.76	119
March.	48	6.17	132
April.	88	3.41	134
May.	191	2.26	222
June.	206	1.77	230
July.	238	0.00	238
August.	276	2.05	304
September.	312	2.11	341
October.	257	8.20	368
November.	176	8.98	298
December.	181	5.93	262

As will be seen from Table VI, the sea-level was lowest in February, and highest in September or October. The annual amounts of fluctuation of the mean monthly height of sea-level at Hamada, Wajima, Iwasaki and Otaru were respectively 396, 330, 317, and 278 mm, decreasing from the south to the north.

From Table VIII, the annual variation of the barometric pressure will be seen, as in the case of the places on the Pacific coast, to be nearly the reverse of that of the height of sea-level. Now the amount of fluctuation of the mean monthly barometric pressure, averaged from the observations at Hamada, Wajima, Aomori, and Sapporo, was 8.98 mm, which corresponds to $8.98 \times 13.6 = 122$ mm height of water. On the other hand, the annual fluctuation of the mean monthly height of sea-level, averaged from the observations at the four places of Hamada, Wajima, Iwasaki, and Otaru, was 312 mm. Along the Japan Sea coast, therefore, the fluctuation of the height of sea surface was opposite to, and nearly 2.6 times larger than, the corresponding fluctuation of the barometric pressure. In other words, the sea bottom is subjected to a greater total pressure in the summer months than in February, March, and April, the difference between the maximum and minimum total pressures being equal to 249 mm of water column, which is equivalent to 18.3 mm of mercury, and almost exactly twice the amount of fluctuation of the barometric pressure. The results containnd in Table VIII are illustrated in Figs. 6,7, and 9.

Comparison of the observations on the Pacific and Japan Sea coasts. According to the observations in 1902, the variations during the year of the height of sea surface and the barometric pressure on the Pacific and Japan Sea coasts were as follows :—

(A). Amount of Fluctuation of the Mean Monthly Values. **1902.**

Place.	Barometric Pressure. (mercury column)	Height of Sea Surface. (water column)	Total Pressure at Sea Bottom. (water column)
Pacific Coast. (Ayukawa and Misaki)	9.3 mm	248 mm	206 mm
Japan Sea Coast (Hamada, Wajima, Iwasaki, Otaru).	8.98	312	249

Again from the observations in 1903 and 1904, we obtain the following results.

(B). Amount of Fluctuation of the Mean Monthly Values.

Pacific Coast. **1903** and **1904.**

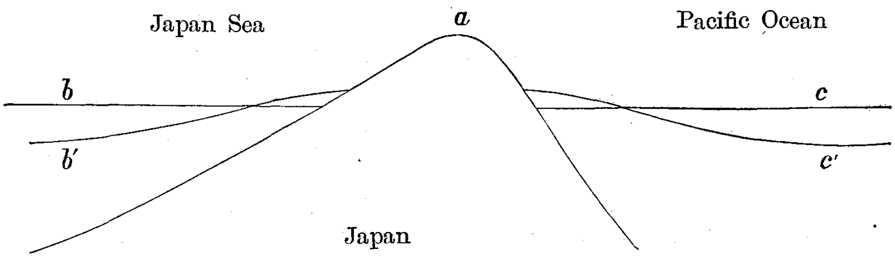
Place	Barometric Pressure.	Height of Sea Surface.	Total Pressure at Sea Bottom.
	(mercury column)	(water column)	(water column)
Ayukawa, Misaki.. ....1903.	8.1 mm	214 mm	198 mm
Choshi ......1904.	6.3	236	224

The relation between the height of sea surface and the barometric pressure, which may change from year to year depends without doubt on geograhphical features of a given coast. But. according to the two above tables, the different fluctuations were contained within fairly uniform limits, the annual variation of the height of sea surface being from 214 to 312 mm, and that of the total pressure at the sea bottom from 198 to 249 mm. There was no marked difference in these respects between the Pacific and Japan Sea coasts. Taking the simple averages from (A) and (B), we obtain the following mean values of the annual variation:—

Barometric Pressure..........8.17 mm of mercury=111 mm of water.
Height of Sea Surface........253 mm of water.
Total Pressure at Sea Bottom..219 mm of water.

Thus the amount of fluctuation of the total pressure at the sea bottom was 219 mm, which is greater than that of the barometric pressure in the ratio of 197 : 100, or very nearly in the ratio of 2 : 1. The sea bottom pressure is maximum in October or September, and minimum in February to April.

The increase during the summer months in the height of sea level, as above described, is to be explained, partly by the



fall in that epoch of the year of the barometric pressure over Japan and the neighbouring seas, and partly by the presence of a high pressure centre on the northern Pacific in the vicinity of the Aleutian Islands. Thus, if b and c (see the annexed diagram) represents the normal, or mean, level of the sea, the latter will be depressed to b' and c' through the influence of the high pressure area at c, and elevated along the coasts of Japanese Islands under the influence of the low pressure at a, the resulting equilibrium surface of water being a curved form, b' and c'. Similarly the decrease of the height of sea level in the winter months is to be explained by the rise of the barometric pressure over Japan and the presence of a low pressure centre on the Northern Pacific. It is probable that the co-existence of the centres of high and low barometric pressures respectively over the land and the ocean (or *vice versa*) causes, by the superposition of the effects, the amount of the annual variation of the height of sea to be approximately double that of the atmospheric pressure.

Seismic frequency and total pressure at sea bottom. To compare the annual variation of the frequency of earthquakes of submarine origin with that of the total pressure at sea bottom, I indicate in the following table the mean monthly percentage numbers of earthquakes for Nemuro, Miyako, Ishinomaki, Kochi, and Hamada; the figures being based on the data given in the "Publications of the Earthquake Inv. Comm.", No. 8. Of these five places, each of which is disturbed mostly by earthquakes of submarine origin, the first four are situated on the Pacific coast of Japan, and the remaining one on the Japan Sea coast.

Table IX. Annual Variation of Seismic Frequency.

Month.	Nemuro.	Miyako.	Ishino-maki.	Kochi.	Hamada.	*Mean.*
January.	6.5	6.2	4.1	6.9	6.8	5.9
February,	6.5	4.4	5.7	11.7	6.8	6 5
March.	7.7	8.1	5.3	9.3	6.8	7.8
April.	7.8	10.0	8.1	9.3	3.3	8.1
May.	9.4	6.9	8.1	4.8	3.3	7.1
June.	9.4	9.0	7.5	10.5	3.3	8.2
July.	9.6	12.2	11.5	8.1	3.3	9.8
August.	8.0	12.1	13.2	6.9	13.3	10.9
September.	8.4	5.3	10.5	5.7	10.0	8.0
October.	9.4	9.7	8.4	8.1	20.0	10.4
November.	8.4	9.0	11.0	8.1	10.0	9.4
December.	8.8	6.9	6.8	10.5	13.3	8.6

The mean seismic frequency, given in the last column of the above table, has been deduced from the figures for the five different places; the weight of the data relating to Kochi and

Hamada, whose earthquake numbers were not numerous enough, being taken as half of that for the others. The annual variation of the mean seismic frequency thus obtained is illustrated in Fig. 11, while that of the relative total sea bottom pressure, deduced by taking the means of the results relating to the Pacific and Japan Sea coasts is illustrated in Fig. 10.

From a comparison of Figs. 10 and 11, it will be seen that the frequency of submarine earthquakes follows, on the whole, the variation of the total pressure at the sea bottom. Thus, the earthquake number is minimum in January and February, and maximum in August, and the sea bottom pressure is minimum in February to April, and maximum in September and October.

Stronger earthquakes of submarine origin. The seismic frequencies considered in the preceding § relate essentially to small ordinary, or non-destructive, earthquakes and may therefore, in their annual variation, be different from those of shocks which are large. Thus, for instance, taking the 319 stronger earthquakes, which happened between 1902 and 1906 off the coasts of Japan, and whose land area of disturbance was, with a few exceptions, greater than 1,000 square *ri**, we find :—

Table X. Annual Variation of Stronger Submarine Earthquakes.

Month.	Number of Eqkes.	Month.	Number of Eqkes.
January.	25	July.	38
February.	39	August.	27
March.	25	September.	22
April.	19	October.	28
May.	28	November.	20
June.	21	December.	27

* 1 *ri* = 3,927 km, nearly.

The annual variation of these larger submarine earthquakes, illustrated in Fig. 12, indicates the maximum in February, and is, on the whole, opposite to that of the small shocks.

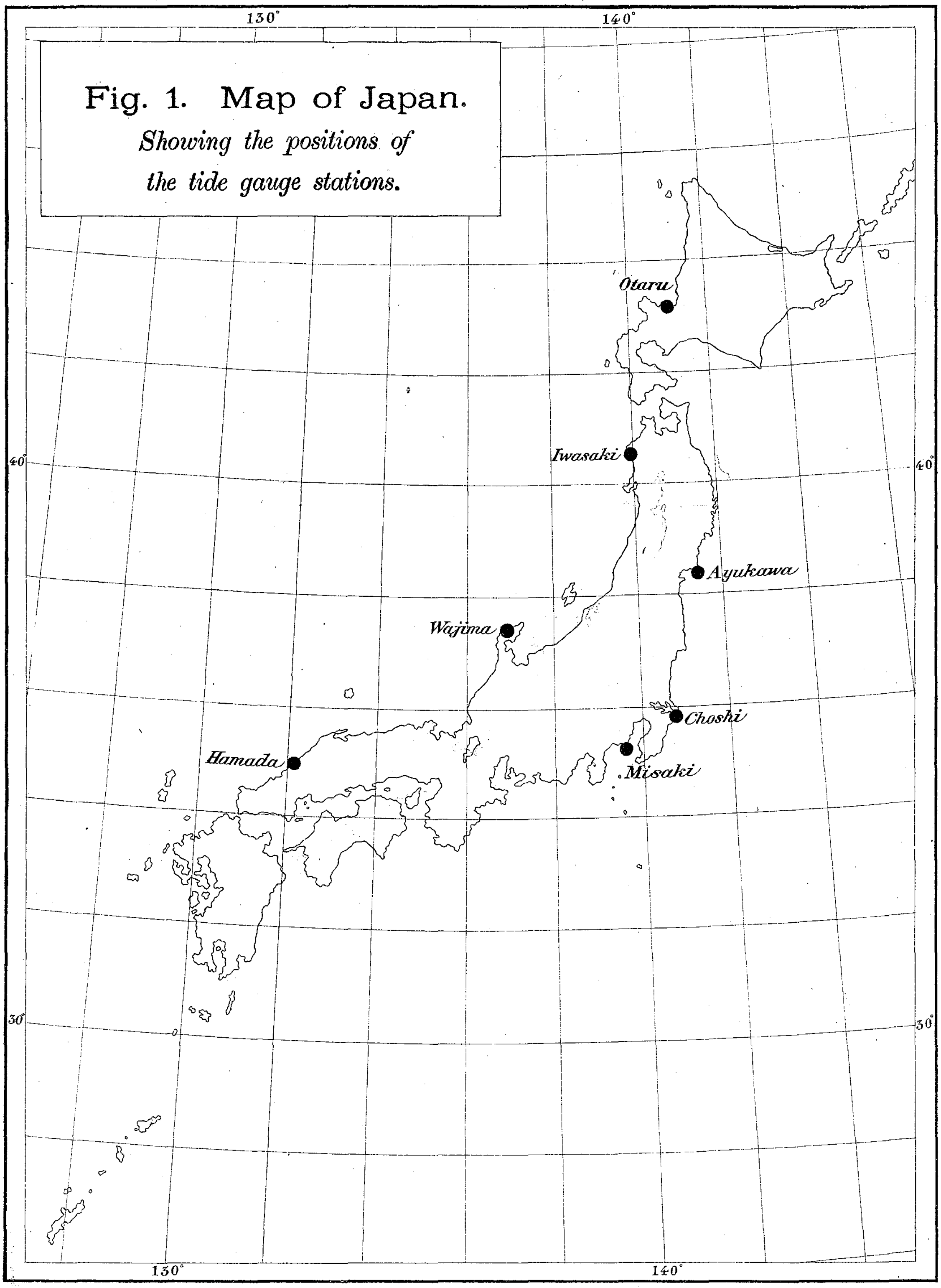


Fig. 1. Map of Japan.
Showing the positions of the tide gauge stations.

Annual Variation of the Height of Sea Surface and the Atmospheric Pressure.

Ayukawa and *Misaki, 1903.*

Fig. 2. Atmospheric Pressure.

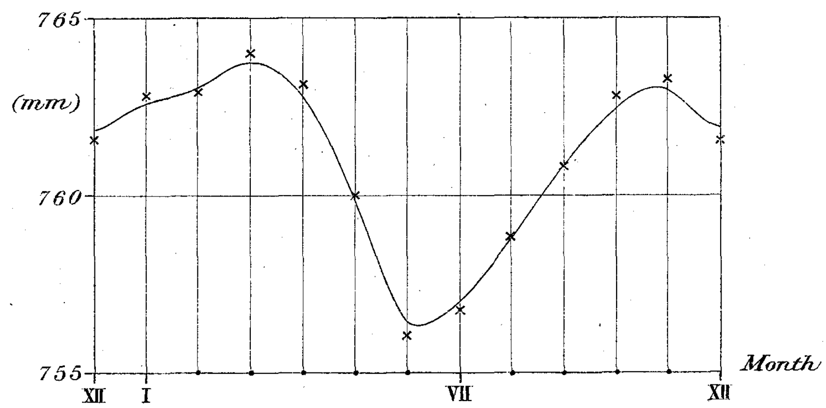
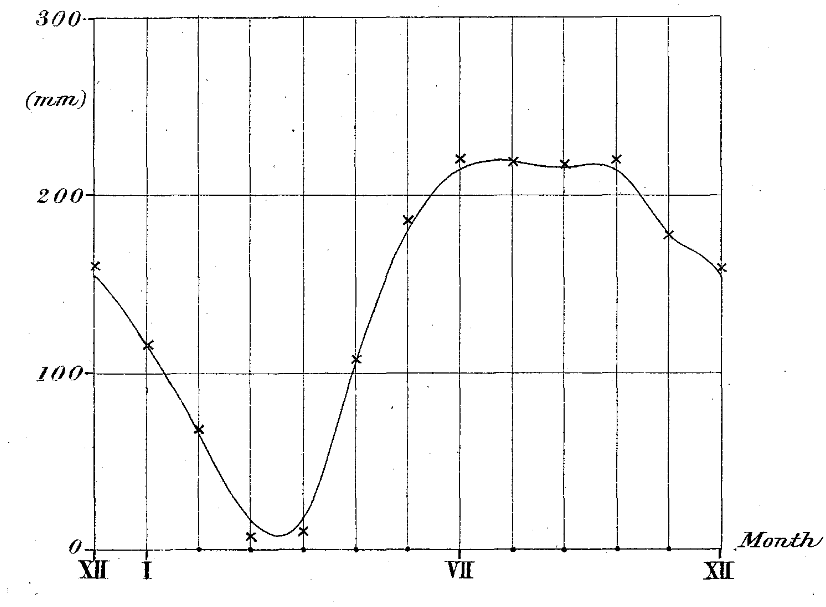


Fig. 3. Height of Sea Surface.



Annual Variation of the Height of Sea Surface and the Atmospheric Pressure.

Choshi, 1904.

Fig. 4. Height of Sea Surface.

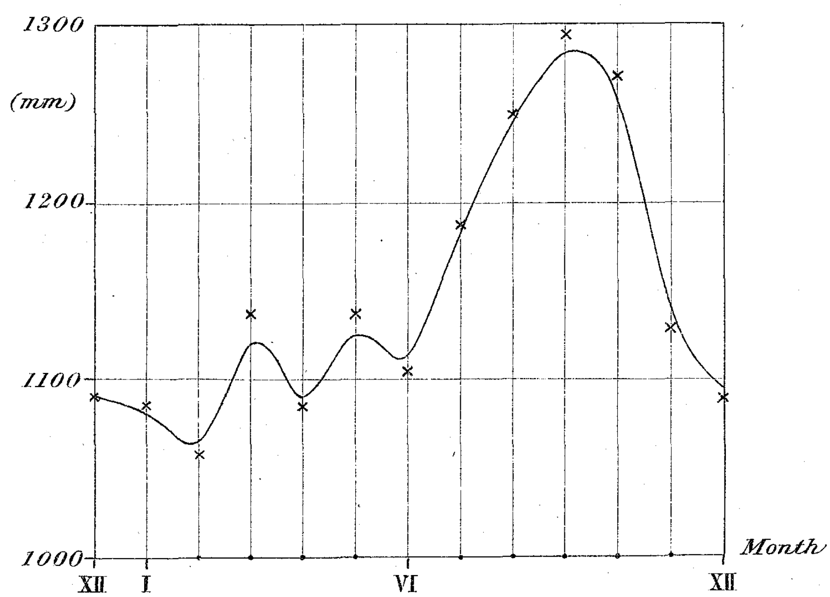
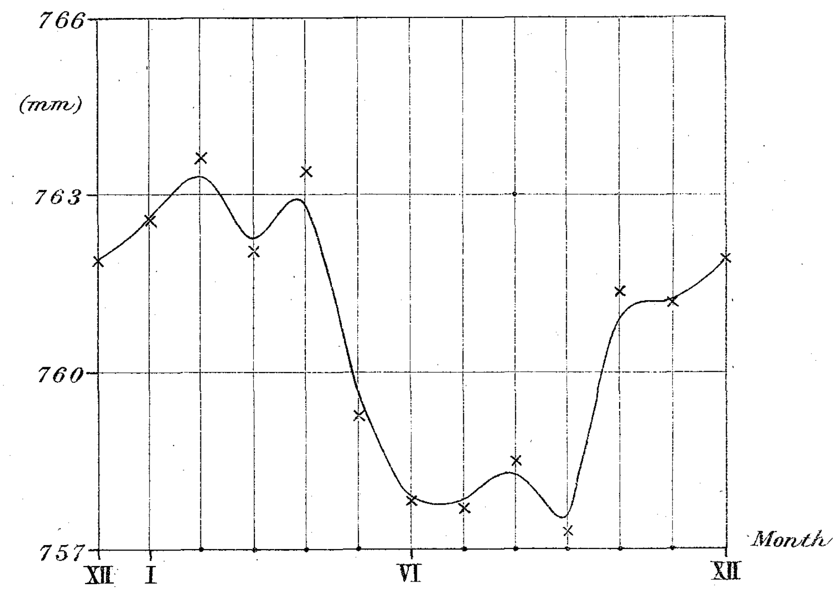


Fig. 5. Atmospheric Pressure.



Annual Variation of the Height of Sea Surface and the Atmospheric Pressure.

Japan Sea Coast, 1902.

Fig. 6. Atmospheric Pressure.

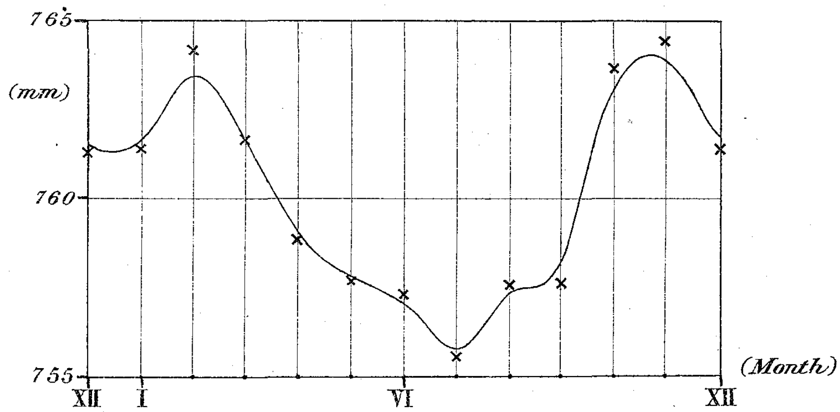
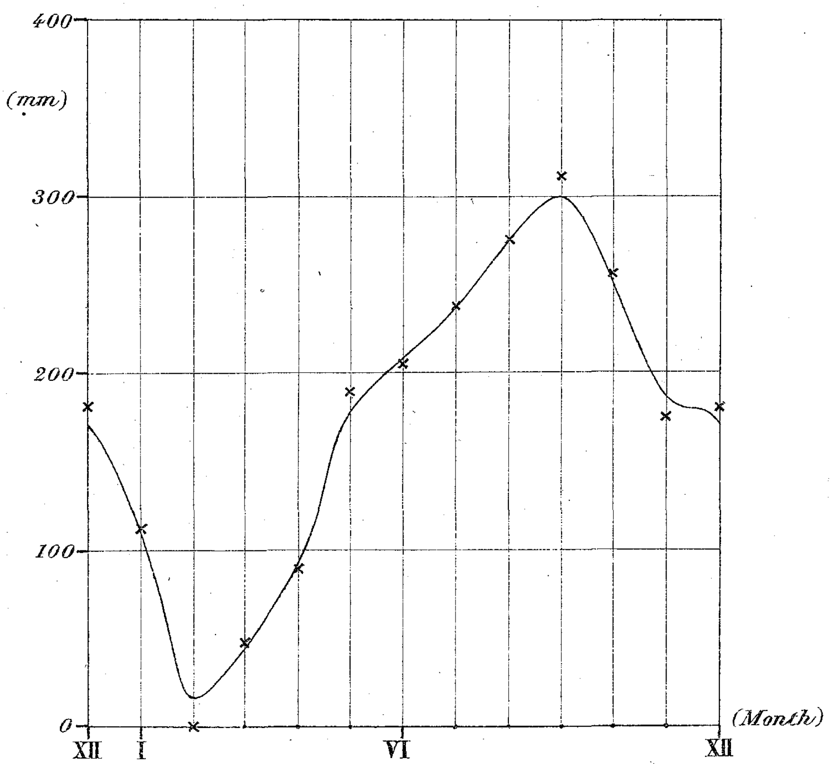


Fig. 7. Height of Sea Surface.



Annual Variation of the Total Pressure at the Sea Bottom.

Fig. 8. *Ayukawa* and *Misaki*. *1902–1903*.

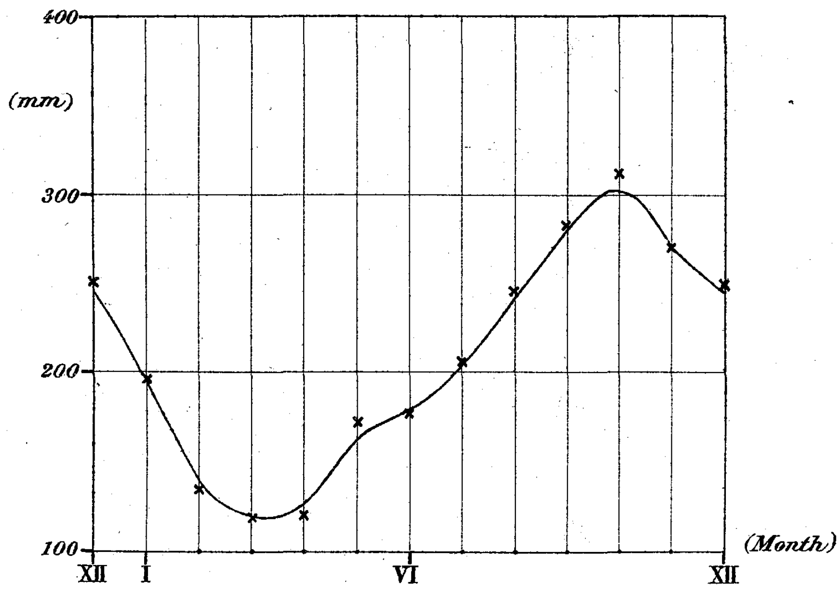
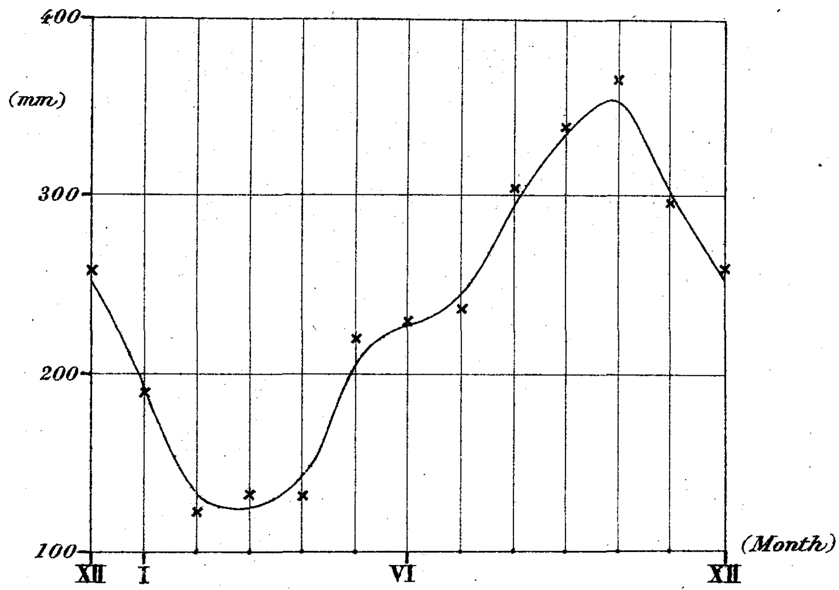


Fig. 9. *Japan Sea Coast*. *1902*.



Annual Variation.

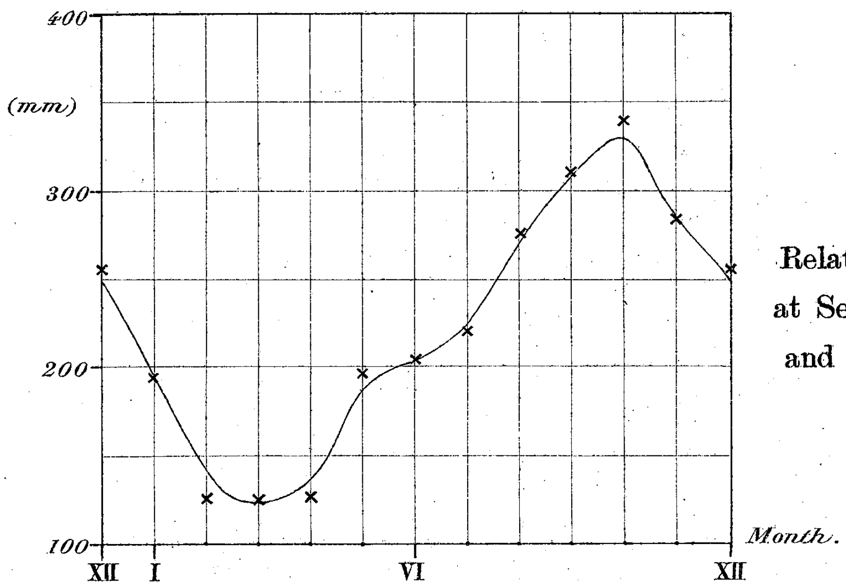


Fig. 10.
Relative Total Pressure at Sea Bottom. (Pacific and Japan Sea Coast.)

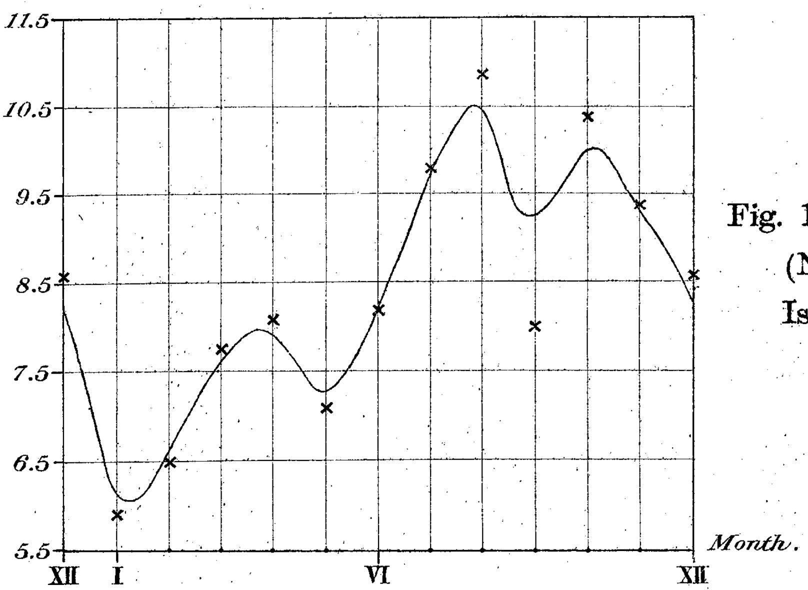


Fig. 11. Eqke Frequency. (Nemuro, Miyako, Ishinomaki, Kochi, and Hamada).

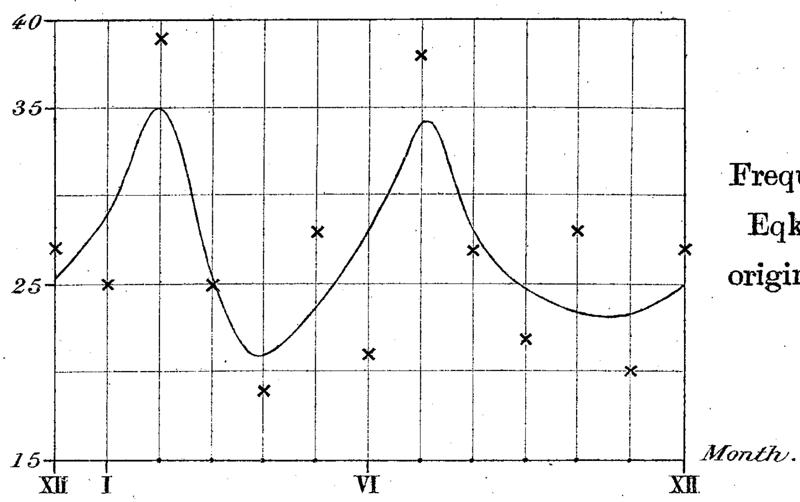


Fig. 12.
Frequency of Stronger Eqkes of submarine origin. (Whole Japan.)