18. *Secular Changes in the Heights of Yearly Mean Sea-Level at Japanese Stations.*

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1. Changes in the heights of sea-levels are caused by various disturbances, such as tidal forces, changes in atmospheric pressure, changes in direction and intensity of wind, fluctuations in sea-water temperature caused by ocean currents and local precipitations, etc. Of these disturbances, the dynamical effect of ocean current is believed to cause the irregular variations in the heights of sea-levels, but it is so small that it is negligible in discussing changes in heights of sea-level greater than a few centimetres.

The changes in height of sea-level caused by most of the other disturbances are regarded as periodic. The periods of the disturbances due to tidal forces are, as is well known, diurnal, semidiurnal, etc., while the period of disturbances due to meteorological disturbance is approximately annual. Hence, if we are dealing, as in the present study, with variations in the yearly mean heights of sea-level, then the effects of astronomical and meteorological disturbances may be disregarded in the first approximation.

For the yearly mean value of the height of sea-level[1], that of the heights of monthly mean sea-level for 12 or 13 lunar months was taken. Since the monthly mean heights of sea-level are given by the mean values of the daily mean heights of sea-level taken for the interval from the day of full moon to that of the next full moon, the yearly mean height of sea-level that was obtained as the mean value of daily mean heights of sea-level for 365 days i. e. from Jan. 1 to Dec. 31, may be regarded as differing, though only slightly, from the yearly mean height of the sea-level determined above. To serve as an example, these two kinds of mean values are compared in Table I, the data belonging to Kusimoto. As the table shows, it was found that the difference is very small, so that the yearly mean height deduced from the monthly mean values of 12 or 13 lunar months may well be substituted for the

1) Data taken from "*The Report of Tidal Observation,*" (Marine Mateorological Observation) Vols 1—13, and "*Tidal Record,*" (Military Land Survey).

yearly mean height for the interval from Jan. 1 to Dec. 31, within the limit of possible accuracy.

Table I.

Year	Mean height (From. Jan. 1 to Dec. 31.)	Mean height (12 or 13 Lunar Months.)	Difference.
	cm	cm	cm
1932	173·6	173·4	0·2
1933	177·2	178·2	−0·8
1934	170·4	170·2	0·2
1935	175·4	175·2	0·2

2. The changes in the heights of the yearly mean sea-level at various stations thus obtained may be regarded as showing the secular changes in the height of the land at the respective places; in certain cases, with an accurary of about ± 2 cm[2].

The changes in heights of the yearly mean sea-level at various stations thus obtained are shown by graphs in Fig. 1, the numerical data being given in Table II.

The station for which changes in the heights of the yearly mean sea-level are deduced and plotted in Fig. 1, are

HONTO in Karahuto, (Saghalin)
OSYORO, HANASAKI in Hokkaido,
MERA, ABURATUBO, TOBA, KATUURA, KUSIMOTO, SIMOTU on the Pacific side of Honsyū,
KOBE, in the Seto-naikai (Inland Sea).
WAZIMA, TONOURA (HAMADA) on the Japan Sea side of Honsyū,
SIMIZU, UWAZIMA in Sikoku, and HUKABORI, TOMIE, HOSOZIMA, ABURATU in Kyūsyū.

Mareograph observations were begun, in 1930, at Mera, Katuura, Tomie, Aburatu, and in 1931 at Simizu. At the other mereograph stations, the data were taken since, or considerably before, 1925 or 1926.

The geographical distribution of these mareograph stations may be seen from Fig. 2.

3. From the curves in Fig. 1, showing the secular variations in the yearly mean heights of sea-level, the following points outstand;

(i) The height of the sea-level at Hanasaki has dropped considerably since 1932;

(ii) The drop in sea-level at Toba in 1929 and 1930 is also con-

2) K. MUTO and N. MIYABE, *Bull. Earthq. Res. Inst.*, **16** (1938), 70~86.

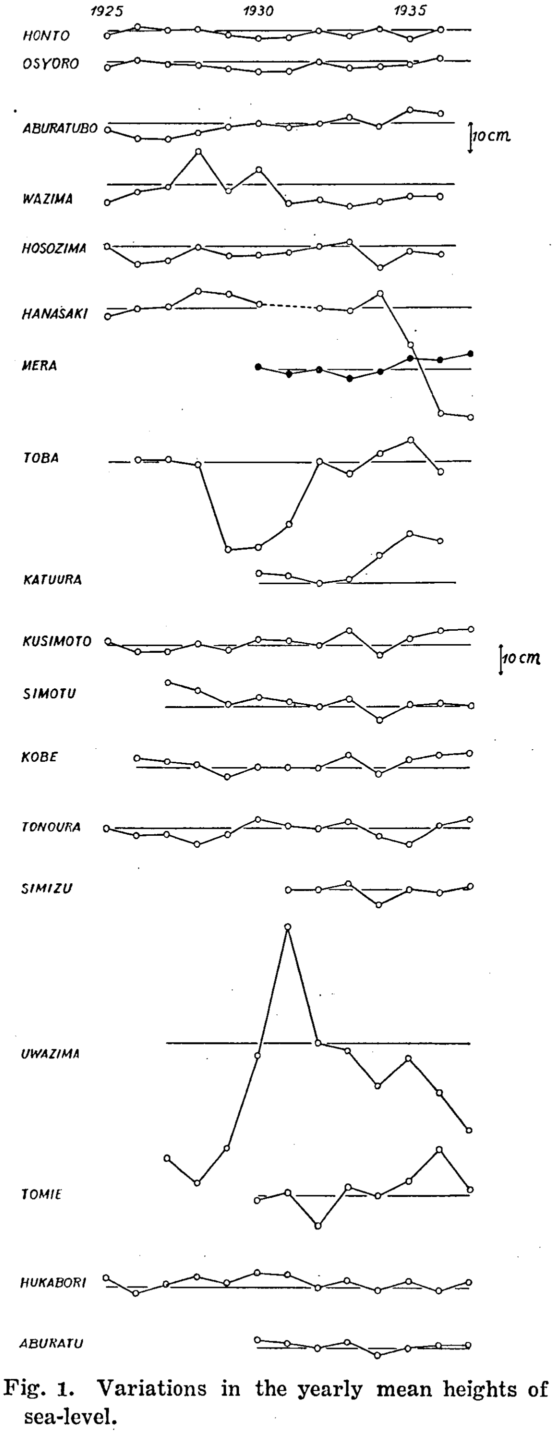

Fig. 1. Variations in the yearly mean heights of sea-level.

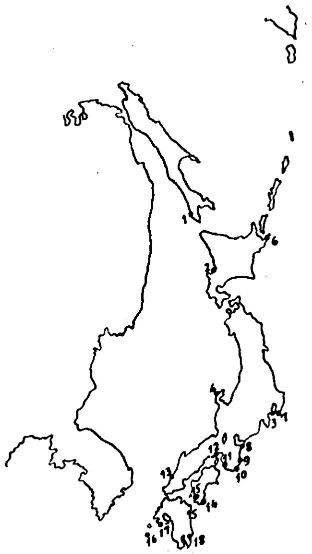

Fig. 2. Distribution of Mareograph Stations.

1 HONTO
2 OSYORO
3 ABURATUBO
4 WAZIMA
5 HOSOZIMA
6 HANASAKI
7 MERA
8 TOBA
9 KATUURA
10 KUSIMOTO
11 SIMOTU
12 KŌBE
13 TONOURA
14 SIMIZU
15 UWAZIMA
16 TOMIE
17 HUKABORI
18 ABURATU

Table II.

	Station \ Year	1925	1926	1927	1928	1929	1930	1931	1932	1933	1934	1935	1936	1937
		cm	cm	cm	cm	cm	cm	cm	cm	cm	cm	cm	cm	
I	1 HONTO	407·2	404·3	405·3	405·3	406·9	407·9	407·9	405·7	407·4	405·3	408·2	405·6	
I	2 OSYORO	203·5	201·5	202·4	202·8	204·0	205·0	204·6	201·8	204·0	203·4	202·6	200·7	
I	3 ABURATUBO	498·4	501·0	501·3	499·1	497·4	496·3	497·7	496·3	494·1	497·1	492·2	493·1	
I	4 WAZIMA	244·3	241·0	239·2	227·8	240·7	233·8	244·7	243·7	241·8	243·3	243·0	243·0	
I	5 HOSOZIMA	244·2	249·6	248·4	244·2	247·0	246·7	245·9	244·0	242·5	250·7	245·4	246·5	
II	6 HANASAKI	149·8	152·4	152·8	158·0	156·8	153·8	—	152·4	151·6	156·8	140·7	117·7	116·7
II	7 MERA						124·3	122·0	123·4	120·7	122·7	126·8	126·2	128·4
II	8 TOBA		216·0	216·0	214·8	185·8	187·4	195·1	215·5	211·7	217·9	222·7	212·0	
II	9 KATUURA						172·1	171·4	168·7	170·2	177·9	185·3	182·8	
II	10 KUSIMOTO	174·8	171·6	171·4	173·8	172·0	175·4	175·0	173·4	178·0	170·2	175·2	177·8	178·1
II	11 SIMOTU			174·2	172·0	167·3	169·3	168·1	166·5	169·0	162·0	167·1	167·5	166·8
II	12 KŌBE		158·5	157·5	156·3	152·3	155·6	155·6	155·4	159·5	153·1	158·0	159·4	160·0
II	13 TONOURA	104·6	102·4	102·8	99·4	103·0	108·0	105·6	104·8	107·0	102·6	100·6	106·3	108·4
II	14 SIMIZU							167·7	167·8	169·7	163·1	167·9	166·7	168·6
II	15 UWAZIMA			165·8	157·6	169·0	199·6	241·5	203·5	201·0	189·8	199·0	187·6	175·1
II	16 TOMIE						189·1	191·8	180·5	193·4	190·2	194·9	205·7	192·6
II	17 HUKABORI	189·0	184·0	187·0	189·4	187·4	191·0	190·6	186.0	188·2	185·2	187·8	184·9	187·7
II	18 ABURATU						145·4	144·3	142·9	144·7	140·6	142·6	143·9	144·2

I: Military Land Survey. II: Meteorological Observatory.

siderable; since 1932 the sea-level at Toba and at Katuura rose at the same rate;

(iii) The rise and fall of sea-level at Uwazima since 1926 are very marked;

(iv) The heights of the yearly mean sea-level at six stations, i. e., Kusimoto, Simotu, Kōbe, Simizu, Hosozima, and Aburatu, have all changed in the same way, although the amount is not very large.

The remarkable fall in sea-level observed at Hanasaki is believed to be due to an artificial change in the height of the datum line and also to lack of observation data for a fairly long period of time.

The fluctuating curve in Fig. 3 suggests that the changes in the heights of the daily mean sea-level at Hanasaki were the result of frequent artificial changes in the height of the datum line.

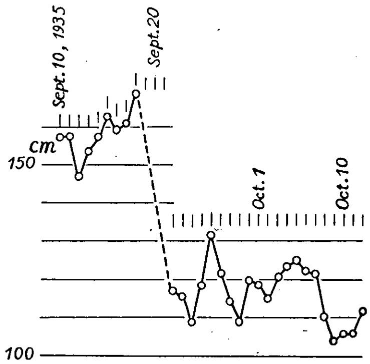

Fig. 3.

Similarly, the abnormal drop in sea-level at Toba in 1930 may be regarded as due to the fact that data for certain periods are lacking, and that the height of the datum line has been changed artificially.

It is also notable, as mentioned above, that the height of the yearly mean sea-level at Toba since 1932 varies approximately in the same way as that observed at Katuura. Toba lies at the mouth of Isewan (bay), while Katuura is situated near Kusimoto, about 100 km distant S—W from Toba. Although Katuura is nearer Kusimoto than is Toba, the secular variation in the height of the sea-level there is similar to that observed at Toba, not like that observed at Kusimoto, a fact probably showing that, while on the one hand, the observed secular changes in the height of the yearly mean sea-level are more likely to be real, on the other hand, the coast of Kumanonada, where Toba and Katuura are situated, has moved downwards these number of years at the rate of about 2∼4 cm/year. If this rate of downward movement was not a local subsidence of the land, it would be remarkable.

4. As shown in Fig. 1, the rise and fall of the yearly mean height of sea-level at Uwazima is remarkable. The yearly mean sea-level at this station gradually rose since 1927, until it reached about 90 cm in 1932, after which it began to drop, the subsidence in 1938, that is for 6 years, amounting to about 60 cm.

The rise of yearly mean sea-level at this station, however, seems to be exaggerated, as the result of lack of observational data for the close of 1931. To verify this point, the changes in the monthly mean heights of sea-level are shown. In this case, the variations with approximate annual period, estimated as below, are substracted from the actual values of the monthly mean heights of sea-level.

The annual variation in the monthly mean heights of sea-level were estimated as follows. The deviations in the heights of the monthly mean sea-level from the yearly mean sea-level were deduced for the years 1933, 1934, 1935, 1936, and 1937, the results of which are given in Table III.

Table III.

Month \ Year	1933	1934	1935	1936	1937	Mean
	cm	cm	cm	cm	cm	cm
January	− 6·3	− 3·1	− 0·9	−15·4	− 7·2	− 6·6
February	−17·3	−16·2	− 9·8	−16·6	−16·4	−15·3
March	−13·1	−16·1	−10·2	− 8·3	−19·4	−13·4
April	− 5·7	−15·7	−10·9	−14·0	−15·1	−12·3
May	−11·3	−12·1	− 3·2	− 5·3	−16·2	− 9·6
June	2·6	− 5·3	8·2	3·0	7·9	3·3
July	3·3	7·6	11·7	6·8	15·2	8·9
August	10·7	11·5	13·4	3·8	18·2	10·8
September	17·8	10·9	17·5	3·9	14·8	13·0
October	12·2	9·5	20·4	20·3	13·4	15·2
November	7·6	0·9	1·8	19·1	8·4	7·6
December	4·9	− 2·4	− 5·4	3·0	− 5·7	− 1·1

The mean deviation for each month is then calculated as given in the last column of Table III, which is regarded as showing the mean annual variation of the monthly mean heights of the sea-level at Uwazima.

The curve in Fig. 4 shows the secular variation of the monthly mean height of sea-level, in which the terms of the mean annual variation are excluded. From this curve, we notice that the datum line for sea-level might have dropped toward the end of 1931 by about 20 cm. The datum line was raised again artificially by about 10 cm in the beginning of 1933. Taking into account these artificial changes in the height of the datum line, the rise in sea-level during 1927∼1932 amounts to about 70 cm, and that of the fall during the period 1932∼1938 to about 50 cm.

We have the data of vertical displacements of bench-marks distributed in this region for comparison with the secular change in the height of sea-level. Precise levels in this region were rerun in 1932, with the result that the vertical displacements of the bench-marks near

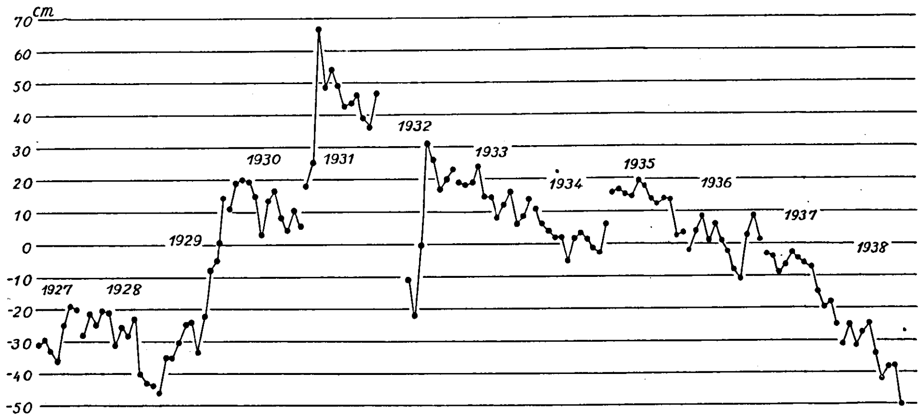

Fig. 4. Secular variation in monthly mean heights of sea-level at Uwazima.

Uwazima during the years 1898～1932 work out to –80 mm[3], relative to the bench-mark whose height was assumed to have remained unchanged. This subsidence of land is much less than the rise in sea-level during 1927～1932. This discordance in changes in the height of sea-level may be explained by assuming that the sea-level in 1898 was higher than that in 1927. It may be natural to assume that the land level which changes its height in an undulatory manner with time, reached minimum height in 1927, the integrated amount of the change in the height of the land level over the period from 1898 to 1932 being nearly –8 cm. Should, therefore, precise levels be rerun through this region and the rise of the land be found to be 50 cm and more, it will show that the secular change in height of the sea-level as deduced above gives the rise of the land.

It was supposed that if the land had risen about 50 cm it should be possible to confirm it by direct observations, resulting in the writer's visit to Uwazima to measure directly the amount of rise of the land through marks that may be found along the sea-shore. Marks of the old sea-level were found at several places more or less clearly. The heights of these marks above sea-level at the time of the measurement was made were recorded. The heights of the marks thus measured were reduced with the aid of predicted curves of the tides for Uwazima on the days the observations were made, to heights above the yearly

2) Rikuti Sokuryobu, (Military Land Survey) "Report on the results of precise levels in 1932".

mean sea-level. The distribution of heights of these marks thus measured and deduced are shown in Fig. 5.

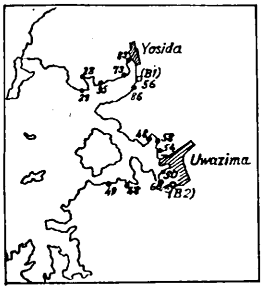

Fig. 5. Distribution of the amounts of rise of the land in the neighbour-hood of Uwazima.

(Amounts of rise shown by numerals are in cm.)

The height of a bench-mark near the seashore, marked B 1 in Fig. 5. was measured and compared with the height given in the map. The comparison shows that the land rose about 58 cm.

Seeing that, with regard to the data of the yearly mean sea-level measured at Simizu, 70 km south of Uwazima, no marked change in the height of the sea-level, such as that found in Uwazima, was observed. The remarkable change in the height of the sea-level may be of a local character, confined to a certain area, including Uwazima.

Notwithstanding the marked fall and rise of the land level in the neighbourhood of Uwazima, no marked changes are seen in seismic activity, which may usually be regarded as having some relation to crustal deformation, such as those observed in this locality.

5. As already mentioned, the yeaaly mean sea-level at six mareograph stations, namely, Kusimoto, Simotu, Kobe, Simizu, Hosozima, and Aburatu, have moved in parallel, in that they rose in 1933 and fell in 1934, recovering their general level since 1935. The differences in the heights of the levels in 1933 and in 1934 range from 4 to 8 cm. These abnormal and ordinary changes in the heights of the sea-level may be connected with changes in sea-water temperature.

As already reported by Yamaguti[4], the fluctuations in the monthly mean heights of sea-level are affected by atmospherie pressure and sea-water temperature, as expressed by the formula

$$h = ap + bT.$$

As to the fluctuation in the heights of the yearly mean sea-level, a similar relation to the atmospheric pressures p and the sea-water temperatures T may hold. Since, however, the atmospheric pressure varies with the annual period, and since the yearly mean fluctuations atmospheric pressure are very small, the value of h is mainly affected by T, the sea-water temperature. The sea-water temperature in the neighbourhood of the mareograph station are probably affected by ocean currents, local precipitation, etc.

4) S. YAMAGUTI, *Bull. Earthq. Res. Inst.*, **19** (1941), 39~48.

To serve as an example, the relation between the yearly mean heights of sea-level and the yearly mean values of sea-water temperature at Hosozima was studied. In this case, the data of sea-water temperature from Yamaguti's paper were used, they being the values estimated from the configuration of isothermal curves drawn with reference to the data in "Kairyu Tūhō". The yearly mean heights of the sea-level were plotted against the yearly mean values of the sea-water temperature, as in Fig. 6.

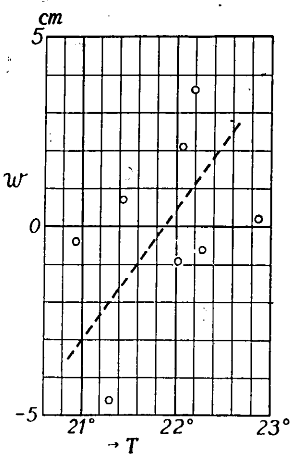

Fig. 6.

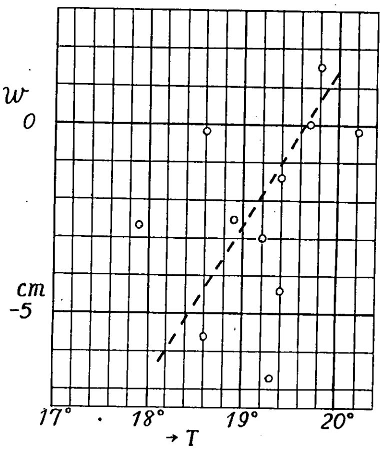

Fig. 7.

A similar relation between the yearly mean heights of the sea-level and the yearly mean values of the sea-water temperatures measured at Hosozima, is also shown graphically in Fig. 7[5].

From these curves in Figs. 6 and 7, the abnormal and ordinary-rise and fall of sea-level common to a number of stations may be regarded as due partly to secular changes in sea-water temperature. The abnormal rise and fall in 1933 and 1934 cannot be satisfactorily explained by assuming that they depend mainly on changes in sea-water temperature. This discordance may be due to the fact that the data of sea-water temperature used for the present discussion ought not to be compared with the changes in the heights of sea-levels.

Similar changes in the heights of yearly mean sea-level at other stations, namely, Kusimoto, Simotu, Kobe, Simizu, and Aburatu, may be due to a common reason, although their relation to sea-water temperature were not studied.

Thus the same rise and fall of the yearly mean heights of sea-

5) Data of sea-water tempertures taken from "*Tidal Record*", Rikuti Sokuryōbu, (Military Land Survey).

level observed in six mareograph stations may be regarded as having been caused by changes in the temperature of the sea-water.

In conclusion, the writer wishes to express his sincere thanks to the Department of Education, whose grant of a research fund enabled prosecution of the present study.

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18. 年平均潮位の高さの變化

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本邦各地に在る 18 個の驗潮場に於ける年平均潮位の最近の 10 餘年の間の變化を調べた．その結果，稍々異常的な變化をなして居るものが見出された．それらを擧げてみると

(i) 花咲に於いては昭和 10 年以後，水位が著しく，且つ急激に低下してゐる．これは，併し，主として人爲的に基準面を移動させた結果であると思はれる．

(ii) 鳥羽の，昭和 3—4—5 年における潮位も上述の花咲の場合に見られる樣な，人爲的の基準面移動の結果であると見られるが，昭和 7 年以後の變化は，勝浦のそれと稍々平行してゐる．

斯樣な變動が，鳥羽，勝浦を含む地域の全般的な沈下運動を示すか否かは甚だ疑ばしい．ただ，勝浦の潮位變化が，場所的にはより近い串本に於ける潮位變化に似ず，遠い鳥羽のそれに似てゐるといふ點に注意をひかれる．

(iii) 宇和島における潮位の變化は極めて著しいものがあるが，色々の點から見て，陸地の隆起を示すもののやうである．併し，清水における潮位の變化には，斯樣な著しいものはないから，陸地の變形も局部的のものと思はれる．

(iv) 串本，下津，神戸，清水，宇和島，細島，油津等，西南部の太平洋岸の驗潮場における年平均潮位の變化には共通なものが認められる．それは，海水の温度によつて支配される現象であらうと推察される．
